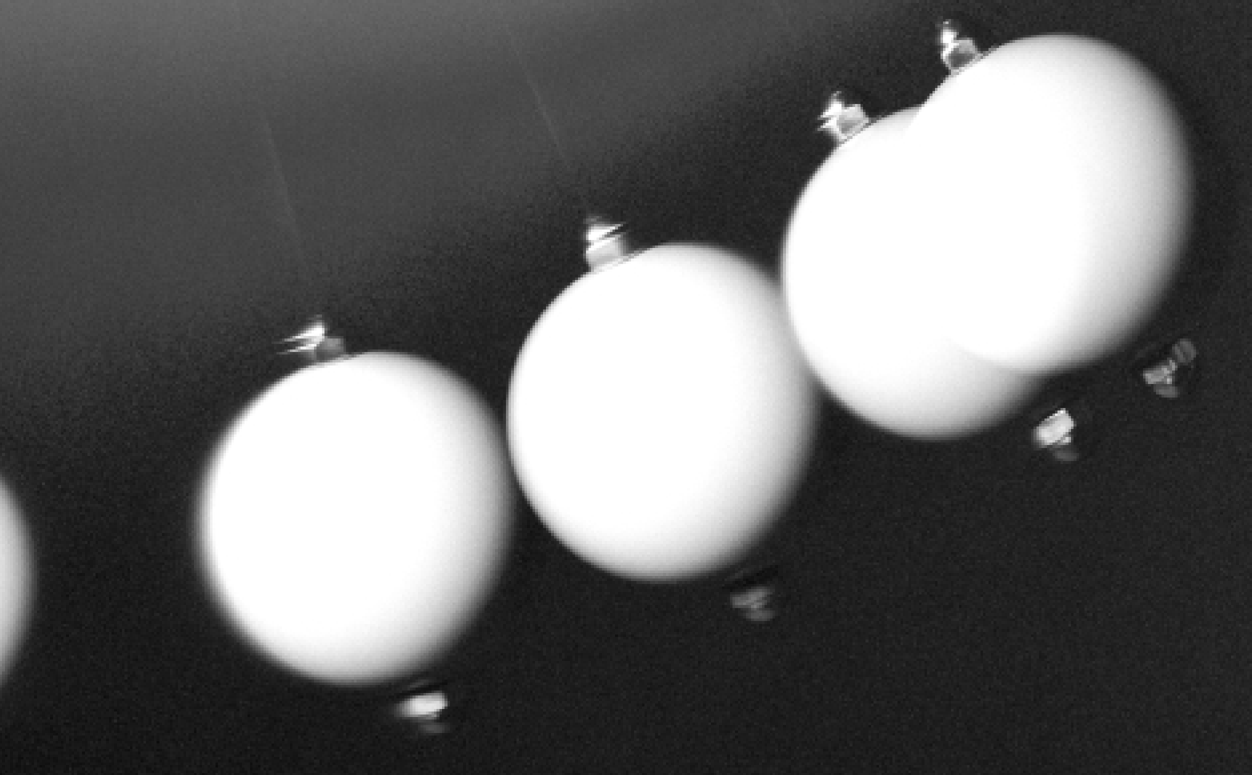
ScienceWorkshop®

Physics Labs with Computers

Student Workbook

Volume 1

Physics experiments using the *ScienceWorkshop*® or DataStudio™ program and interfaces from PASCO scientific®



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Contents

Preface

I. Overview of Physics Labs with Computers, Volume 1: Student Workbook (CI-7014)

This manual has thirty-five activities in the following areas: linear and angular motion, mechanics, thermodynamics, sound and waves, electricity and magnetism, and optics. These activities can be done with the sensors that are included in the Physics Bundles for the *ScienceWorkshop* 500 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.

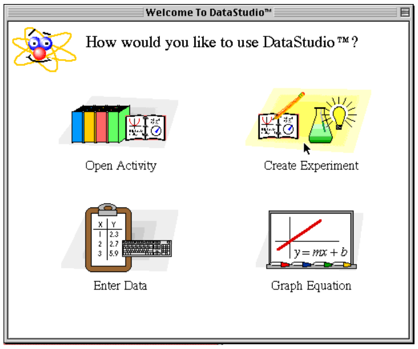
III. Acknowledgements

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

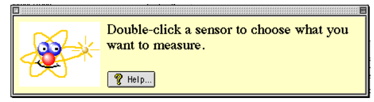
July 20, 1999.

Quick Reference Guide for *DataStudio*

Create an Experiment

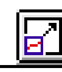
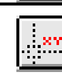
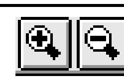
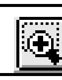
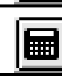
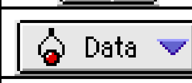
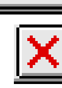
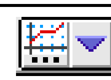


(1) Double-click a sensor.

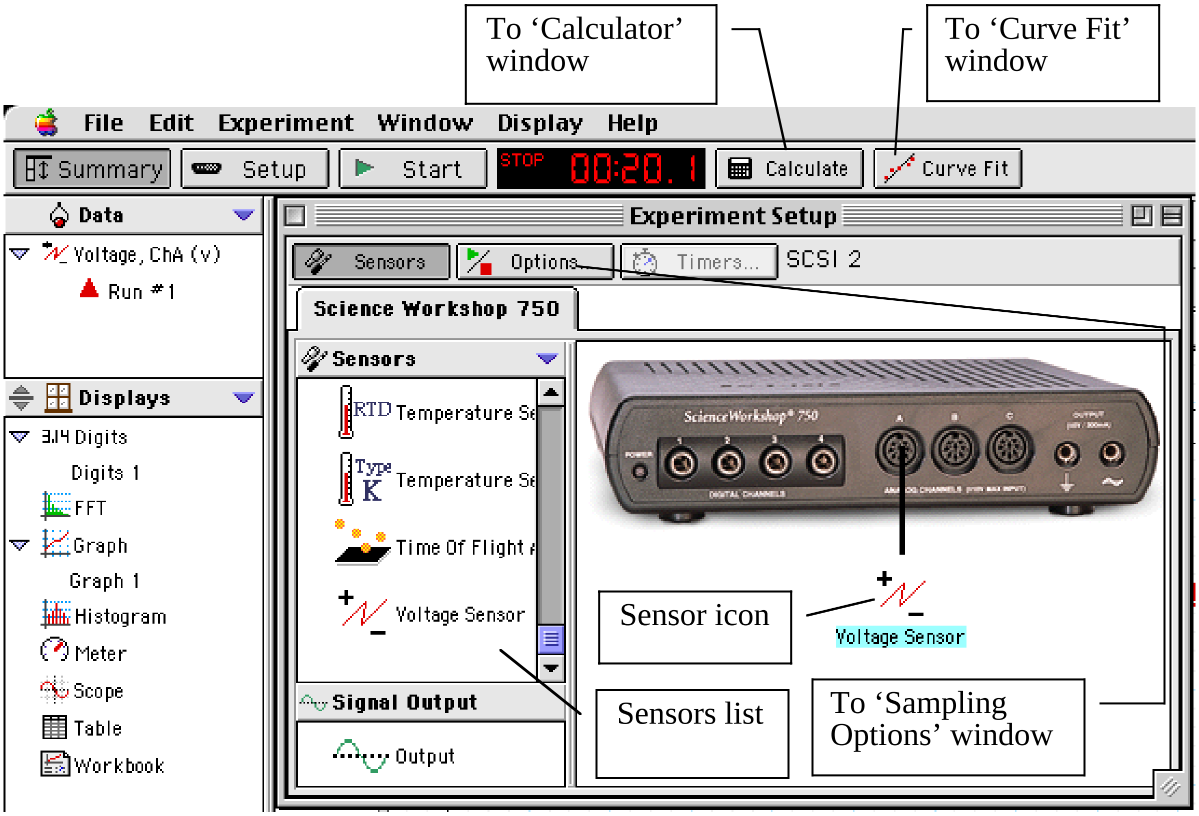


(2) Double-click a display.

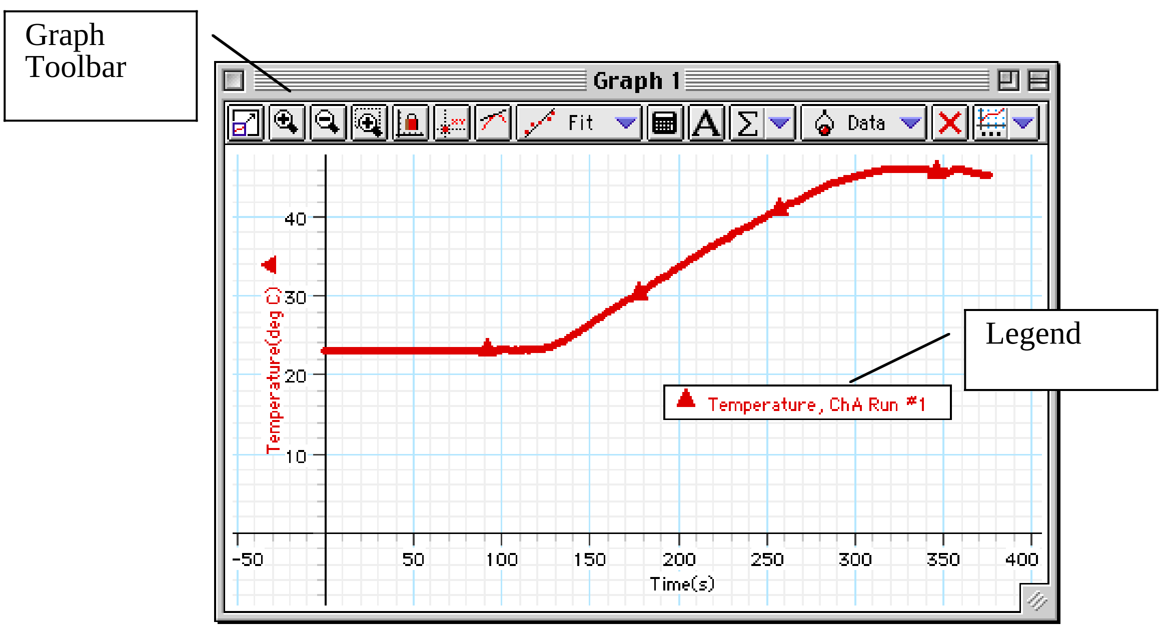
What You Want To Do	How You Do It	Button
Start recording data	Click the ‘Start’ button or select ‘Start Data’ on the Experiment menu (or on the keyboard press CTRL - R (Windows) or Command - R (Mac))	
Stop recording (or monitoring) data	Click the ‘Stop’ button or select ‘Stop Data’ on the Experiment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

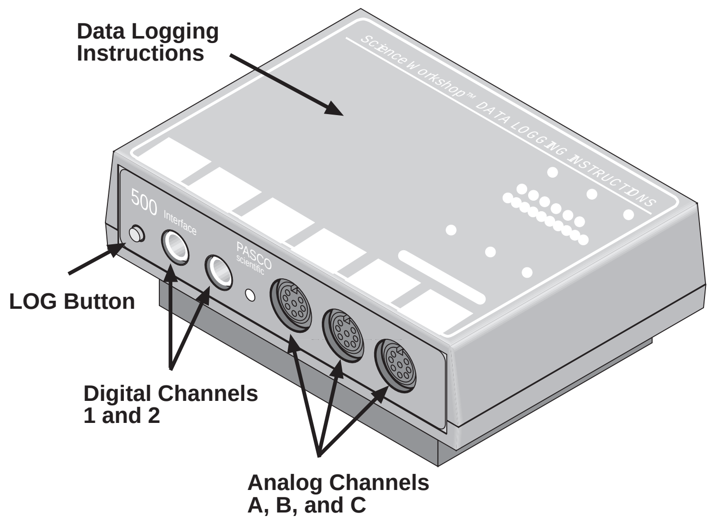
There are several features that make *DataStudio* a unique and powerful teaching tool for science and math. Section #1 covers the mechanics of the interface. Section #2 covers setting up an experiment with the software. Section #3 covers data analysis in more detail.

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 500 Interface

Data Logging with the *ScienceWorkshop* 500 Interface Box

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



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

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

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

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

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

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

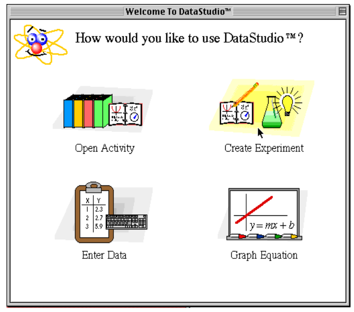
The **Analog Channels** allow up to three analog sensors to be plugged into the *500* interface. You can plug in an analog sensor’s DIN plug in only one way. The Force Sensor is an example of an analog sensor.

The **Digital Channels** allow one or two digital sensors to be plugged into the *500* interface. The Photogate and Motion Sensor are examples of digital sensors. For example, you can connect two Photogates or one Motion Sensor to a *500* interface.

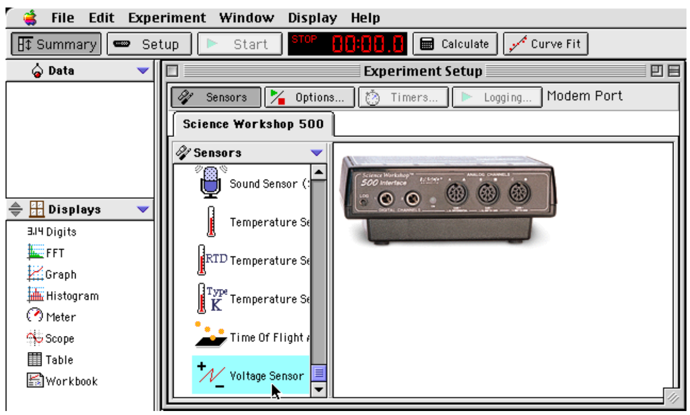
Section #2: Setting Up Your Own Experiment in DataStudio

The Summary List and the Setup Window

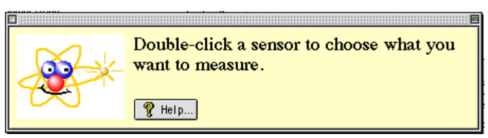
Start *DataStudio*. In the 'Welcome to DataStudio™' window, click 'Create Experiment'.



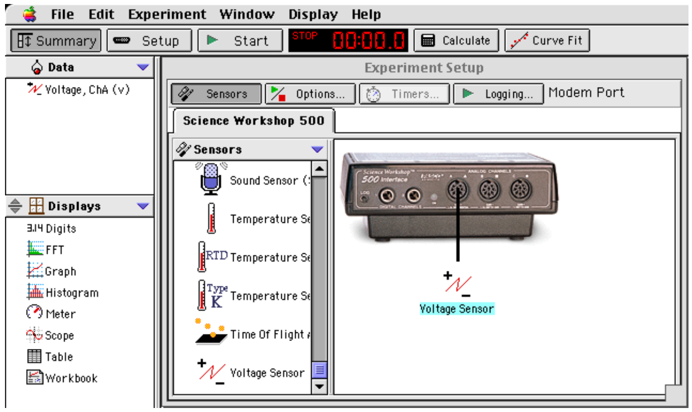
The first step to becoming proficient with *DataStudio* is to understand the Summary List and the Experiment Setup window. The Summary List shows runs of data (under 'Data') and the available displays (under 'Displays'). The Experiment Setup window shows the list of sensors (under 'Sensors') and the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



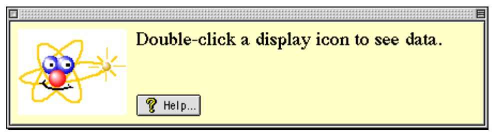
Select a sensor. The sensors are listed by name. Scroll through the list to find the 'Voltage Sensor', and then double-click the sensor to select it.



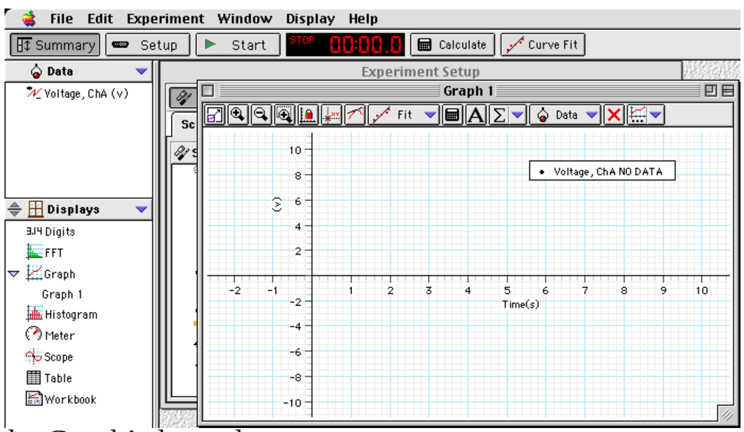
The Voltage Sensor icon appears below Channel A of the interface, and 'Voltage, ChA (v)' appears in the Data list.



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



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

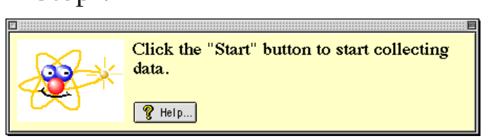


appears in the Graph's legend.

Finally, click the 'Start' button (

) 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.

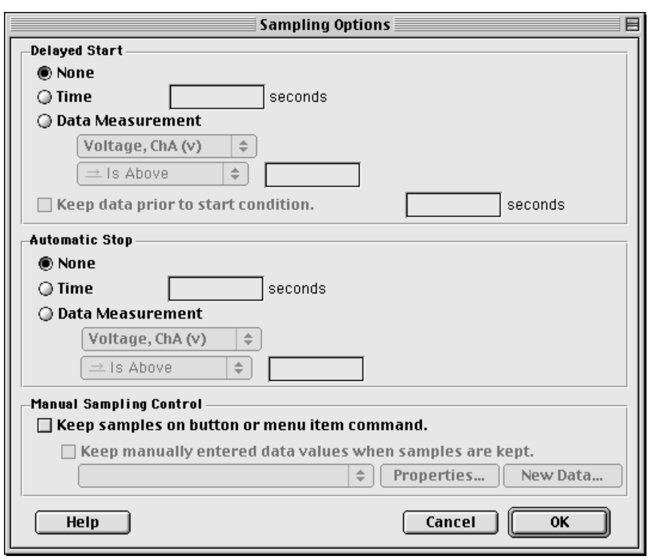
- Use the **File** menu to make a new activity, open an activity, save an activity, save an activity with a specific filename or in a specific location, import data, export data, select options (for saving *to* or opening *from* a particular directory), setup the page for printing, print, or quit.
- 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, disconnect for data logging or re-connect after data logging, set sampling options, open a new empty data table, or add a display.
- Use the **Window** menu to close, minimize, or maximize a window, to tile or cascade windows, or to select a window so it 'pops-to-the-top'.
- Use the **Display** menu to export data or a picture of a display or to activate any of the buttons in a display's toolbar.
- Use the **Help** menu to open the online help files, see the most recent help message, turn on or turn off the tips and confirmation windows, or change the license key.

Features of the Experiment Setup Window

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

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

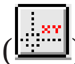
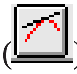
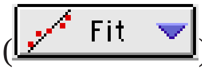
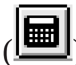
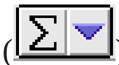
Use the 'Sampling Options' window to set a 'Delayed Start', an 'Automatic Stop' or to set the 'Manual Sampling Control'.

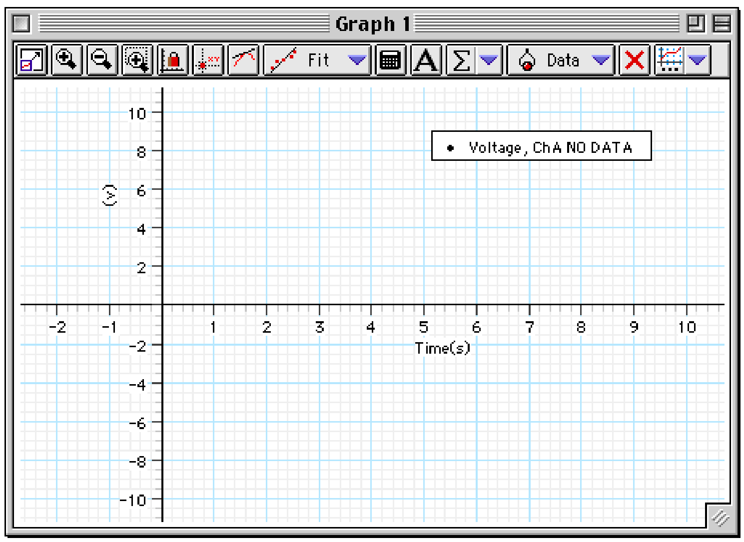


Section #3: Data Analysis

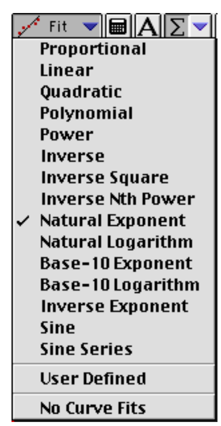
DataStudio offers several ways to analyze data:

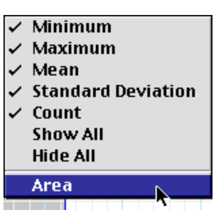
- Use the built-in analysis tools in the Graph display toolbar
- Use the 'Calculator' to create calculations based on your measured data or on a range of numbers that you select.
- Use the 'Curve Fit' to compare your data to mathematical models.

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



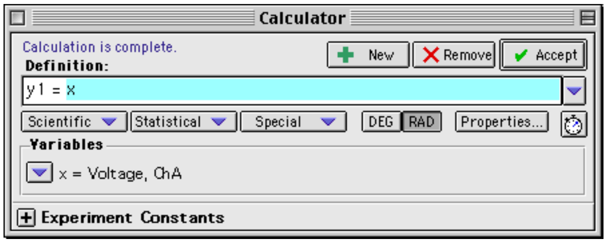
- Use the 'Smart Tool' to see the coordinates of any point.
- Use the 'Slope Tool' to see the slope of a line tangent to a point on a curve.
- Use the 'Fit' menu button to select a mathematical model.
- Use the 'Calculate' button to create a calculation on the data in your Graph.
- Use the 'Statistics'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



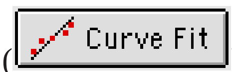


Click the ‘Calculate’ button in the main toolbar (

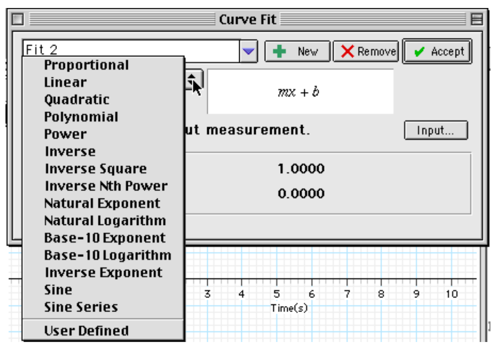
) to open the ‘**Calculator**’ window:



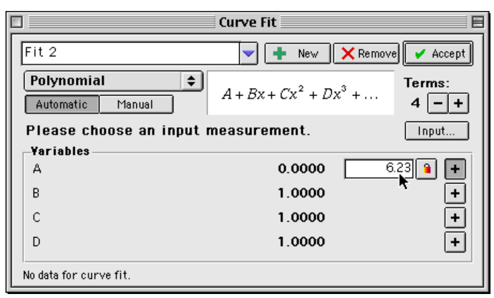
Use the ‘Definition:’ area to create your own calculation, or use the ‘Scientific’, ‘Statistical’, or ‘Special’ menus to select a specific calculation to apply to your data. After you have created the calculation, click ‘Accept’. Your calculation will appear in the Data list. You can drag your calculation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



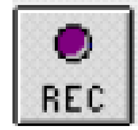
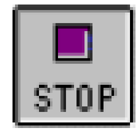
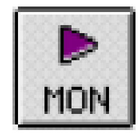
You can enter values for the coefficients or ‘lock’ a coefficient. After you have created the mathematical model, click ‘Accept’. Your curve fit will appear in the Data list. You can drag your curve fit to a Graph display, for example.

Online Help

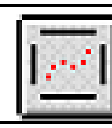
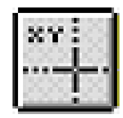
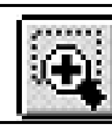
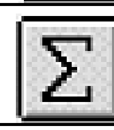
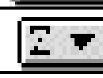
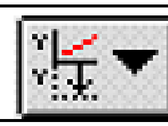
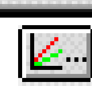
Click ‘Contents’ or ‘Search…’ in the Help menu to open the online help file. You can use the online help file to learn about any button, icon, menu, control, function or feature of the program.

Quick Reference Guide for *ScienceWorkshop*

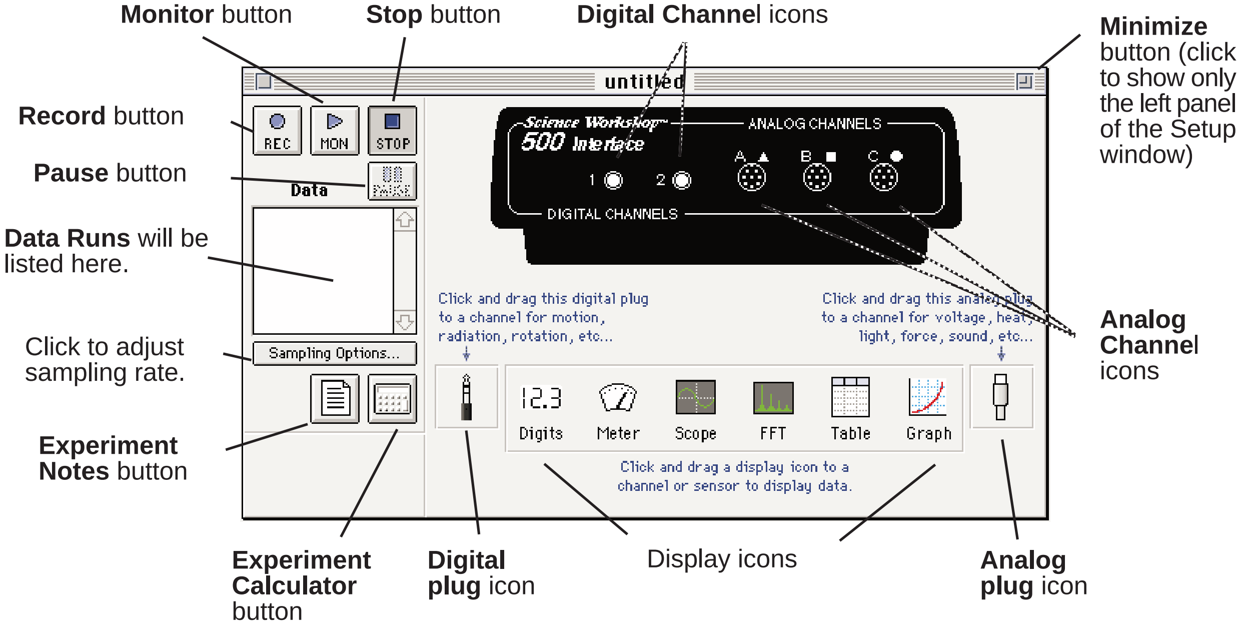
In the Experiment Setup Window:

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))	

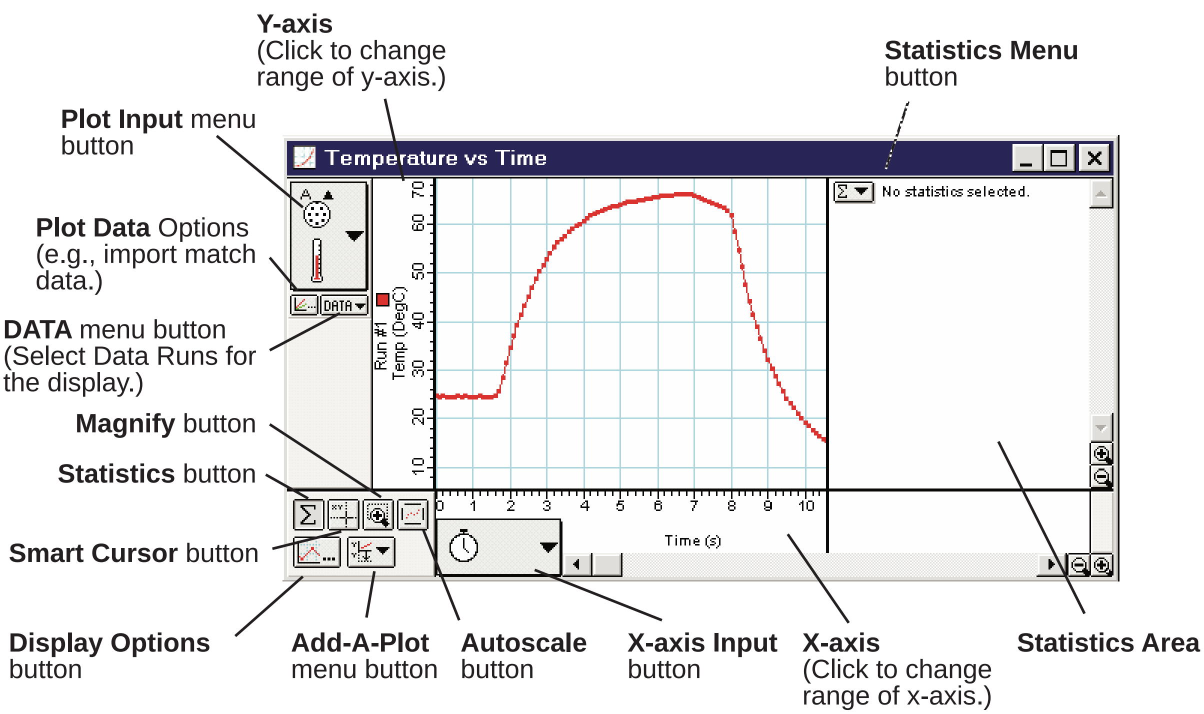
On the Graph Display:

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



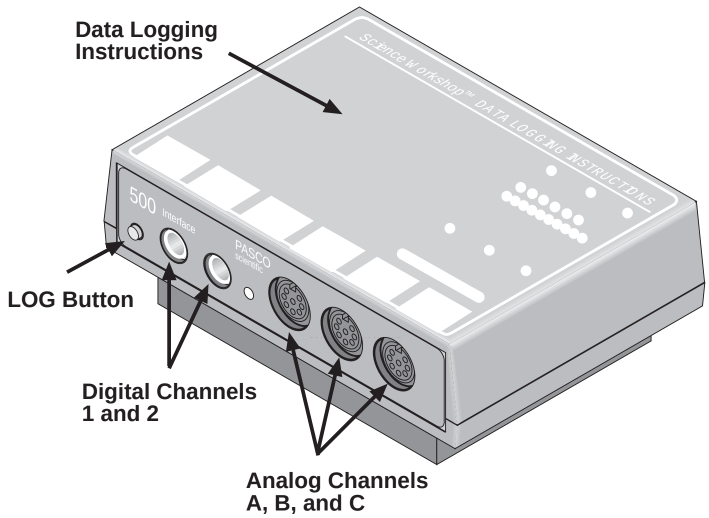
Instructions – Using *ScienceWorkshop®*

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: Experiment Setup

The *ScienceWorkshop* 500 Interface Box



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

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

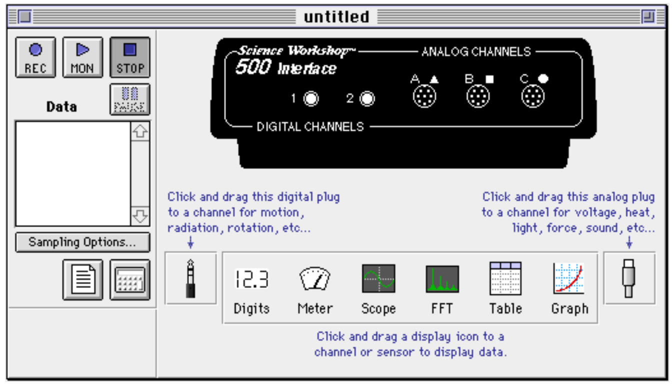
The **green LED (light-emitting diode)** on the front of the interface box indicates the mode of the interface box. A green light indicates that the power is ON. When you disconnect the interface for remote data logging the light will flash slowly when in the sleep mode and rapidly when you are collecting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

The **Analog Channels** allow up to three analog sensors to be plugged into the *500* interface. You can plug in an analog sensor’s DIN plug in only one way. The Force Sensor is an example of an analog sensor.

The **Digital Channels** allow one or two digital sensors to be plugged into the *500* interface. The Photogate and Motion Sensor are examples of digital sensors. For example, you can connect two Photogates or one Motion Sensor to a *500* interface.

The Experiment Setup Window

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



The Menu Bar   File   Edit   Experiment   Display

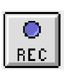
The **menu bar** at the top of the Experiment Setup window is very similar to menus bars found in Macintosh® and Windows® programs.

- Use the **File** menu to open, close, save, print, and import data.
- Use the **Edit** menu to copy, cut, clear, and paste data or runs of data.
- Use the **Experiment** menu to control the data collection.

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

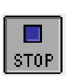
- Use the **Display** menu to select any of the six display windows (either to set up a new display or toggle to a display already in use).

Features of the Experiment Setup Window

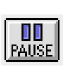


The **Record button** is in the top left corner of the Experiment Setup window. Press this button to collect data and store the data in memory. The flashing bar below the button shows when *ScienceWorkshop* is collecting data.

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



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



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

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

Suggested Periodic Sampling rates for common measurements:

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

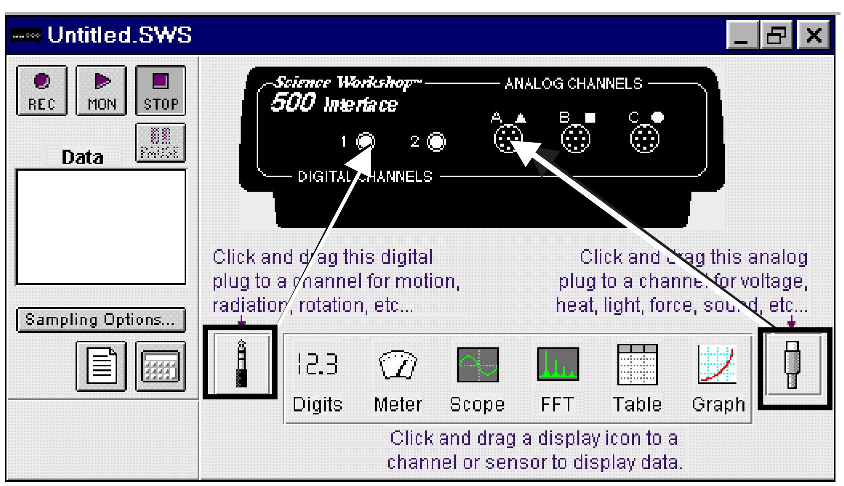
Press the **Experiment Calculator button** to open the Experiment Calculator window that allows you to do mathematical operations on collected data. You can also use it as a stand-alone calculator.

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

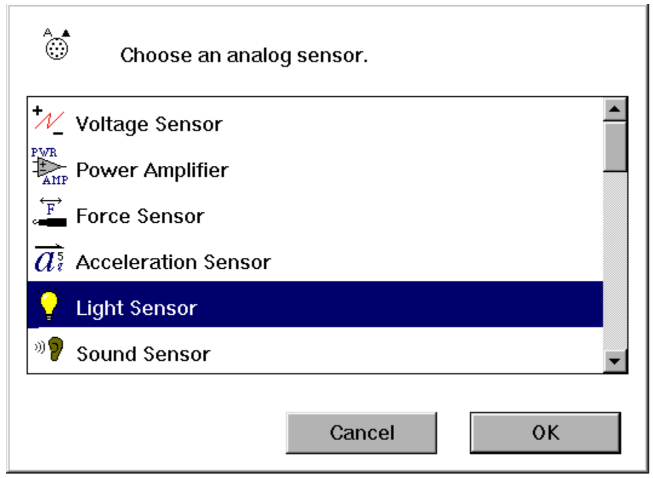
Drag the **analog plug icon** to Analog Channel A, B, or C to add an analog sensor to the Experiment Setup window. Then select the correct analog sensor from the list of sensors than opens. Click **OK** to return to the Experiment Setup window.

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

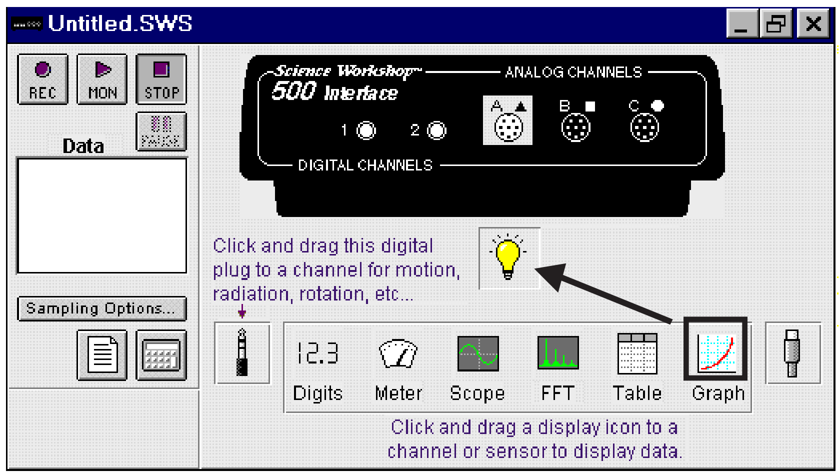


2. Choose the sensor from the sensor list that pops up. Click **OK** to return to the Experiment Setup window.



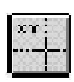
3. Drag a display icon to the Sensor icon.

You are ready to collect data!



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

Section #2: Data Analysis

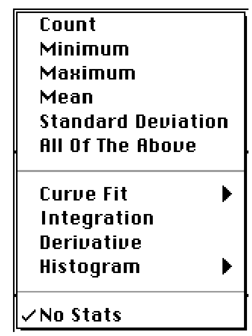
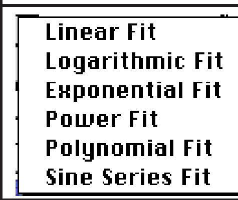
Analysis: The Smart Cursor 

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

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

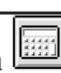
The Statistics Tool 

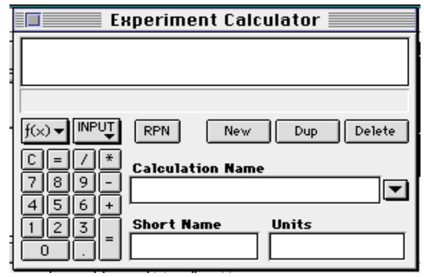
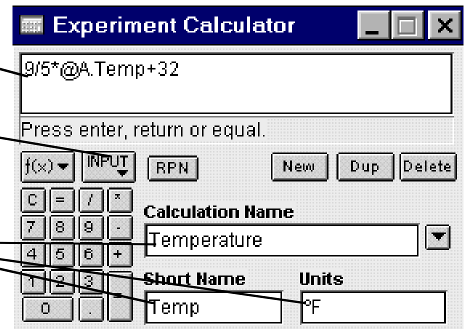
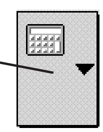
The Table and Graph displays have built-in statistics. Click the S**tatistics button** to open the statistics area at the bottom of a Table or on the right side of a Graph.

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.

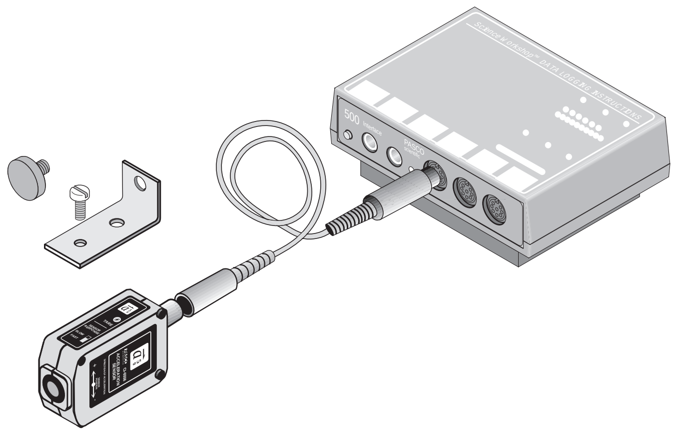
Tutorial Activities – Exploration of Sensors

Practice using the sensors included in the Physics Bundles for the *ScienceWorkshop* 500 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.

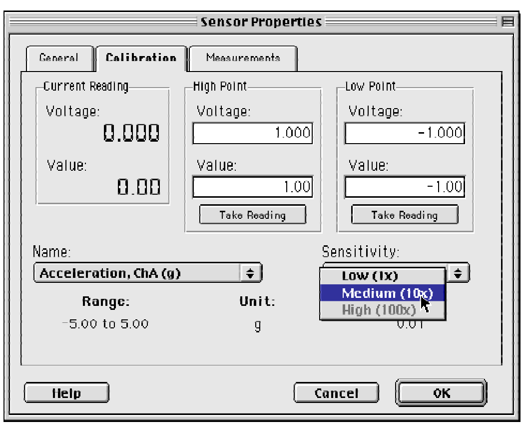


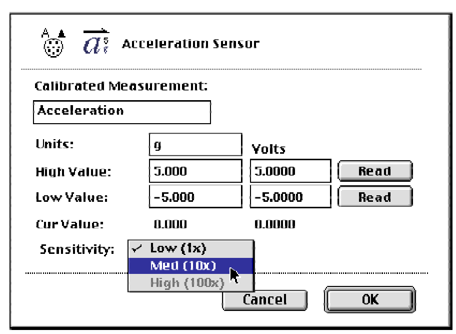
The sensor has two built-in controls located on the top of the sensor:

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.





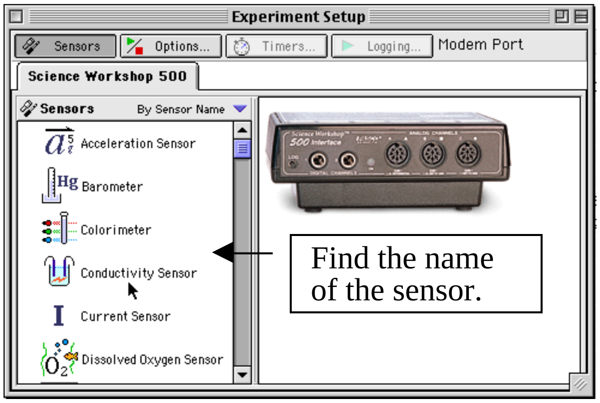
The sensing unit inside the sensor is oriented so that the greatest sensitivity is along the direction of the two arrows on the label.

Set up the sensor with the interface

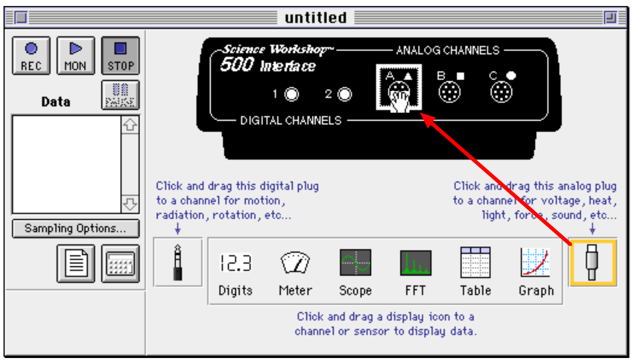
- Plug one end of the DIN-to-DIN cable into the sensor and then connect the other end of the cable into **Analog Channel A** on the interface.
- Note: You can connect the sensor directly into the interface if needed.

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 parameters (e.g., Acceleration (g).) appear in the Data list.

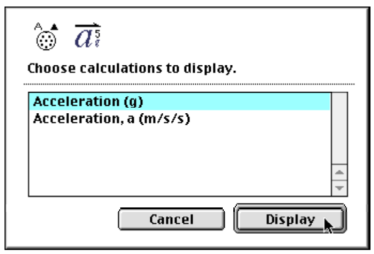


- In *ScienceWorkshop*, click-and-drag the 'analog sensor plug' icon to the Channel A icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface.

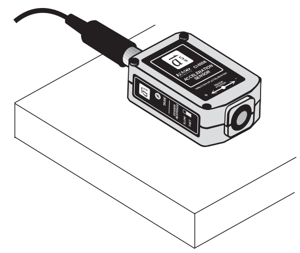


Set up a display

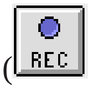
- In *DataStudio*, double-click the 'Graph' icon in the Displays list. **Result**: The display automatically shows acceleration versus time.
- In *ScienceWorkshop*, click-and-drag the 'Graph' display icon to the sensor's icon in the Experiment Setup window. Select 'Acceleration (g)' from the 'Choose…display' window and click 'Display'.



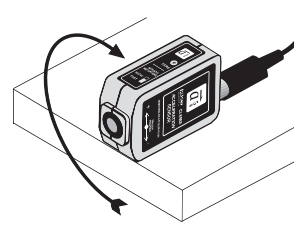
Start recording data



- 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.



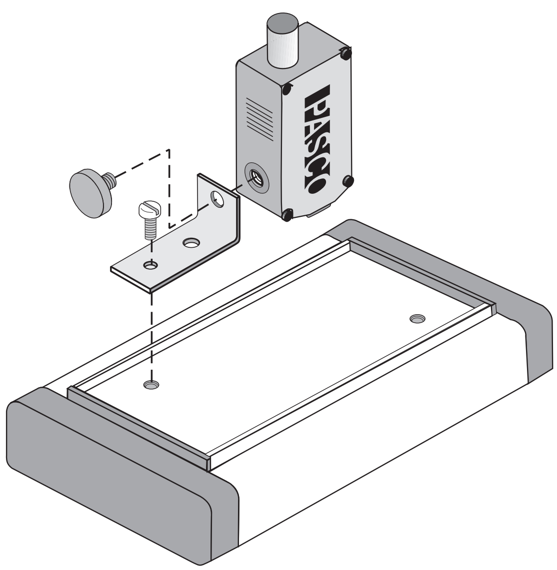
Stop recording data.

- Click 'Stop' to end data recording.

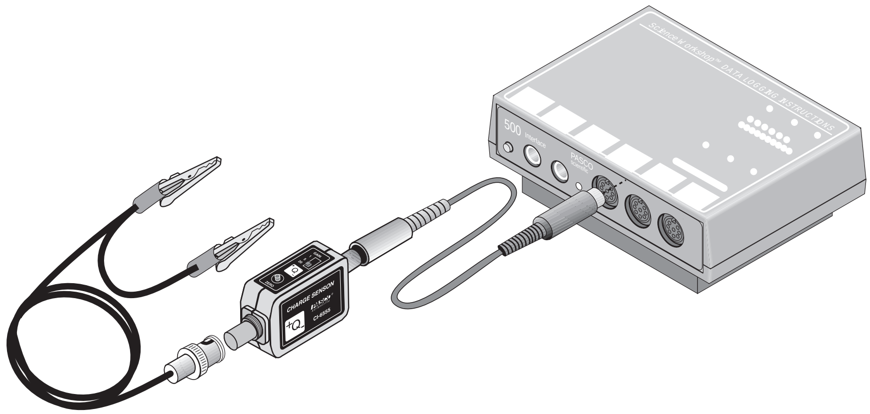
Mounting on a PASCO Cart

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.



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.

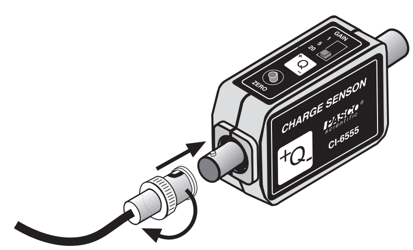
Gain Select Switch: Use the gain select switch to set the full-scale input range of the sensor. The three settings are as follows.

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.

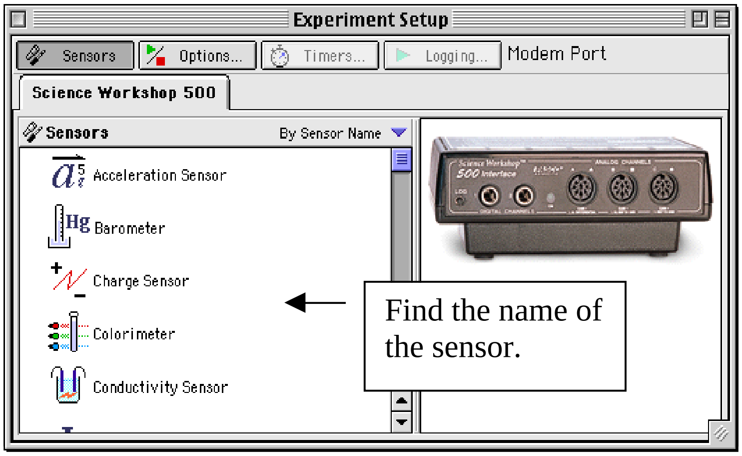
Set up the sensor with the interface



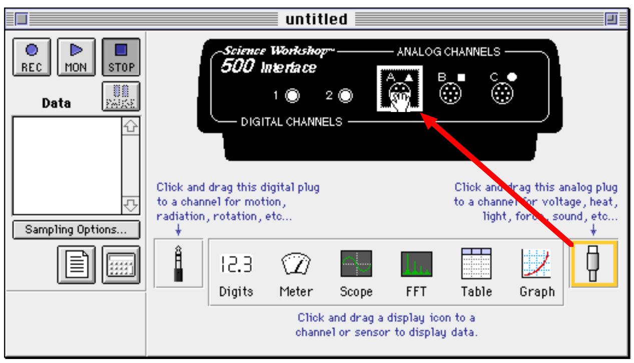
- Plug the sensor directly into **Analog Channel A** on the interface.
- Note: You can use the interface cable to connect the sensor into the interface if needed.
- Connect the cable assembly to the BNC port on the sensor. Line up the connector on the end of the cable with the pin on the BNC port. Push 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.



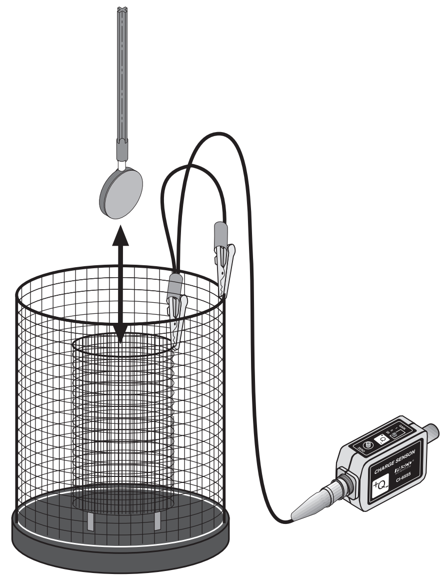
- In *ScienceWorkshop*, click-and-drag the 'analog sensor plug' icon to the Channel A icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface.



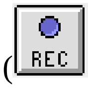
Set up a display

- 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.

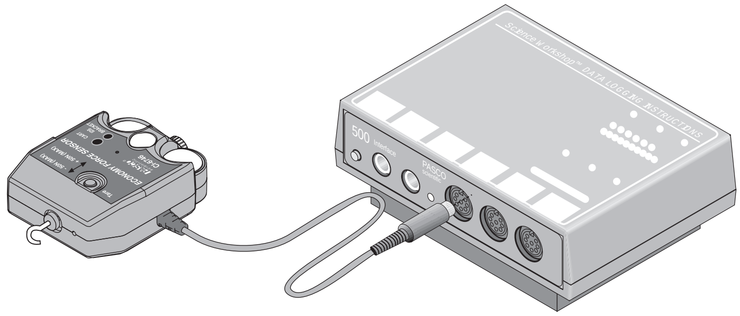
Stop recording data.

- 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.

Economy Force Sensor



The Economy 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.

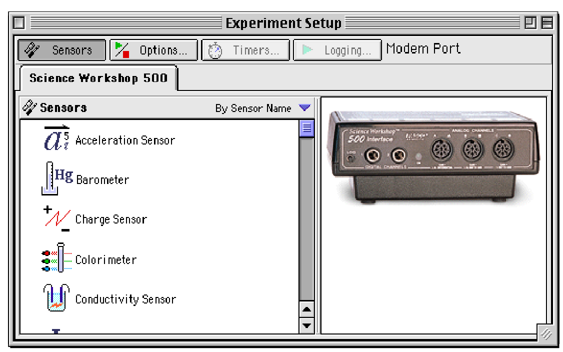
To calibrate the sensor you will need an object of known mass, such as one kilogram.

Set up the sensor with the interface

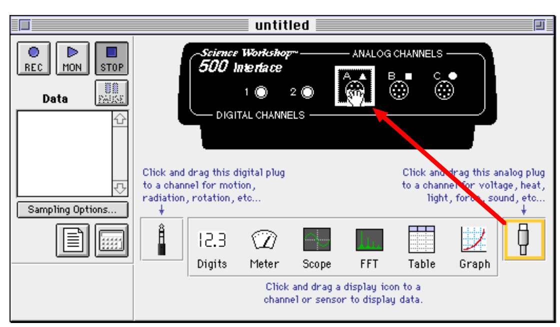
- Plug the sensor cable into **Analog Channel A** on the interface.

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.



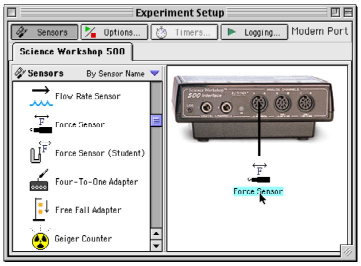
- In *ScienceWorkshop*, click-and-drag the 'analog sensor plug' icon to the Channel A icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface.

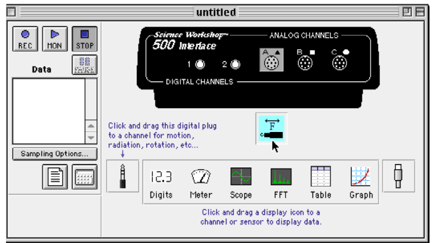


Calibrate the sensor

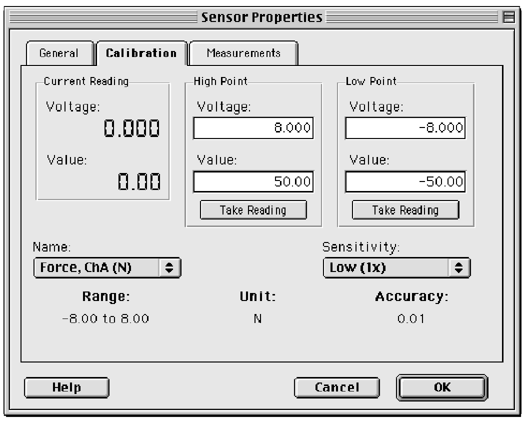
The general method for calibrating the force sensor is as follows:

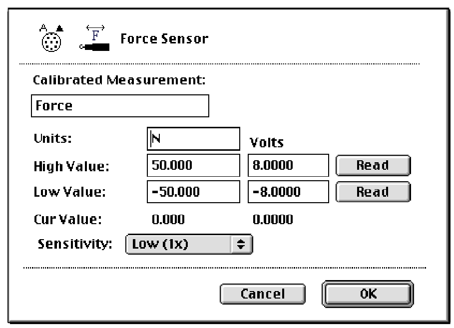
1. In the Experiment Setup window, double-click the sensor's icon.





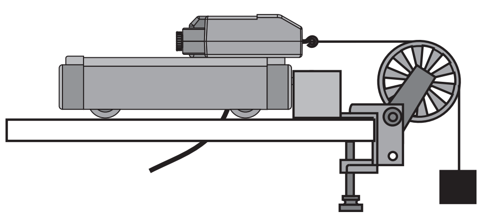
- **Result**: In *DataStudio*, the Sensor Properties window opens. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window opens.

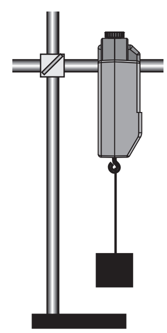




2. Calibrate the software.

- **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.



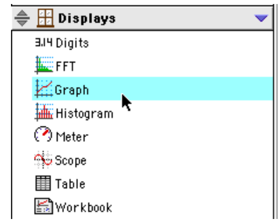


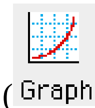
- **Second**, check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*. When the voltage stabilizes, click the 'Take Reading' button under 'Low Point' in *DataStudio* or the 'Read' button in the row for 'Low Value:' in *ScienceWorkshop*. Enter '0' as the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

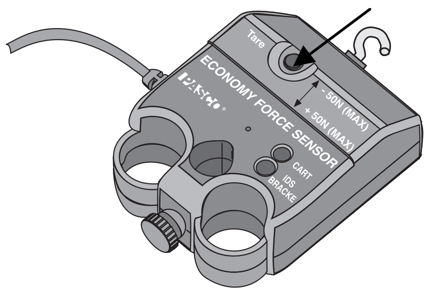


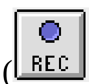
- In *DataStudio*, double-click ‘Graph’ in the Displays list. **Result**: The display automatically shows force.
- In *ScienceWorkshop*, click-and-drag the ‘Graph’ display icon () to the sensor’s icon in the Experiment Setup window.

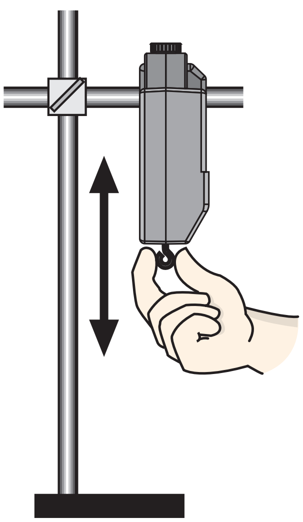
Start recording data

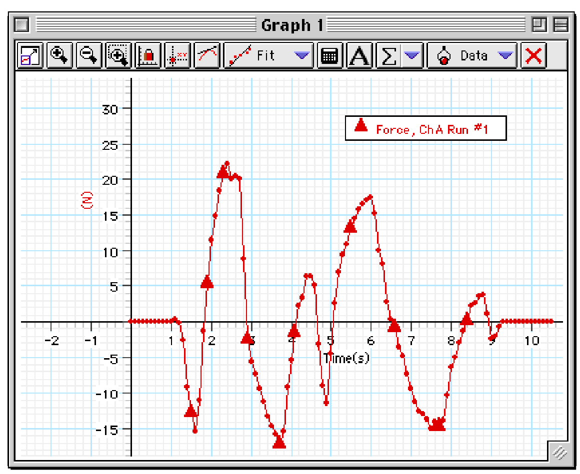
- Press the tare button on the sensor to zero it.

Tare button



- 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.



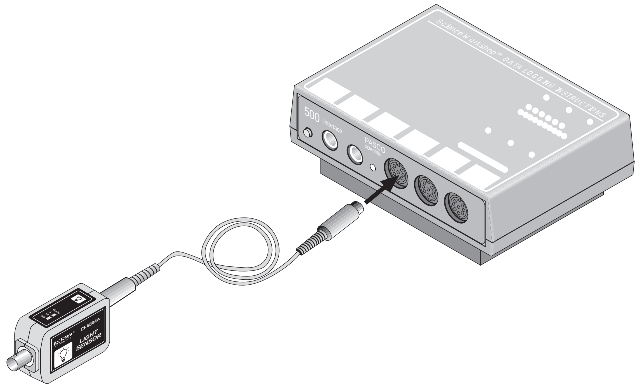


Stop recording data.

- 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.

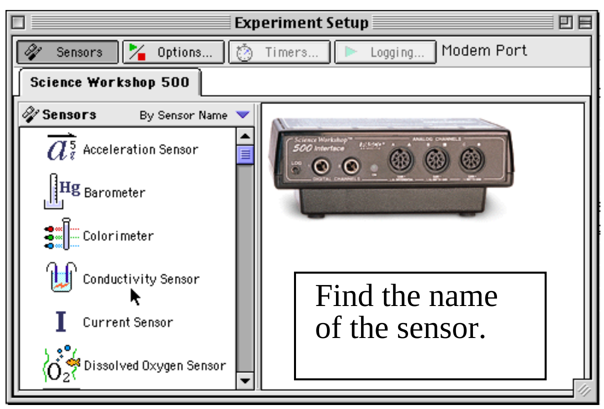
Gain Select setting	Maximum Input (lux)
1	500
10	50
100	5

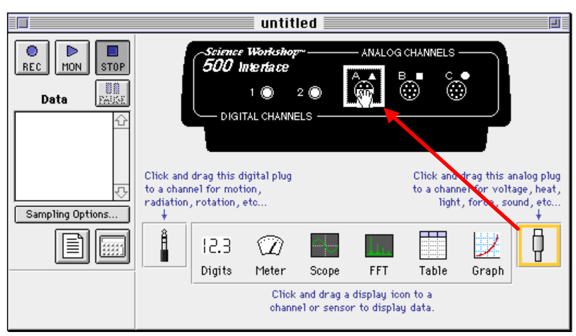
Set up the sensor with the interface

- 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

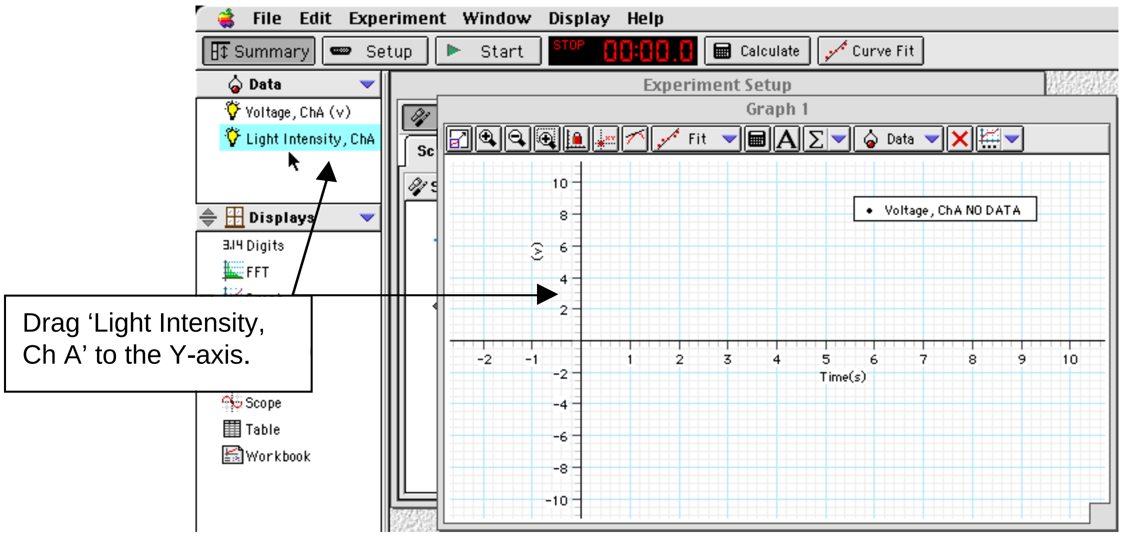
- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Channel A of the interface. The sensor's parameters appear in the Data list.
- In *ScienceWorkshop*, click-and-drag the 'analog sensor plug' icon to the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



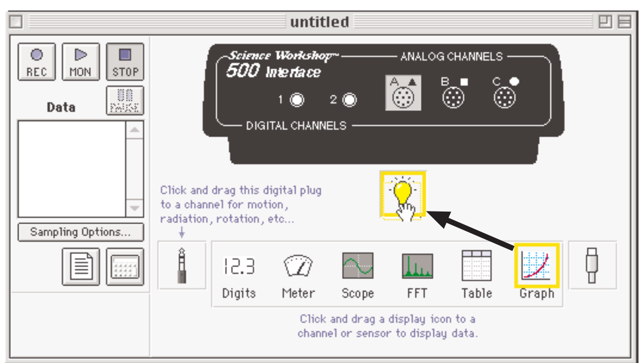


Set up a display

- 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.

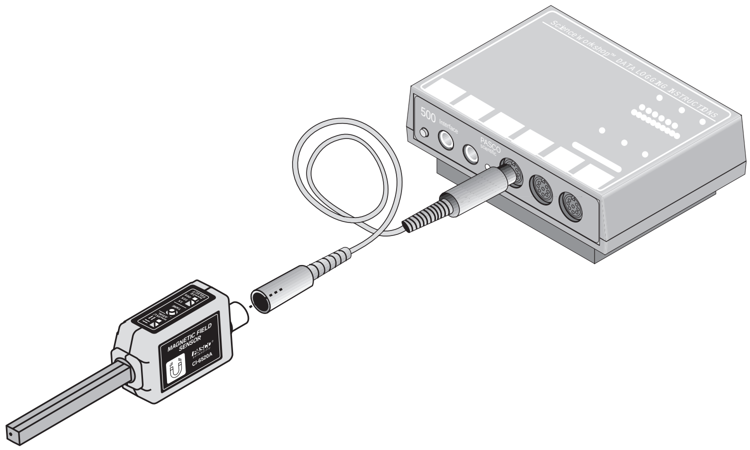
Stop recording data.

- 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

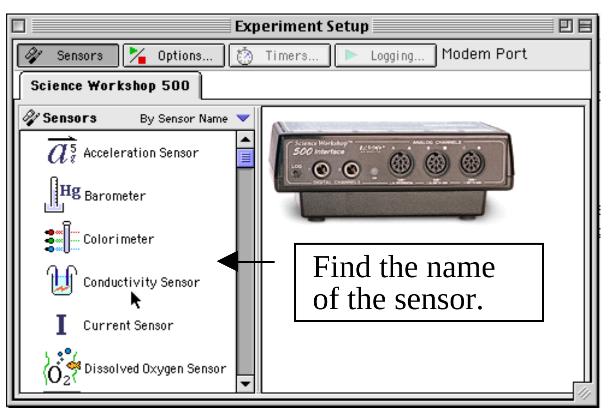
For this activity you will need a bar magnet.

Set up the sensor with the interface

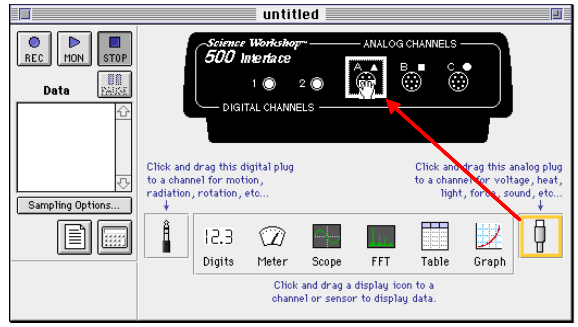
- Plug one end of the DIN-to-DIN cable into the sensor and then connect the other end of the cable into **Analog Channel A** on the interface.
- Note: You can connect the sensor directly into the interface if needed.

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.

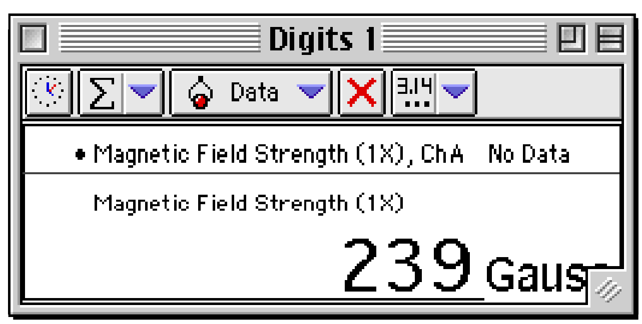


Set up a display

- 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.

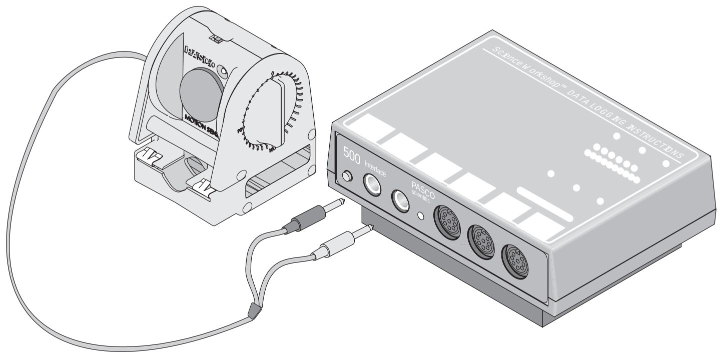


Stop recording data

- 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.

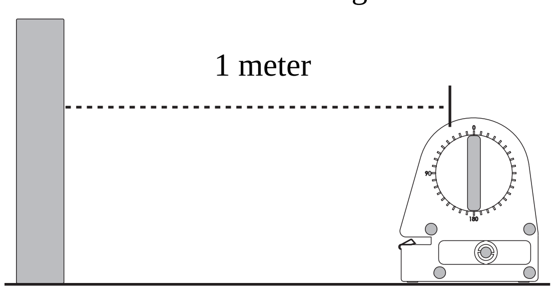
Narrow/Standard (Std.) Switch: Set the switch to *Narrow* for measuring highly reflective targets (such as a PASCO cart) at distances of 2 m or less. Set the switch to *Std* for measuring targets that are poor reflectors or for distances longer than 2 m.

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.

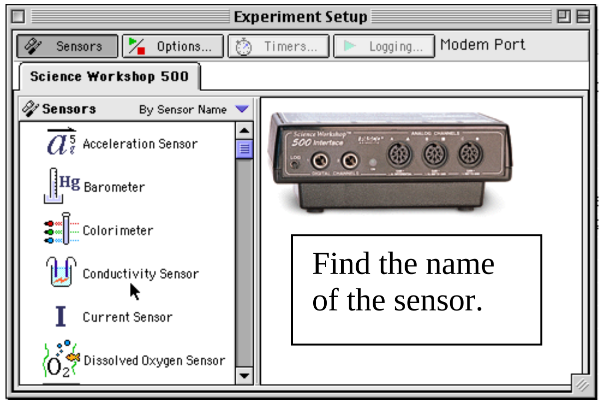
Set up the sensor

- 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.

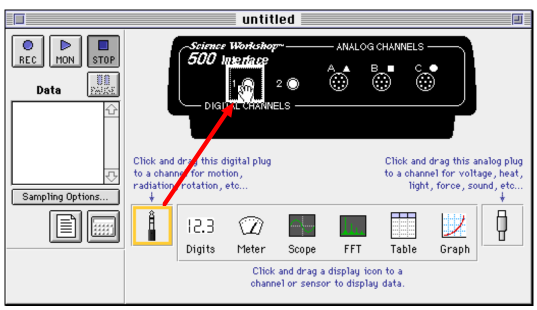


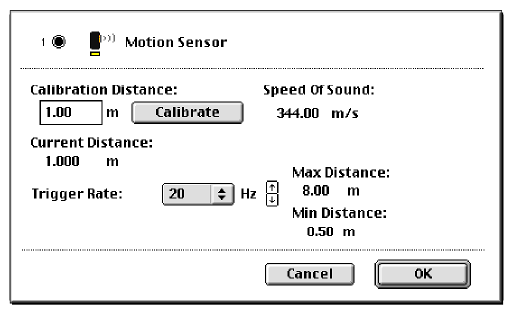
Set up the sensor in the software

- 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.

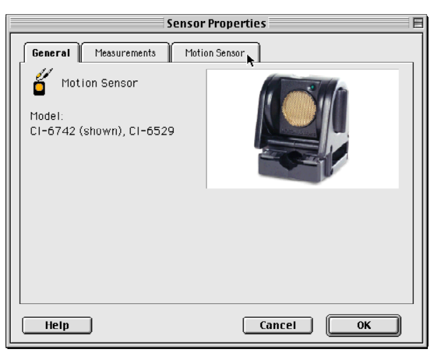


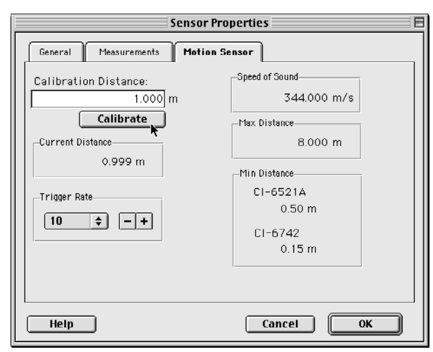


Calibrate the sensor

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. Click the 'Motion Sensor' tab. **Result**: The calibration window opens and the sensor begins to click a few times per second.

3. Calibrate the 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

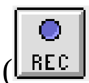
4. Click 'OK' to return to the Experiment Setup window.

Set up a display

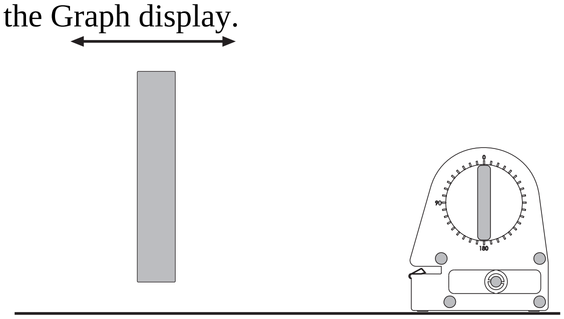
- In *DataStudio*, double-click the 'Graph' icon from the Displays list. **Result**: The Graph display shows position versus time.
- In *ScienceWorkshop*, click-and-drag the 'Graph' display icon to the sensor's icon in the Experiment Setup window. Select 'Position, x (m)' from the list of and click 'Display'.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

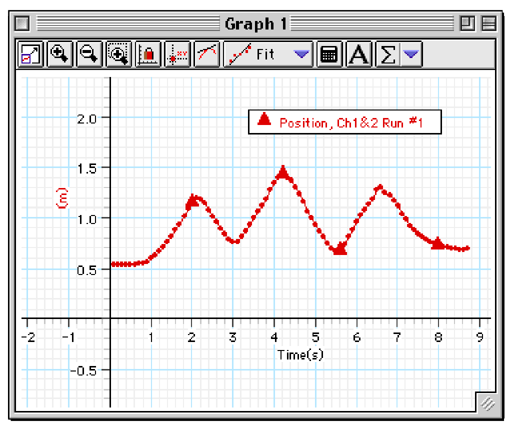
Start recording data

- 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.

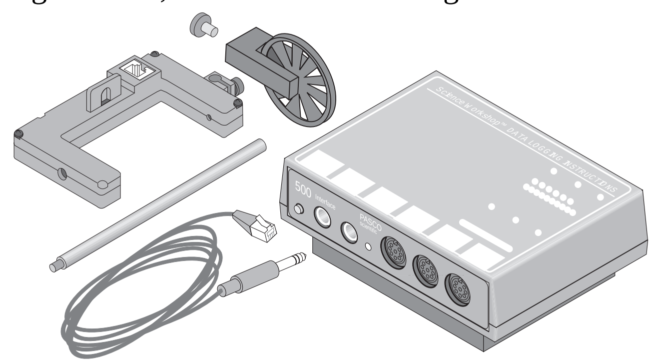




Stop recording data

- Click 'Stop' to end data recording.

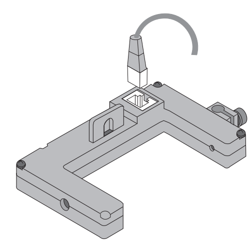
Photogate/Pulley System



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.

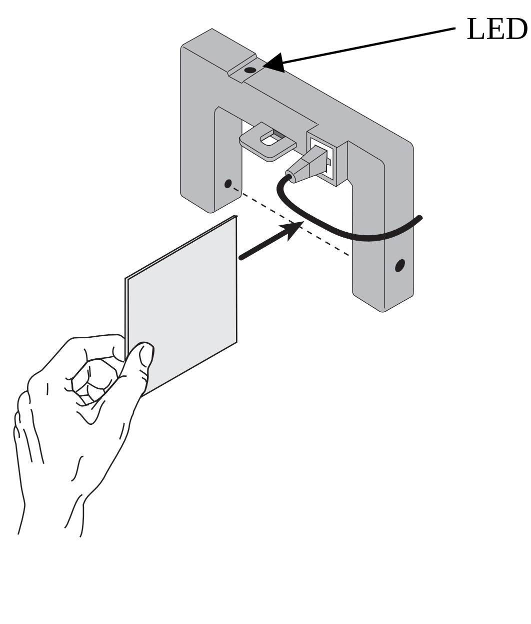
You can attach the Super Pulley to the tab on the side of the Photogate Head using the attachment screw or the Pulley Mounting Rod. The Photogate Head itself can be held in place several different ways. It has a 1/4-20 threaded hole on one side and a rod clamp on the other side.

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



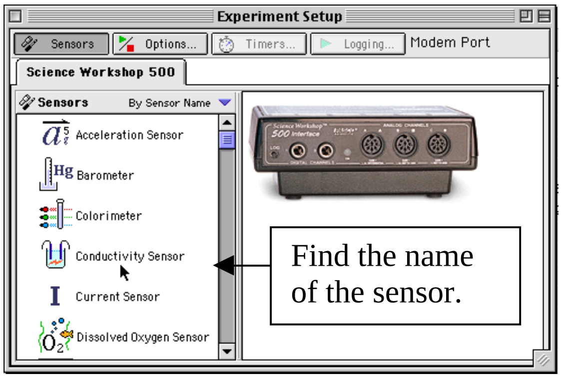
Set up the sensor

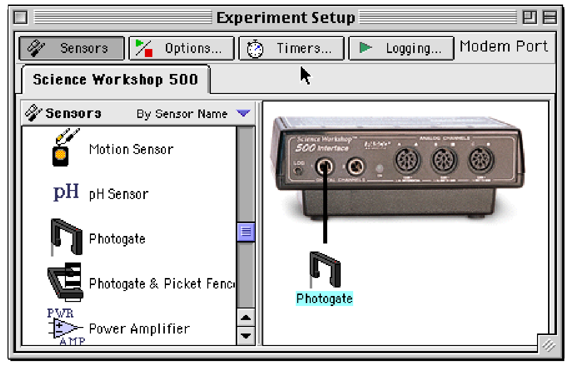
- Plug the modular connector on one end of the cable into the Photogate Head and plug the other end of the cable into **Digital Channel 1** on the interface.
- Watch the LED (light-emitting diode) on top of the Photogate Head as you pass a card back-and-forth through the opening.



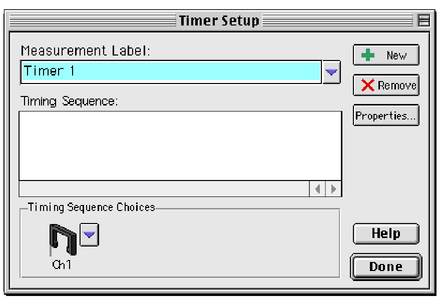
Set up the sensor in the *DataStudio* software

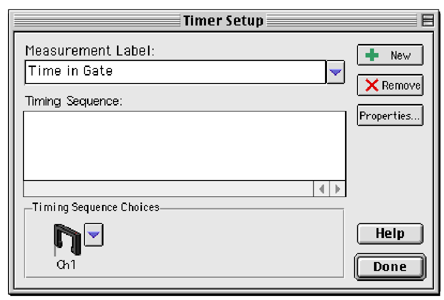
- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Digital Channel 1 of the interface. The ‘Timers’ button () becomes active in the Experiment Setup window toolbar.



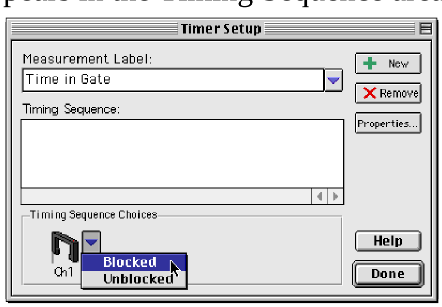


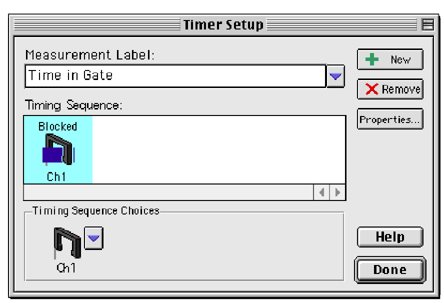
- Click the ‘Timers’ button in the setup window toolbar. **Result**: The Timer Setup window opens. For this activity you will measure the amount of time that a card interrupts the Photogate’s infrared beam, so enter ‘Time in Gate’ as the Measurement Label.



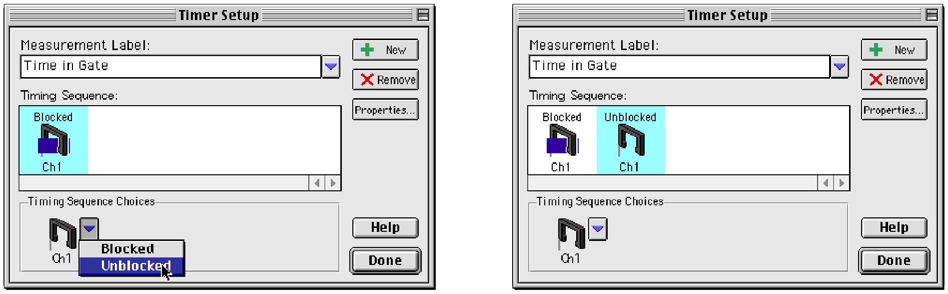


- The ‘Timing Sequence’ for this activity is ‘blocked-to- unblocked’. Click the ‘Timing Sequence Choices’ menu button and select ‘Blocked’. **Result**: The ‘Blocked Photogate’ icon appears in the Timing Sequence area.



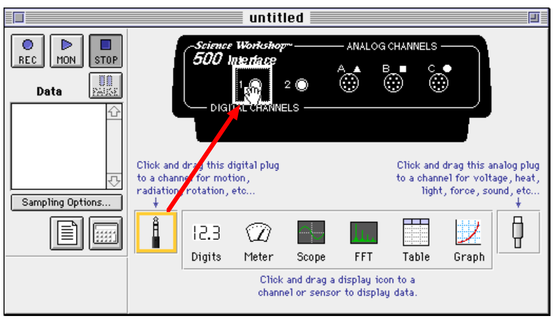


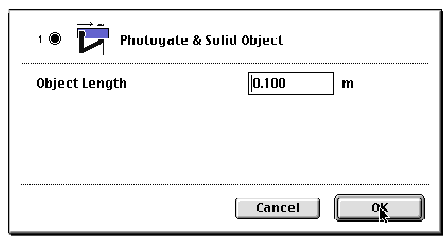
- Click the ‘Timing Sequence Choices’ menu button again and select ‘Unblocked’. **Result**: The ‘Unblocked Photogate’ icon appears next to the ‘Blocked Photogate’ icon in the Timing Sequence area. Click ‘Done’ to return to the setup window.



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

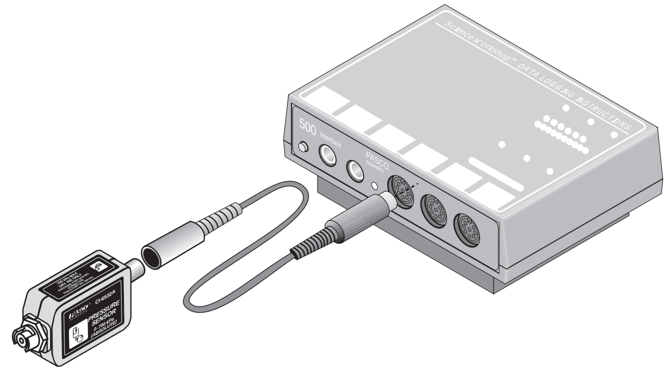
- Click ‘Stop’ to end data recording.

Pressure Sensor

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

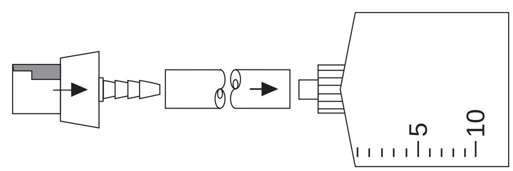
The sensor can measure pressures as high as 700 kilopascals, or about seven atmospheres. It is designed for non-corrosive gases. Do not put liquids into the sensor.

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

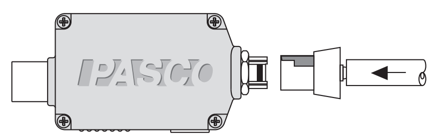


Set up the sensor

- 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.

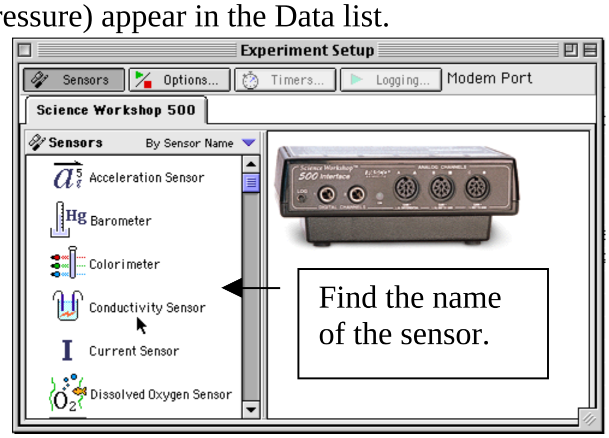


- Connect the syringe to the sensor. Line up the quick-release connector with the pressure port on the sensor. Push the connector onto the port and turn the connector clockwise until it clicks.

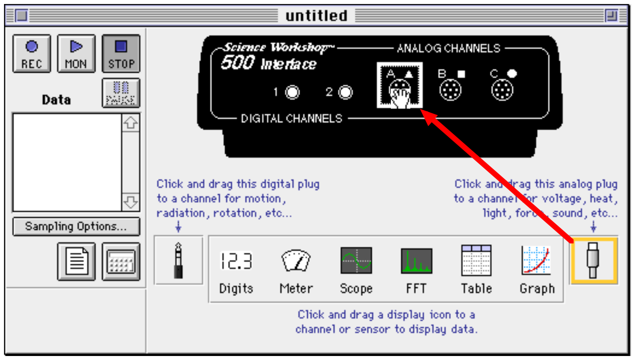


Set up the sensor in the software

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



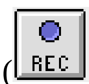
- In *ScienceWorkshop*, click-and-drag the 'analog sensor plug' icon to the Channel A icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. Result: The sensor's icon appear belows Channel A of the interface.

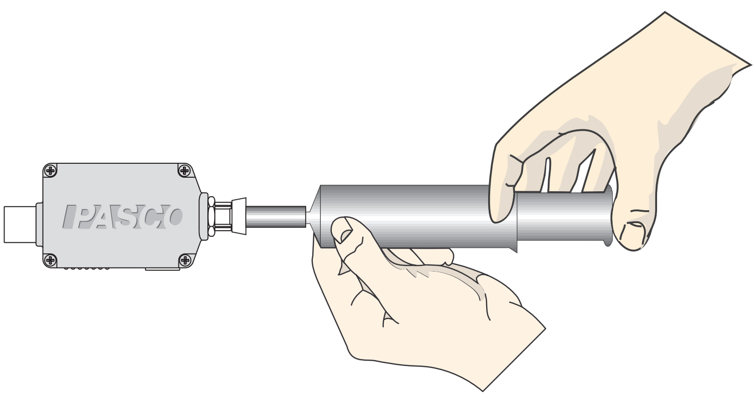


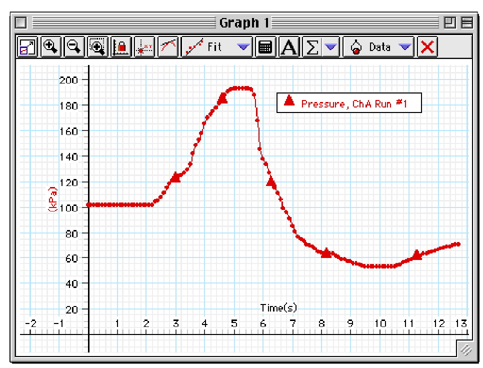
Set up a Graph display of Pressure versus Time

- 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.





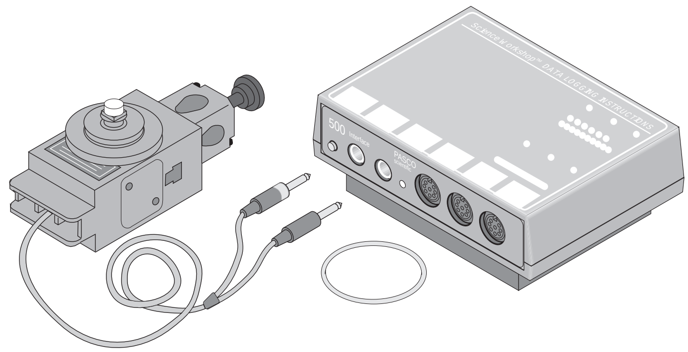
- Note the change in pressure in the Graph display.

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.



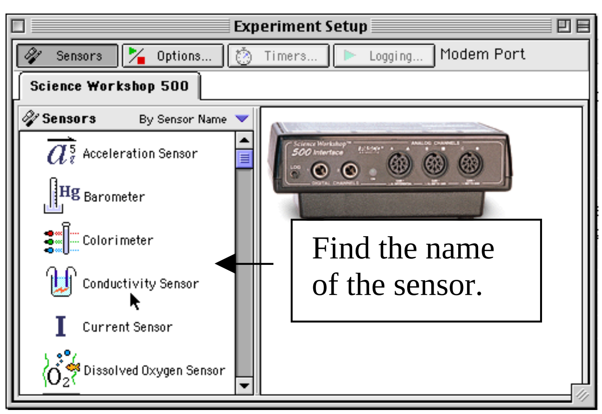
The sensor has a detachable three-step pulley and comes with a rubber "O" ring that fits in the groove of the largest step on the pulley. The sensor has an attached cable for connecting to the interface and a rod clamp that can be attached to the sensor at three different places.

Set up the sensor

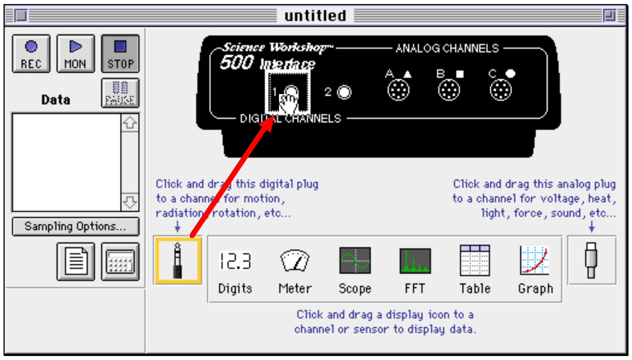
- Connect one of the phone plugs into **Digital Channel 1** on the interface. Connect the other phone plug into **Digital Channel 2**. (NOTE: The order of the plugs is not critical. If rotating the sensor's shaft produces a negative displacement when you want a positive displacement, reverse the order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

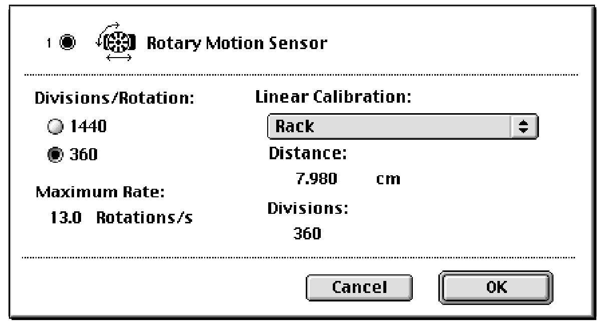
Set up the sensor in the software

- 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.



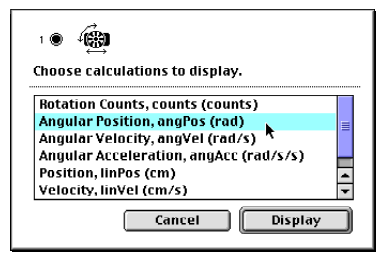


Click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channels 1 and 2 of the interface.

Set up a Graph display of Angular Position versus Time.

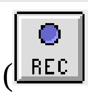
- In *DataStudio*, double-click the 'Graph' icon in the Displays list. **Result**: The Graph display automatically shows 'Angular Position' versus 'Time'.

- 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'.

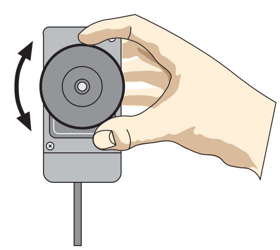


Start recording data

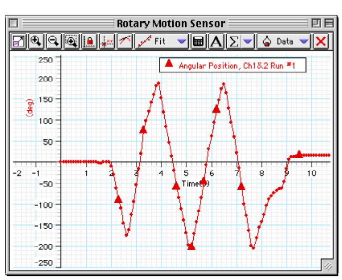
- In *DataStudio*, click the 'Start' button (

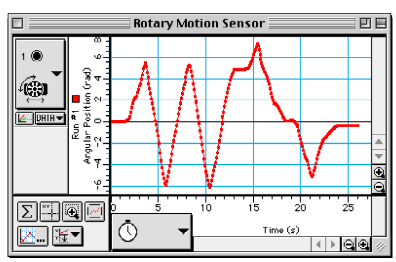
). In *ScienceWorkshop*, click the 'REC' button (

).



- 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.

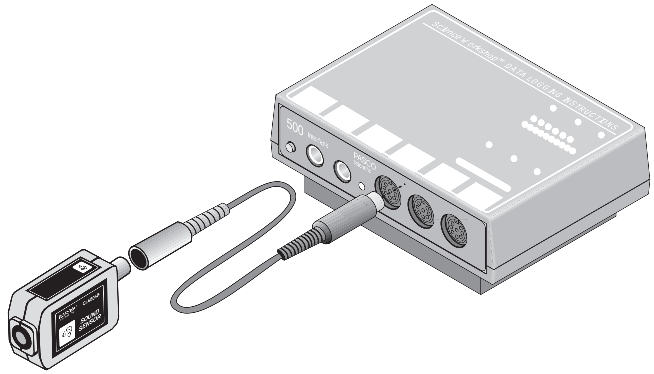




Stop recording data

- 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.

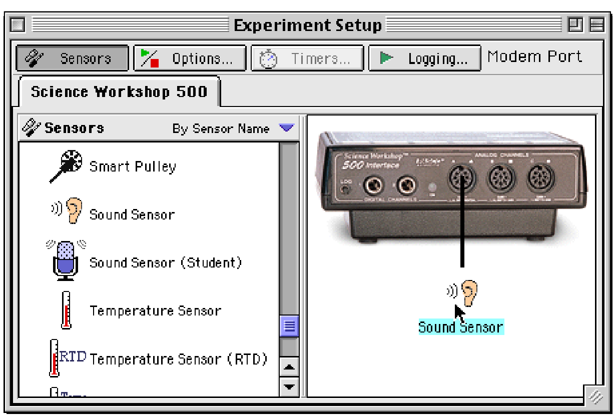
The sensor can detect sound levels ranging from 45 decibels (dB) to over 100 dB over a frequency range from 20 to 16,000 hertz (Hz). The sensor uses an electret condenser microphone. You can use the software to amplify the signal from the sensor. For example, if you select a 'Sensitivity' of Medium (10x) 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.)

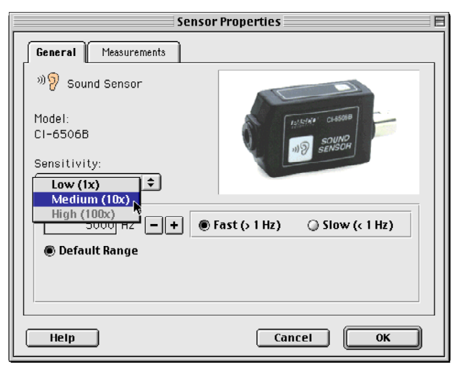
Set up the sensor

- 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.

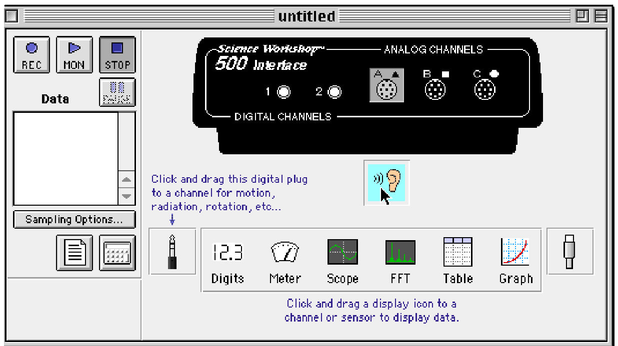
Set up the sensor in the software

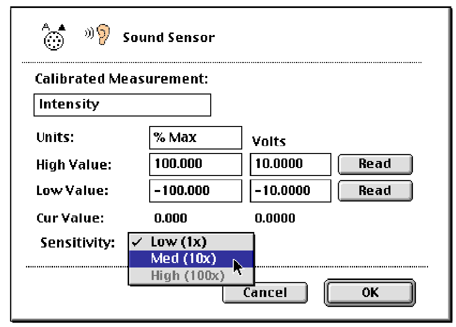
- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window. **Result**: The sensor icon appears below Channel A of the interface. The sensor's parameter (e.g., Voltage) appears in the Data list.
- Double-click the sensor's icon to open the Sensor Properties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





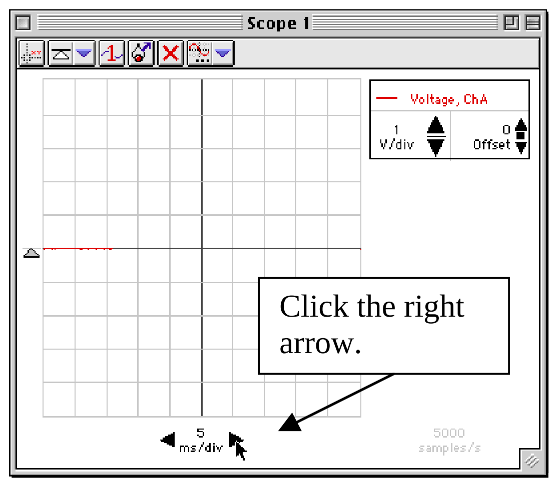
- In *ScienceWorkshop*, click-and-drag the 'analog sensor plug' icon to the Channel A icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon will appear below Channel A of the interface.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



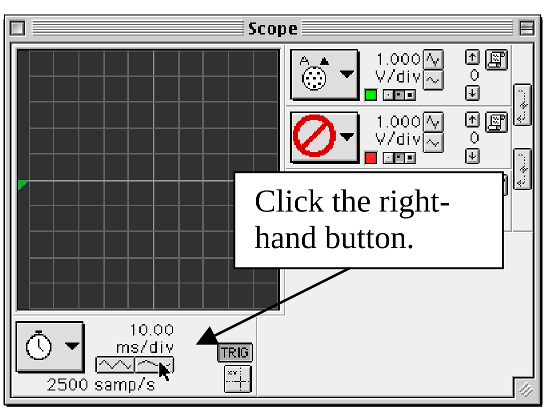


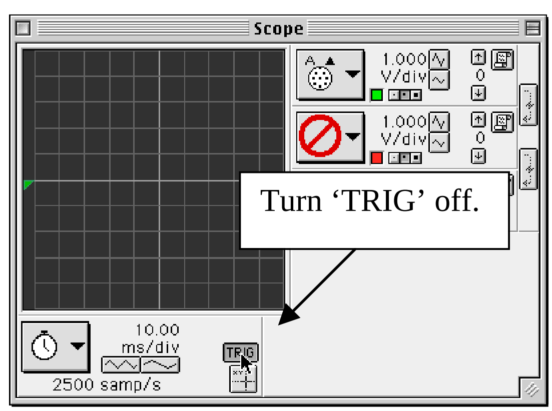
Set up a Scope display

- 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).

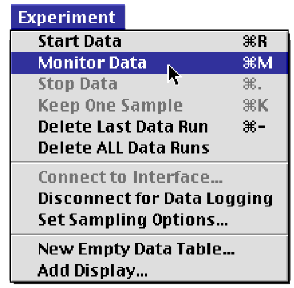


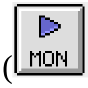
- Click the 'TRIG' button to de-select it (that is, turn off 'Triggering').



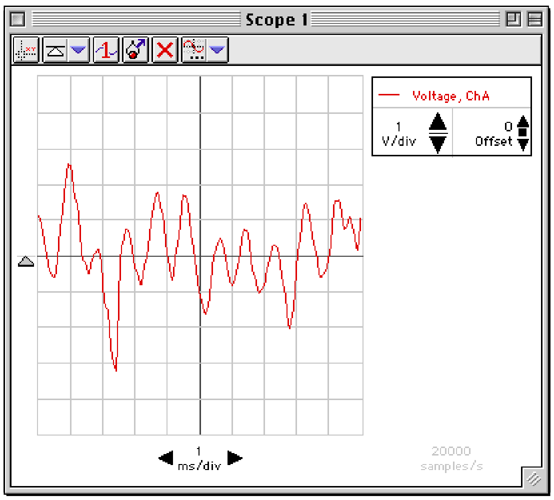


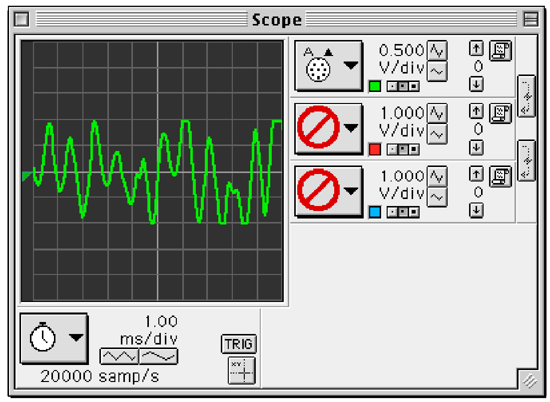
Start monitoring data



- 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

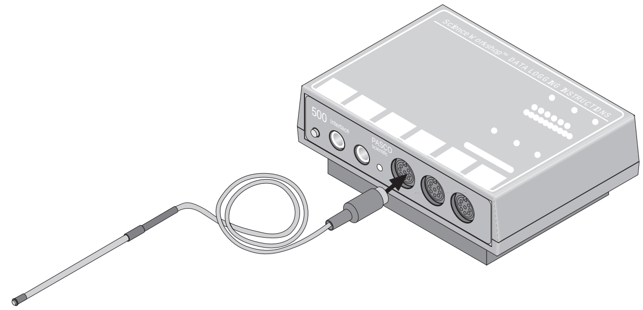




- Click 'Stop' to end data monitoring.

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.



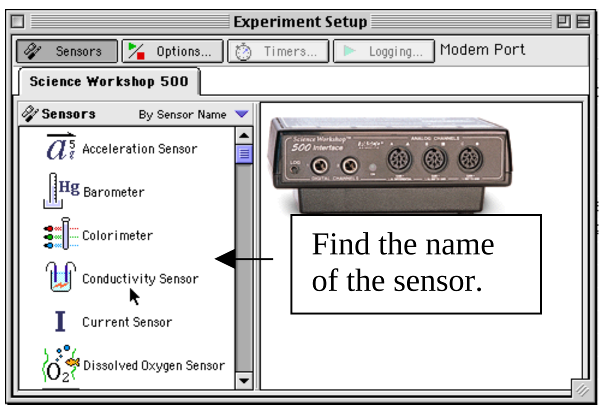
The sensor's operating range is from –5 ˚C to 105 ˚C. Do not use the sensor in a direct flame or on a hot plate.

Set up the sensor

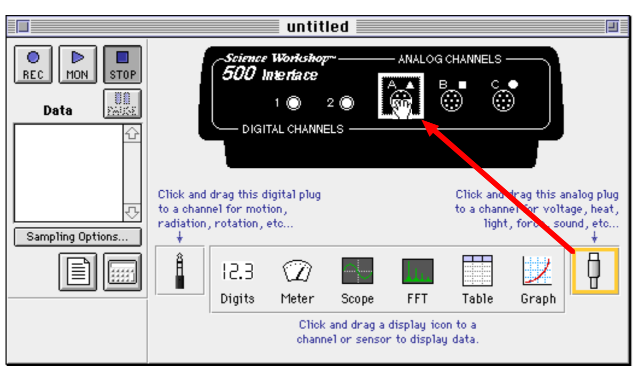
- Plug the sensor's DIN plug into **Analog Channel A** on the interface.

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.



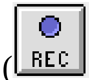
- In *ScienceWorkshop*, click-and-drag the 'analog sensor plug' icon to the Channel A icon in the Experiment Setup window, select the name of the sensor from the list of sensors and click 'OK' to return to the Experiment Setup window. **Result**: The sensor's icon appears below Channel A of the interface.



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'.

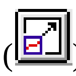
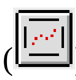
Start recording data

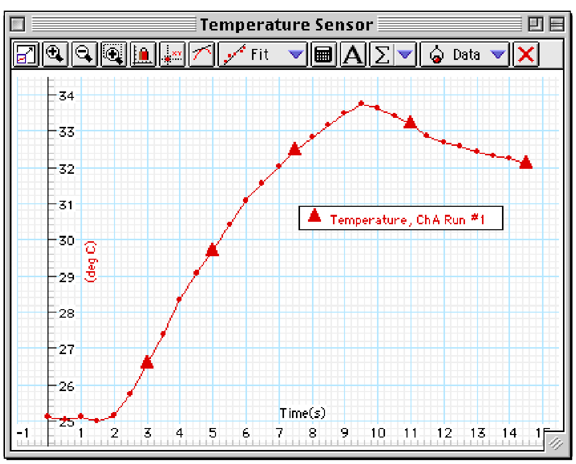
- In *DataStudio*, click the 'Start' button (
). In *ScienceWorkshop*, click the 'REC' button (
).
- Measure the temperature of your hand. Place the tip of the sensor in the palm of your hand and rub the sensor against your skin for several seconds. Note the temperature in the Graph display. Then move 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.

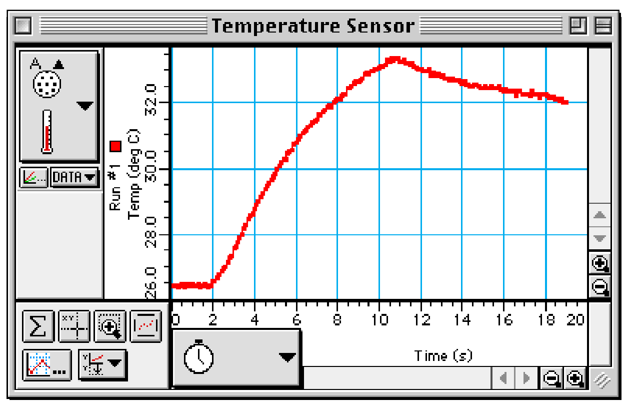
Stop recording data

- Click 'Stop' to end data recording.

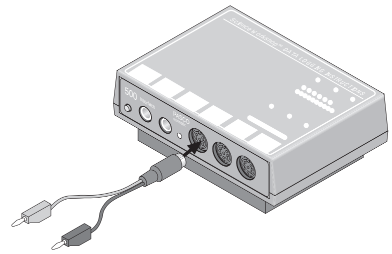
Rescale the Graph display

- 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

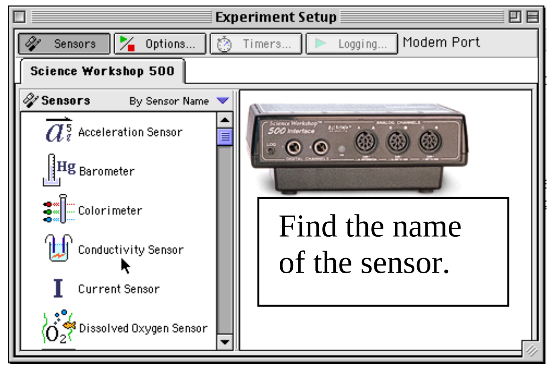


The Voltage Sensor measures voltages from –10 volts to +10 volts. The probe ends are stackable banana plugs. The sensor comes with two insulated alligator clips.

For this activity you need a 1.5 volt battery.

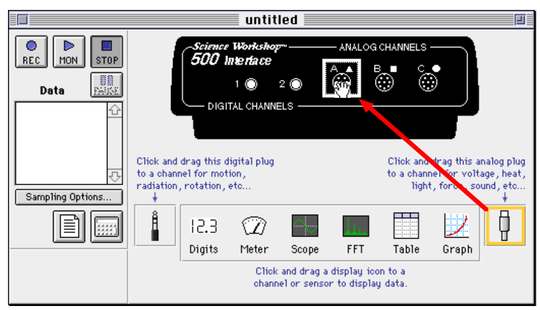
Set up the sensor with the interface

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



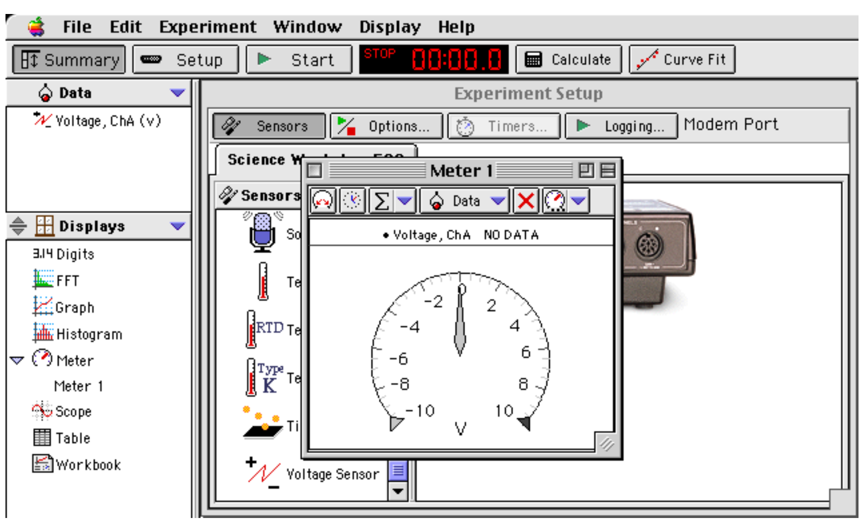
Set up the sensor in the software

- 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.

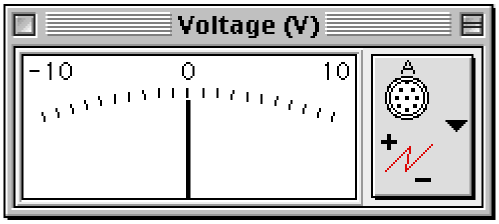


Set up a 'Meter' display

- 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.

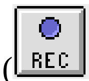


- In *ScienceWorkshop*, click and drag the 'Meter display' icon to the Voltage Sensor icon in the Experiment Setup window. The Meter display shows 'Voltage (V)'.



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.

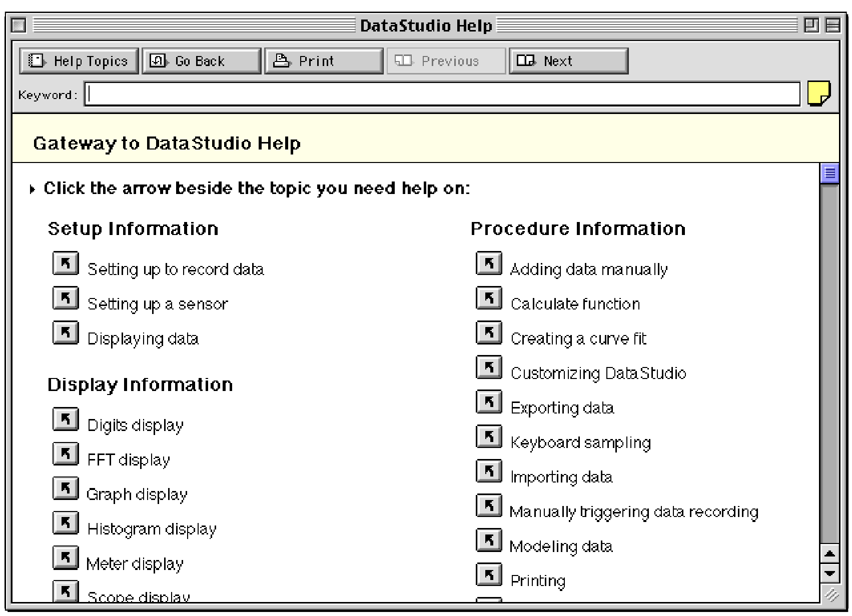
Stop recording data

- 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.



Name ____________________ Class _____________ Date _________

Activity P01: Position and Time – Understanding Motion 1 (Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Linear motion	P01 Position and Time.ds	P01 Understanding Motion 1	P01_MOT1.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Motion Sensor (CI-6742)	1	**Base and Support Rod (ME-9355)**	1

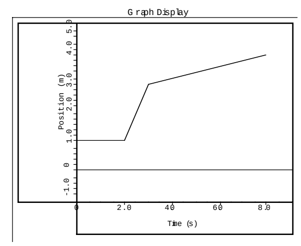
What Do You Think?

What is the relationship between the motion of an object – YOU – and a graph of position and time for the moving object?

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

Background

When describing the motion of an object, knowing where it is relative to a reference point, how fast and in what direction it is moving, and how it is accelerating (changing its rate of motion) is essential. A sonar ranging device such as the PASCO Motion Sensor uses pulses of ultrasound that reflect from an object to determine the position of the object. As the object moves, the change in its position is measured many times each second. The change in position from moment to moment is expressed as a velocity (meters per second). The change in velocity from moment to moment is expressed as an acceleration (meters per second per second). The position of an object at a particular time can be plotted on a graph. You can also graph the velocity and acceleration of the object versus time. A graph is a mathematical picture of the motion of an object. For this reason, it is important to understand how to interpret a graph of position, velocity, or acceleration versus time. In this activity you will plot a graph of position in real-time, that is, as the motion is happening.



SAFETY REMINDER

- Follow all safety instructions.
- Keep the area clear where you will be walking.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

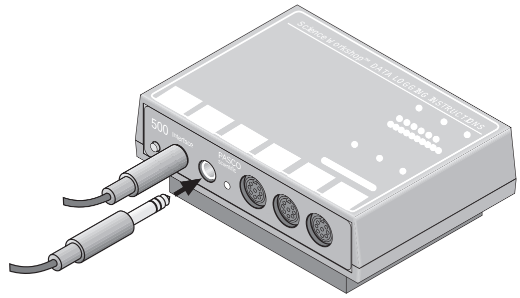
- **This activity is easier to do if you have a partner to run the computer while you move.**

For this activity, <u>you</u> will be the object in motion. Use the Motion Sensor to measure your position as you move in a straight line at different speeds. Use *DataStudio* or *ScienceWorkshop* to plot your motion on a graph of position and time.

The challenge in this activity is to move in such a way that a plot of your motion on the same graph will "match" the line that is already there.

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 plugs of the Motion Sensor to Digital Channels 1 and 2 on the interface. Connect the yellow plug to Digital Channel 1 and the other plug to Digital Channel 2.
3. Open the file titled as shown:



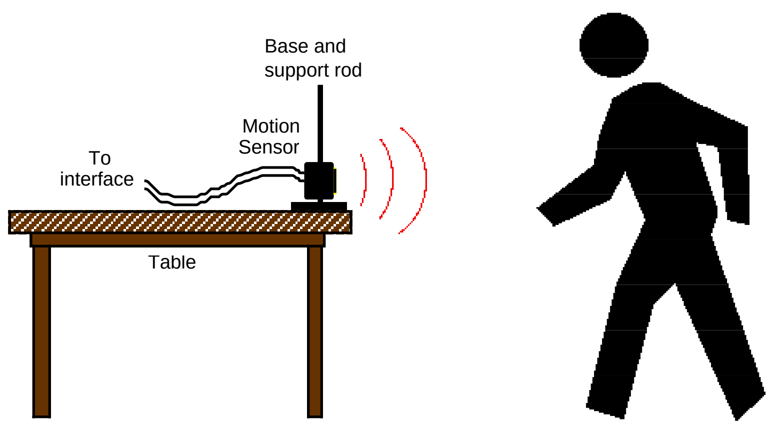
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P01 Position and Time.ds	P01 Understanding Motion 1	P01_MOT1.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Position versus Time.
- The Graph shows Position and Time values that were entered into the Graph.
- Data recording is set to stop automatically at 10 seconds. In the *DataStudio* file there is a three-second 'countdown' before data recording begins.

PART II: Sensor Calibration and Equipment Setup

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

1. Mount the Motion Sensor on a support rod so that it is aimed at your midsection when you are standing in front of the sensor. Make sure that you can move at least 2 meters away from the Motion Sensor.
2. Position the computer monitor so you can see the screen while you move away from the Motion Sensor.



Understanding Motion 1: Position and Time

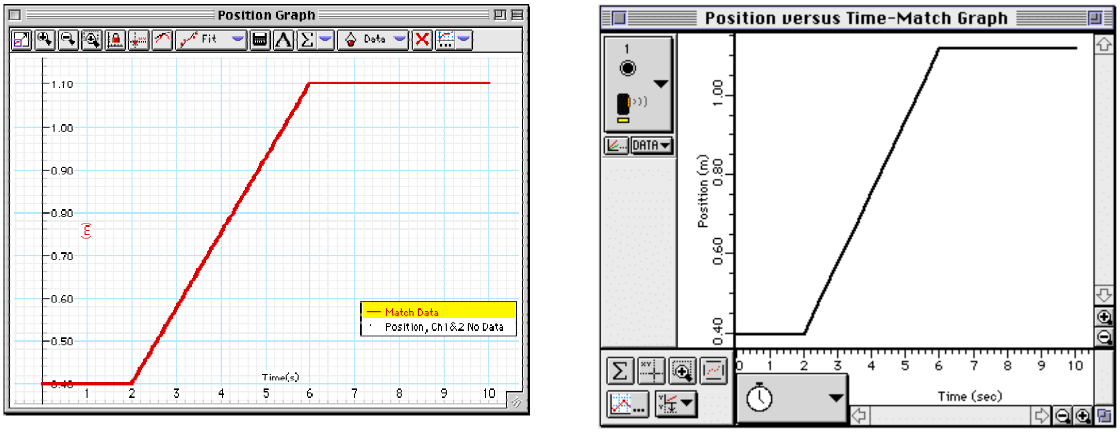
- **You will be moving backwards for part of this activity. Clear the area behind you for at least 2 meters (about 6 feet).**

Name ____________________ Class _____________ Date ________

PART III: Data Recording

1. Enlarge the Graph display until it fills the monitor screen.
2. Study the plot of Position versus Time in order to determine the following:

- How close should you be to the Motion Sensor at the beginning? _______ (m)
- How far away should you move? _______ (m)
- How long should your motion last? _______ (s)



3. When you are ready, stand in front of the Motion Sensor.

- **WARNING: You will be moving backward, so be certain that the area behind you is free of obstacles.**

4. When everything is ready, start recording data.

- In *DataStudio*, click 'Start'. There is a three-second countdown before data recording begins. The 'cursor' on the vertical axis of the Graph will move up and down as you move forward and backward relative to the sensor. Use the feedback from 'cursor' to find your best starting position.
- In *ScienceWorkshop*, click 'REC'. Data recording will begin almost immediately.
- The Motion Sensor will make a faint clicking noise.

5. Watch the plot of your motion on the Graph and try to move so the plot of your motion matches the Position versus Time plot already there.

If the Motion Sensor is having difficulty picking up the echo, use a notebook as a reflector. Hold the notebook at the same height as the sensor.

6. Repeat the data recording process a second and a third time. Try to improve the match between the plot of your motion and the plot already on the Graph.

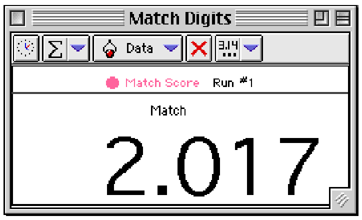
- The Graph can show more than one run of data at the same time.

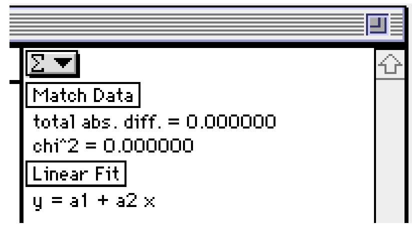
Analyzing the Data

1. Determine the slope of the best-fit line for the middle section of your best position versus time plot. You may want to resize the graph to fit the data.

- The slope of this part of the position versus time plot is the velocity during the selected region of motion.

2. Determine how well your plot of motion fits the plot that was already in the Graph. (Hint: In *DataStudio*, examine the 'Match Data' calculation. In *ScienceWorskhop*, examine the 'total abs. diff.' (total absolute difference) and the chi^2 (goodness of fit) terms from the Statistics area.)





Name ____________________ Class _____________ Date _________

Lab Report - Activity P01: Position & Time – Understanding Motion 1

What Do You Think?

What is the relationship between the motion of an object – YOU – and a graph of position and time for the moving object?

Questions

1. In the Graph, what is the slope of the line of best fit for the middle section of your plot?

2. What is the description of your motion? (Example: “Constant speed for 2 seconds followed by no motion for 3 seconds, etc.”)

3. What would be the physical meaning of a steeper slope on the graph?

4. What would be different about the motion if the slope were negative?

Name ____________________ Class ______________ Date _________

P02: Velocity and Time – Understanding Motion 2 (Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Linear motion	P02 Velocity and Time.ds	P02 Understanding Motion 2	P02_MOT2.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Motion Sensor (CI-6742)	1	**Base and Support Rod (ME-9355)**	1

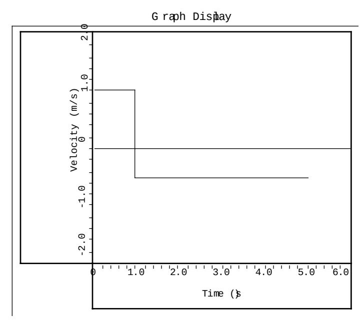
What Do You Think?

What is the relationship between the motion of an object – YOU – and a graph of velocity and time for the moving object?

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

Background

When describing the motion of an object, knowing where it is relative to a reference point, how fast and in what direction it is moving, and how it is accelerating (changing its rate of motion) is essential. A sonar ranging device such as the PASCO Motion Sensor uses pulses of ultrasound that reflect from an object to determine the position of the object. As the object moves, the change in its position is measured many times each second. The change in position from moment to moment is expressed as a velocity (meters per second). The change in velocity from moment to moment is expressed as an acceleration (meters per second per second). The position of an object at a particular time can be plotted on a graph. You can also graph the velocity and acceleration of the object versus time. A graph is a mathematical picture of the motion of an object. For this reason, it is important to understand how to interpret a graph of position, velocity, or acceleration versus time. In this activity you will plot a graph of velocity in real-time, that is, as the motion is happening.



SAFETY REMINDERS

- Follow all safety instructions.
- Keep the area clear where you will be walking.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

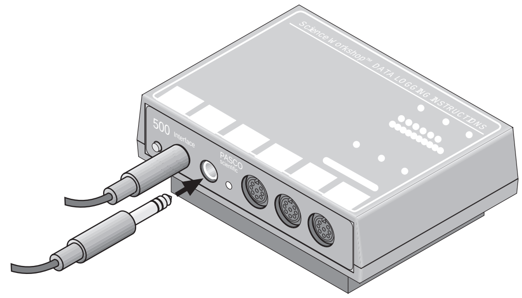
- **This activity is easier to do if you have a partner to run the computer while you move.**

For this activity, you will be the object in motion. Use the Motion Sensor to measure your position as you move in a straight line at different speeds. Use *DataStudio* or *ScienceWorkshop* to plot your motion on a graph of position and time.

The challenge in this activity is to move in such a way that a plot of your motion on the same graph will "match" the line that is already there.

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 plugs of the Motion Sensor to Digital Channels 1 and 2 on the interface. Connect the yellow plug to Digital Channel 1 and the other plug to Digital Channel 2.
3. Open the file titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P02 Velocity and Time.ds	P02 Understanding Motion 2	P01_MOT2.SWS

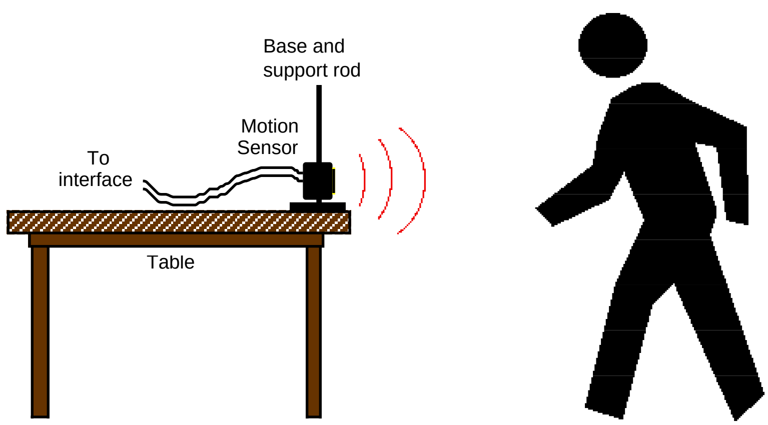
- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Velocity versus Time.
- The Graph shows Velocity and Time values that were entered into the Graph.
- Data recording is set to stop automatically at 10 seconds.

PART II: Sensor Calibration and Equipment Setup

- **You do not need to calibrate the motion sensor for this activity. Moving away from the motion sensor is considered a positive velocity. Moving toward the motion sensor is considered a negative velocity.**

1. Mount the motion sensor on a support rod so that it is aimed at your midsection when you are standing in front of the sensor. Make sure that you can move at least 2 meters away from the motion sensor.
2. Position the computer monitor so you can see the screen while you move away from the motion sensor.

- **You will be moving backwards for part of this activity. Clear the area behind you for at least 2 meters (about 6 feet).**



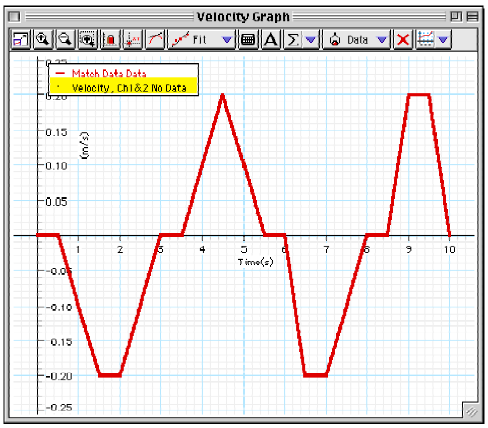
Understanding Motion 2: Velocity and Time

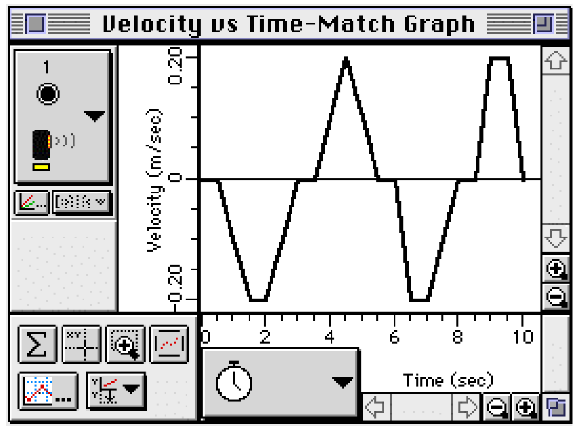
Name ____________________ Class _____________ Date ________

PART III: Data Recording

1. Enlarge the Graph until it fills the monitor screen.
2. Study the Velocity versus Time plot in order to determine the following:

- Which direction (positive or negative) should you go at the beginning? _______
- What is the maximum speed (positive or negative) you must achieve? _______ (m/s)
- How long should your motion last? _______ (s)





3. When you are ready, stand in front of the motion sensor.

- **WARNING: You will be moving backward, so be certain that the area behind you is free of obstacles.**

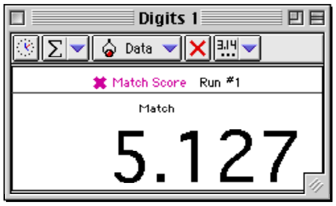
4. When everything is ready, start recording data. Data recording will begin almost immediately. The motion sensor will make a faint clicking noise.
5. Watch the plot of your motion on the Graph, and try to move so that the plot of your motion matches the Velocity versus Time plot that is already there.
6. Repeat the data recording process a second and a third time. Try to improve the match between the plot of your motion and the plot that is already on the Graph.

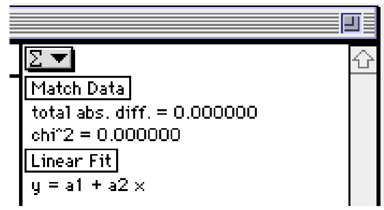
- The Graph can show more than one run of data at the same time.

Analyzing the Data

1. Determine how well your best plot of velocity versus time matches the velocity versus time plot that was already on the Graph. You may want to resize the graph to fit the data.

- In *DataStudio*, check the 'Match Score' calculation in a Digits display. In *ScienceWorkshop*, examine the 'total abs. diff.' (total absolute difference) and the 'chi^2' (goodness of fit) terms from the Statistics area.





Name ______________________ Class _______________ Date _________

Lab Report - Activity P02: Velocity & Time – Understanding Motion 2

What Do You Think?

What is the relationship between the motion of an object – YOU – and a graph of velocity and time for the moving object?

Question

1. For your best attempt, how well did your plot of motion fit the plot that was already in the Graph?

Name ____________________ Class _____________ Date _________

Activity P03: Acceleration on an Incline (Acceleration Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Linear motion	P03 Acceleration.ds	(See end of activity)	(See end of activity)

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Acceleration Sensor (CI-6558)	1	**Dynamics Cart (inc. w/ Track)**	1
Angle Indicator (inc. w/ Track)	1	Meter stick	1
Base and Support Rod (ME-9355)	1	**1.2 m Track System (ME-9429A)**	1

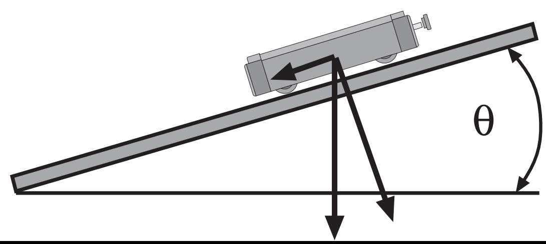
What Do You Think?

When a sled accelerates down a snow-covered hill, on what does its acceleration depend? You may want to consider the height of the hill, the slope of the hill and the mass of the sled. How does its acceleration depend on the variable(s) you selected?

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

Background

A cart on an incline will roll down the incline as it is pulled by gravity. The direction of the acceleration due to gravity is straight down as shown in the diagram. The component of the acceleration due to gravity which is parallel to the inclined surface is $g\sin\theta$ where θ is the angle of the incline. Neglecting friction, this is the acceleration of the cart.



SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use an Acceleration Sensor to measure the motion of a cart as it moves down an inclined track. Use an angle indicator to measure the angle of the inclined track or determine the sine of the angle ($\sin\theta$) from the height of the track and the length of the track.

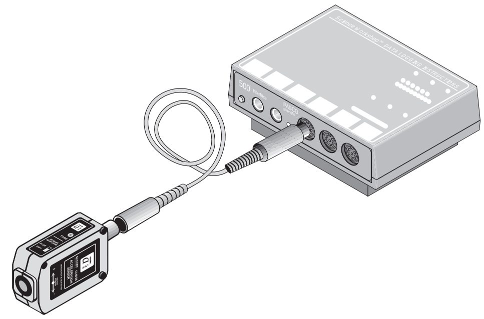
$$\sin ø = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{\text{height}}{\text{length of track}}$$

Use the slope of a graph of the cart's acceleration versus $\sin\theta$ to determine the value of "g", the acceleration due to gravity.

- **NOTE: This activity is easier to do if you have a partner to run the computer while you release the cart.**

PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect one end of the cable to the Acceleration Sensor and connect the other end into Analog Channel A on the interface.
3. Open the file titled as shown:



DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P03 Acceleration.ds	(See end of activity)	(See end of activity)

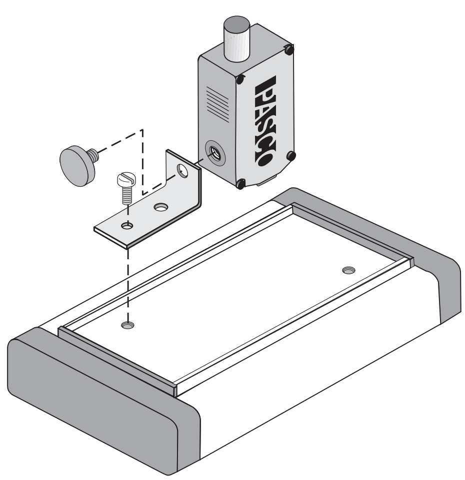
- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook. The file has a Graph display of Acceleration versus Time, a Table display of Acceleration and 'sin (theta)', and a Graph display of Acceleration versus 'sin (theta)'.
- Data recording is set for 50 measurements per second (50 Hz).
- See the pages at the end of this activity for information about creating a *ScienceWorkshop* file.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the sensor for this activity.

1. Carefully measure and record the overall length of your track.
2. Level the track by setting the cart on the track to see which way it rolls. Adjust the leveling screw at the end of the track to raise or lower that end until the cart placed at rest on the track will not move toward either end. Record the height of the end of the track that does not have the end-stop.
3. Mount the Acceleration Sensor onto the cart.

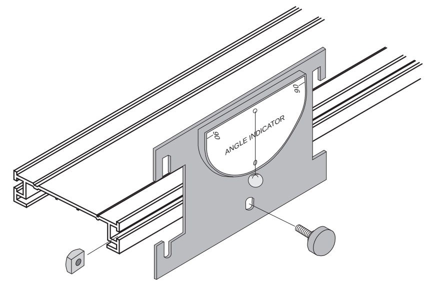
- Use the large thumbscrew to attach the 'short' leg of the bracket to the sensor.
- Use the small thumbscrew to attach the 'long' leg of the bracket to a threaded hole in the top of the cart.

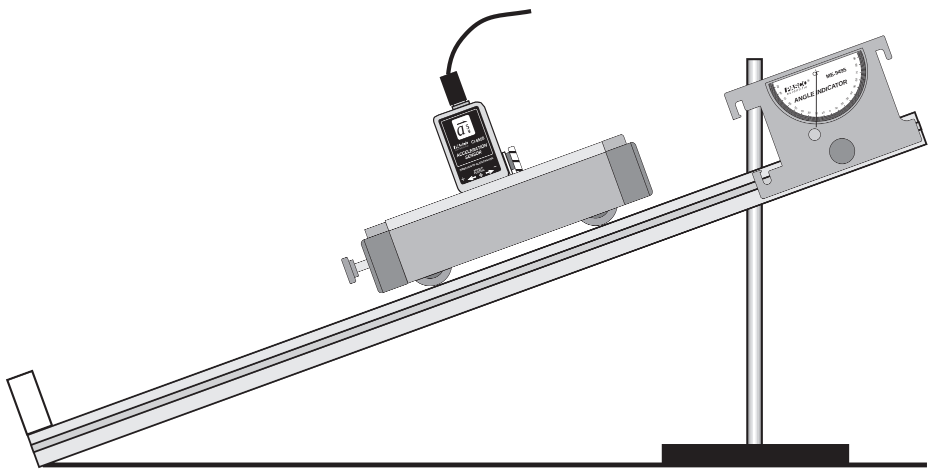


4. Set the 'SENSOR RESPONSE' switch to 'SLOW'.

5. Use the base and support rod to raise the end of the track without an end-stop so that it is 20 cm higher than its position when level.
6. Mount the angle indicator onto the raised end of the track.
7. Use a pencil to put a mark near the midpoint of the track.

- Let the midpoint mark be your starting point for the cart release during data recording.





Preparing to Record Data

Recording data involves the following steps:

- Measure and record the height of the track (or record the angle of the track).
- Tare the sensor. Start data recording.
- Release the cart.
- Catch the cart and stop recording data.

Repeat the process for several heights (several angles).

PART III: Data Recording

1. Determine the angle of the track. (Hint: Use the angle indicator, or measure the height of the track and use the height and length of the track to calculate the sine of the angle.)
2. Put the cart at the starting point on the inclined track. Press the ‘TARE’ button on the sensor to zero the sensor.
3. Start recording data (hint: click ‘Start’ or click ‘REC’) and then release the cart so it moves down the track.
4. Catch the cart when it reaches the end of the track and stop recording data.
5. Lower the raised end of the track by four centimeters.
6. Repeat the procedure at the new height.
7. Continue to repeat the procedure until the raised end is at 4 centimeters.

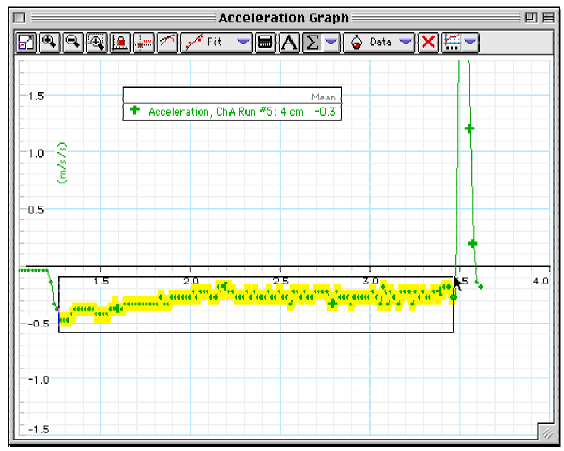
Analyzing the Data

The first part of analyzing the data involves the following steps for each different height:

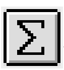
- Determine the sine of the angle. (Hint: Use the measurement from the angle indicator and then find the sine of the angle or calculate the sine of the angle based on the height and length of the track.)
- Examine the Graph display of Acceleration versus Time to determine the average acceleration.
- Enter the average acceleration and the sine of the angle into the Table display of 'Acceleration' and 'sin (theta)'.

Repeat the analysis procedure for the each height.

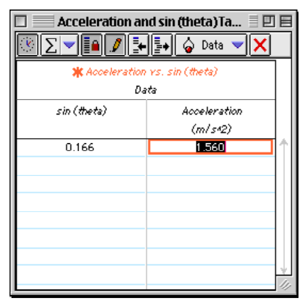
1. Determine the sine of the angle and record the value in the Lab Report section.
2. In the Graph display, click-and-drag the cursor to highlight that section of the data that corresponds to the motion of the cart down the track.



3. Use the Graph's built-in analysis tools to determine the average ('mean') of the acceleration.

- Hint: In *DataStudio*, click the 'Statistics menu' button () and select 'Mean'. In *ScienceWorkshop*, click the 'Statistics' button () to open the statistics area. In the statistics area, click the 'Statistics menu' button () and select 'Mean'.

4. Enter the sine of the angle and the average acceleration for that angle into the Table display.



For the second part of analyzing the data, use the Graph display of Acceleration versus 'sin (theta)'.

1. Find the slope and y-intercept of the best-fit line through your data.

- Hint: In *DataStudio*, click the 'Fit' button and select 'Linear' from the menu. In *ScienceWorkshop*, click the 'Statistics menu' button and select 'Curve Fit, Linear Fit' from the submenu.

2. Record the slope as the acceleration due to gravity, "g".

- Hint: In *DataStudio*, the slope 'm' is shown in the 'Linear Fit' legend on the Graph display. In *ScienceWorkshop*, the slope is the coefficient 'a2'.

Linear Fit	
m (Slope)	9.63458
b (Y Intercept)	-0.06153
r	0.99189
Standard Deviation m	0.71294
Standard Deviation b	0.07863

Record your results in the Lab Report section.

Name ____________________ Class _____________ Date _________

Lab Report - Activity P03: Acceleration on an Incline

What Do You Think?

When a sled accelerates down a snow-covered hill, on what does its acceleration depend? You may want to consider the height of the hill, the slope of the hill and the mass of the sled. How does its acceleration depend on the variable(s) you selected?

Questions

1. What is the percent difference between your measured value for "g" and the accepted value for "g"?

   Remember, $$\textbf{percent difference} = \left|\frac{\textbf{measured} - \textbf{accepted}}{\textbf{accepted}}\right| \times \mathbf{100\%}$$

2. If the mass of the cart is doubled, how are the results affected? Try it.

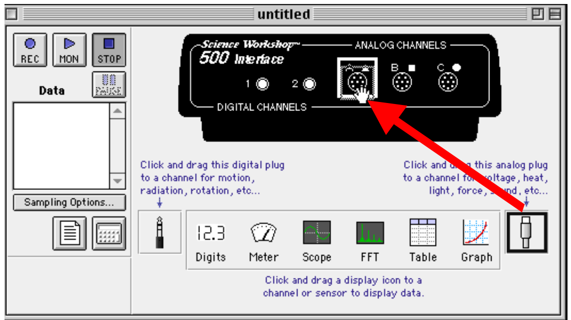
Name ____________________ Class _____________ Date _________

Appendix: Set Up *ScienceWorkshop*

Create a *ScienceWorkshop* file to measure acceleration.

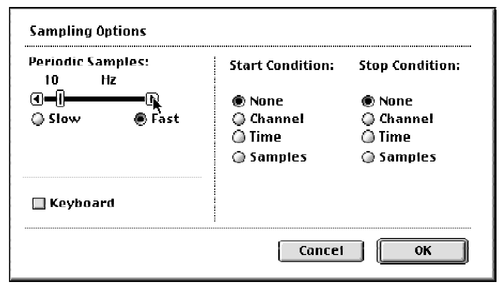
Set Up the Sensor

In the Experiment Setup window, click and drag the analog sensor plug to Channel A. Select 'Acceleration Sensor' from the list of sensors. Click 'OK' to return to the Experiment Setup window.



Set the Sampling Options

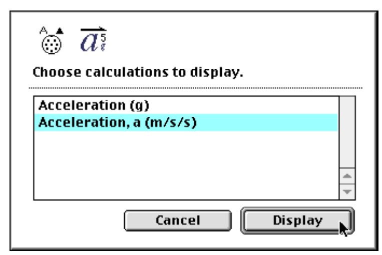
Click the 'Sampling Options' button in the Experiment Setup window or select 'Sampling Options' from the Experiment menu to open the Sampling Options window. Under 'Periodic Samples' click the right arrow to set the sample rate at '50 Hz' (50 measurements per second).



Set Up the Display

In the Experiment Setup window, click and drag the Graph display icon to the Acceleration Sensor icon.

Select 'Acceleration (m/s/s)' from the list of calculations and click 'Display'.



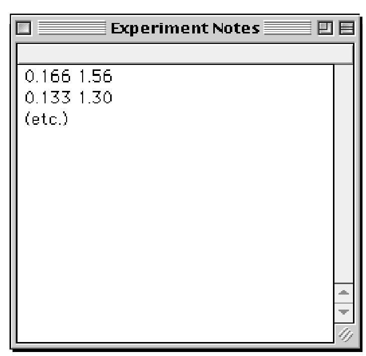
Analyzing the Data

After you have recorded data and determined the sine of the angle and the average acceleration for each trial, use the 'Experiment Notes' window to enter your data into a new Graph display of Acceleration versus sin (theta).

Enter the Data

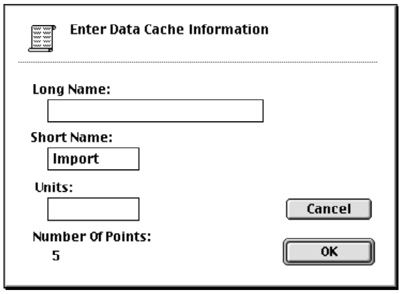
1. Open a 'Notes' window. Use the following format to enter your data pairs of the sine of the angle and the average acceleration for each angle:

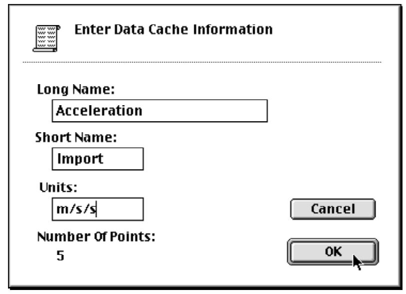
   'sine of angle' <TAB> 'average acceleration' <RETURN>



2. Pick 'Select All' in the Edit menu and then pick 'Copy' in the Edit menu. **Result**: The data pairs in the Notes window are highlighted.

3. Click the Experiment Setup window to make it active. Pick 'Paste' from the Edit menu to 'paste' the data into the Data list. **Result**: The 'Enter Data Cache Information' window opens.



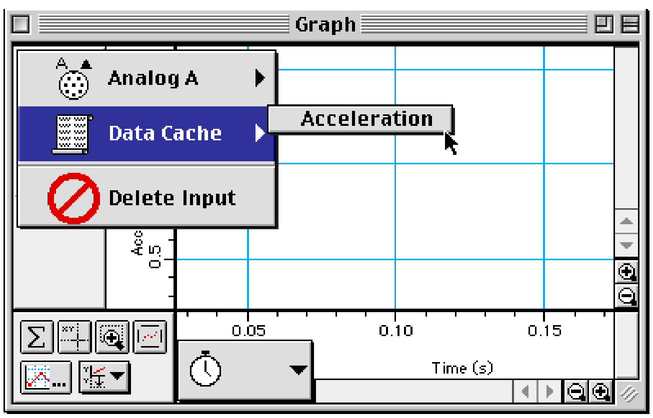


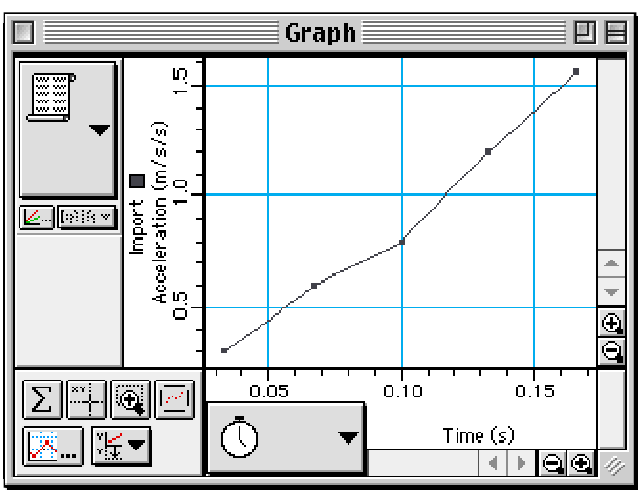
Enter 'Acceleration' as the Long Name and 'm/s/s' as the Units and click 'OK'. **Result**: 'Import' appears in the Data list in the Experiment Setup window.

Display the Data

1. In the Graph display, select 'Data Cache, Acceleration' from the 'Data Input' menu.

Result: The data pairs are plotted. Note that the horizontal axis label is 'Time (s)' but the 'x' values correspond to the sine of the angle.





Name ____________________ Class _____________ Date _________

Activity P04: Position, Velocity and Acceleration Graphs (Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Linear motion	P04 Motion Graphs.DS	P05 Position, Velocity, Acceleration	P05_POSI.SWS

Equipment Needed	**Qty**	**Optional Equipment**	**Qty**
Motion Sensor II (CI-6742)	1	**String (SE-8050)**	1 m
Fan Cart (ME-9485)	1	**2.2 m Track System (ME-9452)**	1

What Do You Think?

The purpose of this activity is to study the relationship among position, velocity, and acceleration in linear motion. How do the distance vs. time, velocity vs. time, and acceleration vs. time graphs for a fan cart uniformly accelerating, from rest, compare with one another?

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

Background

Equations for motion, given a constant acceleration (*a*), are:

Position: $$x = x_0 + v_0 t + \frac{1}{2}at^2$$

where x_o and v_o are the initial position and initial velocity. Note that if x_o and v_o are zero, the equation is a parabola.

Velocity (1^{st} derivative of Position): $$\frac{dx}{dt} = v_0 + at = v$$

Note that the 1^{st} derivative of position is the slope of the position vs. time graph. This equation is linear. The slope of the velocity vs. time graph is the constant acceleration. The acceleration can also be written:

Acceleration (2^{nd} derivative of Position): $$\frac{d^2x}{dt^2} = a$$

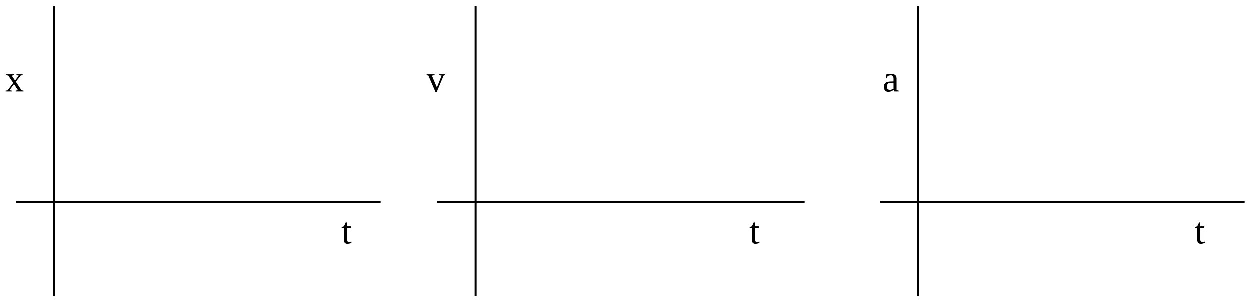
SAFETY REMINDERS

- Keep hands clear of fan blades.
- Do not let the cart run away from the user. Catch the cart before the cart crashes into the bumper or travels off from the table.
- Follow directions for using equipment.

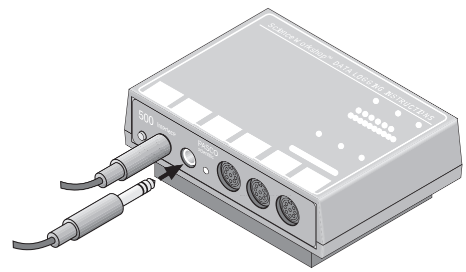
For You To Do

Use a Motion Sensor to measure the position of a Fan Cart as it moves away from the Motion Sensor. Use *DataStudio or ScienceWorkshop* to plot and analyze the cart's position (*x*), velocity (*v*), and acceleration (*a*).

Prediction: Sketch a prediction of the position, velocity, and acceleration vs. time graphs for the Fan Cart's motion.



PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Motion Sensor's phone plugs to Digital Channels 1 and 2 on the interface. Plug the yellow-banded (pulse) plug into Digital Channel 1 and the second plug (echo) into Digital Channel 2.
3. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P04 Motion Graphs.DS	P05 Position, Velocity, Acceleration	P05_POSI.SWS

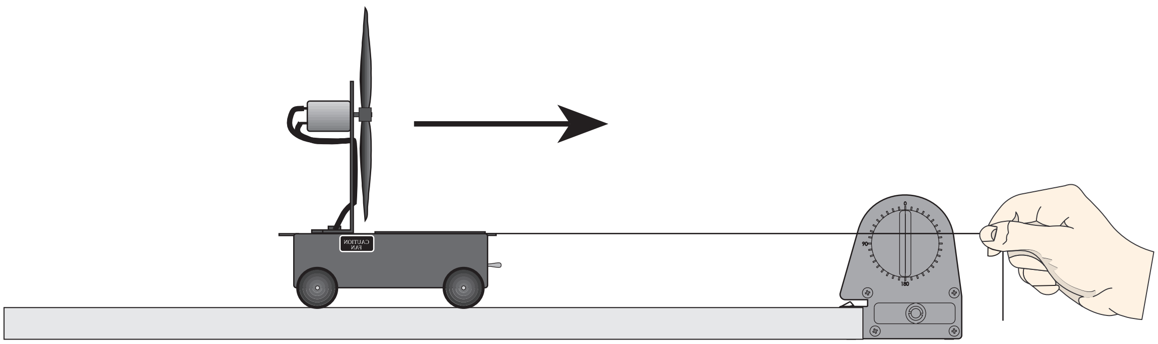
- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document opens with a Graph display of Position (m), Velocity (m/s), and Acceleration (m/s/s) versus Time (s).

Name ____________________ Class _____________ Date _________

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Motion Sensor.

1. Place the Motion Sensor and Fan Cart on a flat horizontal surface. Make sure that there is nothing to obstruct the signal going from the front of the Motion Sensor to the Fan Cart, or the returning echo from the Fan Cart back to the Motion Sensor. (If you have a PASCO Dynamics Track available, you may wish to use it.) The fan should be pointed towards the Motion Sensor as shown below.



2. Tie a string to the Fan Cart so that you can hold the Fan Cart before releasing it without interfering with the Motion Sensor.

PART III: Data Recording

1. Hold the string so that the Fan Cart remains stationary about 40 cm in front of the Motion Sensor. Turn the fan on and select the low speed setting.

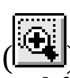
- Make sure that the Fan Cart is pulling *away* from the Motion Sensor.

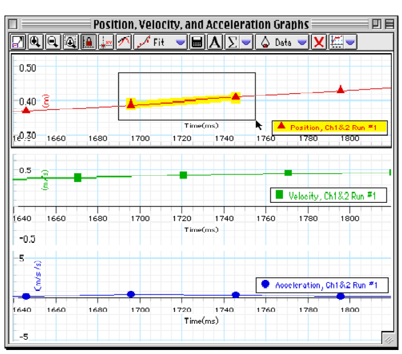
2. When everything is ready, start recording data. Then release the fan cart.
3. Stop data recording before the cart reaches the end of the track and before the cart has traveled the length of the space available, generally less than two meters is best.

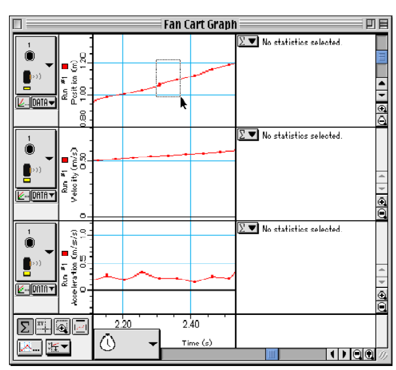
How well did your predicted graphs match the motion sensor generated plots?

Analyzing the Data

Click the Graph to make it active. Use the built-in analysis tools to fit two consecutive position vs. time data points to a mathematical formula.

1. In the Graph display, click on the zoom button (). While holding down on the mouse button, move the cursor to draw a rectangle around four or five points in the position vs. time plot. The points will be highlighted. Release the mouse button and the Graph axes will rescale to zoom in about those points. Next, click and hold the mouse button and drag the mouse to highlight two consecutive position vs. time data points.





2. Select the curve fit.

- In *DataStudio*, click the 'Fit' menu button ( ). Select 'Linear'.
- In *ScienceWorkshop* click the 'Statistics' button to open the Statistics area on the right side of the Graph. In the Statistics area, click the Statistics Menu button ( ). Select **Curve Fit, Linear Fit** from the Statistics Menu.

3. Locate the corresponding velocity value in the velocity vs. time graph.

- In *DataStudio*, select the velocity window. Click the 'Smart Tool' button ( ) and move the Smart Tool to the velocity data point.
- In *ScienceWorkshop*, click the 'Smart Cursor' ( ) and move the Smart Cursor to the velocity data point.

4. Record the slope and the velocity value in the Lab Report Section.

At what point in time did the average velocity occur? How does this time correspond to the times from the two points selected in the position vs. time plot? Record your answers in the Lab Report section.

5. Click anywhere in the position vs. time Graph window to deselect the highlighted points. Click the 'Autoscale' button to automatically rescale the Graph axes to display all of the data. Select a polynomial fit to the position vs. time plot. If your initial data is erratic, you may need to zoom in and select a region of the plot that is smooth.

- Record the coefficients of the fit and answer the questions in the Lab Report section.

6. Click anywhere in the velocity vs. time graph window to deselect the highlighted points. Click the 'Autoscale' button to automatically rescale the Graph axes to display all of the data. Select a linear fit to the velocity vs. time plot. If your initial data is erratic, you may need to zoom in and select a region of the plot that is smooth.

- Record the coefficients of the fit and answer the questions in the Lab Report section.

7. Click anywhere in the acceleration vs. time Graph window. Apply a linear fit to the acceleration vs. time plot.

- Record the coefficients of the fit and answer the questions in the Lab Report section.

Why is the acceleration vs. time plot so much "noisier" than the other plots? Record your answer in the Lab Report section.

Record your results and answer the questions in the Lab Report section.

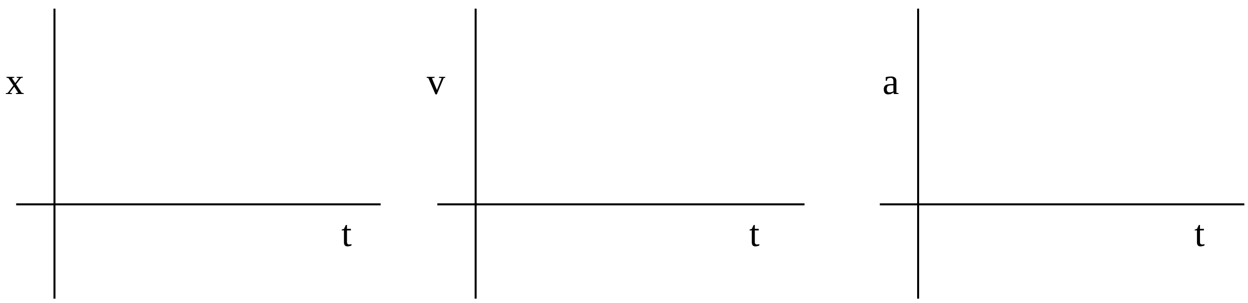
Name ____________________ Class ______________ Date _________

Lab Report - Activity P04: Position, Velocity and Acceleration Graphs

What Do You Think?

The purpose of this activity is to study the relationship among position, velocity, and acceleration in linear motion. How do the distance vs. time, velocity vs. time, and acceleration vs. time graphs for a fan cart uniformly accelerating, from rest, compare with one another?

Prediction: Sketch a prediction of the position, velocity, and acceleration vs. time graphs for the Fan Cart's motion.



Data Table

Item	Result
Slope of Position vs. Time data	
Velocity Value	
Polynomial Equation of fit for Position vs. Time	
Linear Equation of fit for Velocity vs. Time	
Linear Equation of fit for Acceleration vs. Time	

Questions

1. At what point in time did the average velocity occur? How does this time correspond to the times from the two points selected in the position vs. time plot?

2. What are the appropriate units for the slopes of the position and velocity vs. time plots?

3a. How close does the plot of position vs. time fit a polynomial curve? (Hint: In *DataStudio*, the closer Mean Squared Error is to zero, the better the fit of data to the curve. In *ScienceWorkshop*, the closer chi^2 is to zero, the better the fit of data to the curve.)

3b. Did your polynomial fit of the position vs. time graph yield an initial position? If yes, what is the initial position?

3c. Did your polynomial fit of the position vs. time graph yield an initial speed? If yes, what is the initial speed?

3d. Did your polynomial fit of the position vs. time graph yield an acceleration? If yes, what is the acceleration?

4a. How close does the plot of velocity vs. time fit a linear regression? (Hint: In *DataStudio*, the closer r is to one, the better the fit of data to the curve. In *ScienceWorkshop*, the closer chi^2 is to zero, the better the fit of data to the curve.)

4b. Did the linear fit of velocity vs. time yield an initial position? If yes, what is the initial position?

4c. Did your linear fit of velocity vs. time yield an initial speed? If yes, what is the initial speed?

4d. Did your linear fit of velocity vs. time yield an acceleration? If yes, what is the acceleration?

5a. Is the acceleration in the acceleration vs. time Graph constant? (Remember, a nearly horizontal line of fit (near zero slope) indicates a constant value.)

5b. Did the linear fit of acceleration vs. time yield an initial position? If yes, what is the initial position?

5c. Did your linear fit of acceleration vs. time yield an initial speed? If yes, what is the initial speed?

5d. Did your linear fit of velocity vs. time yield an acceleration? If yes, what is the acceleration?

6. Why is the acceleration vs. time plot so much “noisier” than the other plots?

Name ____________________ Class _____________ Date _________

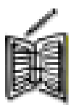
Activity P05: Acceleration of a Freely Falling Picket Fence (Photogate)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Linear motion	P05 Free Fall.ds	P06 Free Fall Picket Fence	P06_FALL.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Photogate/Pulley System (ME-6838)	1	**Universal Table Clamp (ME-9376)**	1
Picket Fence (ME-9377A)	1		

What Do You Think?

The purpose of this activity is to determine the acceleration due to gravity by measuring the time of fall of a picket fence dropped through a photogate. Can an object have an increasing velocity and a constant acceleration? Can the velocity of an object be zero at the same instant its acceleration is non zero?



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

Background

Neglecting air resistance, an object falls a distance proportional to the square of the time.

$$d \propto t^2$$

Galileo was the first to derive this mathematical relationship. He asserted that for a given location on Earth, all objects fall with the same uniform acceleration. This acceleration is commonly referred to as the **acceleration due to gravity**, and it is given the symbol ***g***. This value is approximately g = 9.8 m/s^2.

SAFETY REMINDER

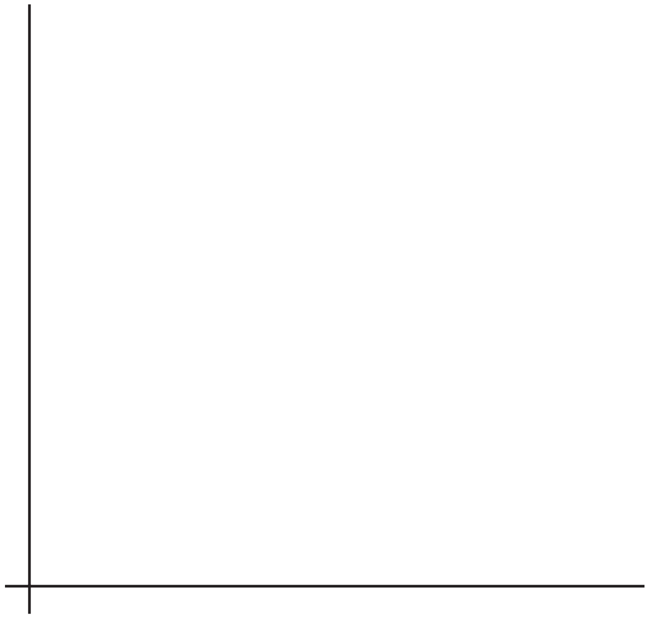
- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

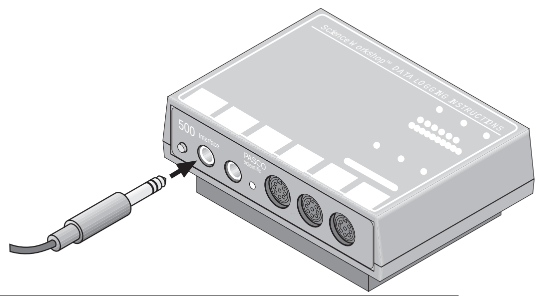
Drop a "Picket Fence" (a clear plastic strip with uniformly spaced opaque bands) through a Photogate. Each opaque band on the 'Picket Fence' blocks the Photogate beam and the time from one blockage to the next becomes increasingly shorter. Knowing the distance between the leading edge of each opaque band, the *DataStudio or ScienceWorkshop* program calculates the average speed of the Picket Fence from one band to the next. The slope of the graph of average speed versus time gives the acceleration of the falling object.

Prediction: Sketch a prediction below of a velocity vs. time graph for a freely falling object.



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 Photogate's stereo phone plug to Digital Channel 1 on the interface.



3. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P05 Free Fall.ds	P06 Free Fall Picket Fence	P06_FALL.SWS

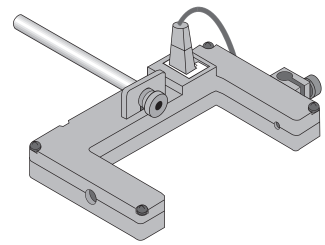
- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document opens with a Graph display that has plots of Position and Velocity versus Time and a Table of Position, Velocity, and Acceleration versus Time.

Name ____________________ Class _____________ Date _________

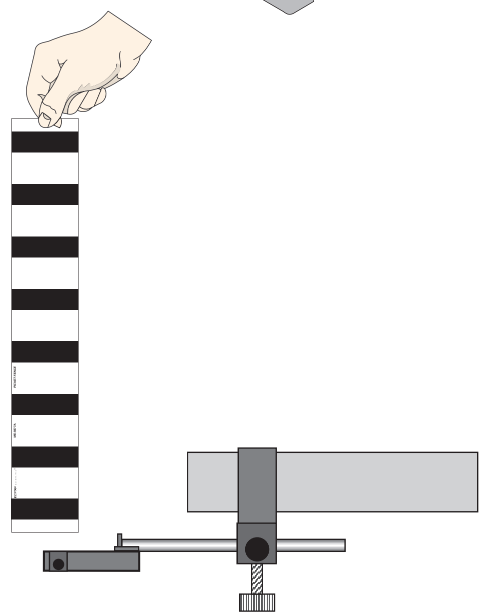
PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Photogate.

1. The program assumes a 5 centimeter (0.05 m) spacing, leading-edge-to-leading-edge, for the opaque bands on the Picket Fence. To change the default setting to another value, double-click on the Photogate & Picket Fence icon in the Experiment Setup window to open the Sensor Setup window. Enter the correct value for the spacing of the opaque bands on your Picket Fence. Click OK to return to the Experiment Setup window.



2. Set up the equipment as shown. Mount the Photogate on the Pulley Mounting Rod. Turn the Photogate head sideways so that you can drop a Picket Fence vertically from above the Photogate and have the Picket Fence move through the Photogate's opening without hitting the Photogate.



Trial Run of Data

1. Before recording data for later analysis, experiment with the Photogate and Picket Fence.

- It is recommended that an old article of clothing, carpet sample, or piece of cardboard be placed on the floor directly below the Photogate, so the Picket Fence has a soft place to land.

2. When everything is ready, start recording data. Drop the Picket Fence vertically through the Photogate. Data recording begins when the Photogate beam is first blocked. **Stop** the recording once the Picket Fence has passed completely through the Photogate.

3. Rescale the data to fill the Graph window.

4. Erase your trial run of data.

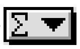
PART III: Data Recording

1. Prepare to drop the Picket Fence through the Photogate beam again. Hold the Picket Fence at one end between your thumb and forefinger so the bottom edge of the Picket Fence is just above the Photogate beam.
2. Start recording data and then drop the Picket Fence through the Photogate beam. Remember, data collection begins when the Photogate beam is first blocked.
3. After the Picket Fence passes completely through the beam, stop recording.

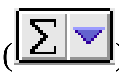
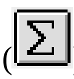
Analyzing the Data

1. Set up your Table display so it shows the values of position, velocity, and acceleration.
2. If necessary, rescale the Graph to fit the data.
3. Examine the plot of Velocity versus Time in the Graph display. Determine the slope of the 'best fit' line for velocity versus time.

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

). In *ScienceWorkshop*, click the 'Statistics' button and then select 'Curve Fit, Linear Fit' from the Statistics menu ().

4. Apply Statistics to each column in the Table display to determine the 'Mean' value of acceleration.

- Hint: In *DataStudio*, select 'Mean' from the 'Statistics' menu (). In *ScienceWorkshop*, click the 'Statistics' button ().

5. Record the value for the Mean of the acceleration, and the slope of the velocity vs. time in the Lab Report section.

Record your results in the Lab Report section.

Name ____________________ Class _____________ Date _________

Lab Report - Activity P05: Free Fall

What Do You Think?

Can an object have an increasing velocity and a constant acceleration? Can the velocity of an object be zero at the same instant its acceleration is non zero?

Prediction: Sketch a prediction below of a velocity vs. time graph for a freely falling object.

Data Table

Item	Value
slope of velocity versus time	
acceleration (mean)	

Questions

1. How does the slope of your velocity versus time graph compare to the accepted value of the acceleration of a free falling object ($g = 9.8\ m/s^2$)?

• Reminder: percent difference = $\left|\frac{\textit{accepted value} - \textit{experimental value}}{\textit{accepted value}}\right| x100\%$

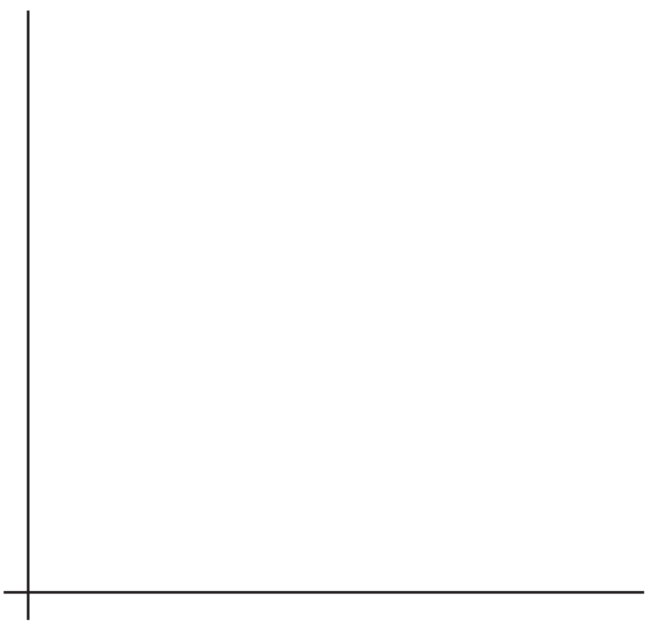
2. How does the mean of the acceleration from the table compare to the accepted value of the acceleration of a free falling object (g = 9.8 m/s2)?

3. What factors do you think may cause the experimental value to be different from the accepted value?

Optional

- Determine whether releasing the Picket Fence from just above the Photogate or from several inches above the Photogate makes any difference in the value of the acceleration. Note that the Table and Graph displays will show the most recently recorded run of data. To view a different run of data, click on the DATA menu and select the data run you want from the list.

- Sketch a graph of velocity vs. time for an object falling from rest, taking into account air resistance.



Name ____________________ Class _____________ Date _________

Activity P06: Acceleration Due to Gravity (Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Linear motion	P06 Gravity.ds	G14 Gravity	G14_GRAV.SWS

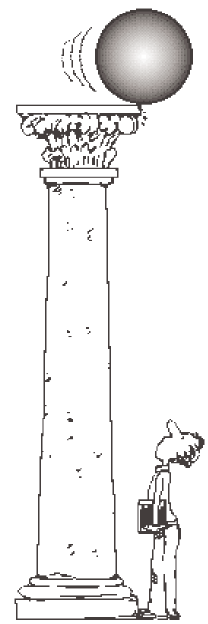
Equipment Needed	Qty	Other	Qty
Motion Sensor (CI-6742)	2	Ball, rubber	1
Base and Support Rod (ME-9355)	1	*Level (optional)*	1
Meter stick	1		

What Do You Think?

How can a Motion Sensor be used to measure the acceleration due to gravity of a falling object?

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

Background



Over twenty-two centuries ago, a Greek philosopher and scientist named Aristotle proposed that there is a natural force that causes heavy objects to fall toward the center of Earth. He called this force "gravity". In the seventeenth century, the English scientist Isaac Newton was able to show that gravity is a universal force that extends beyond Earth. It is the force that causes the moon to orbit the Earth and the Earth to orbit the Sun.

When an object is in "free fall", it means that the only force acting on it is the force of gravity. As an object falls freely, it accelerates. For a falling object near the surface of Earth, the rate of change of velocity is a constant value. This value is the acceleration due to gravity. If you ignore air resistance, a falling ball accelerates as if it is in free fall. You can measure the motion of the falling ball to find the value of the acceleration due to gravity.

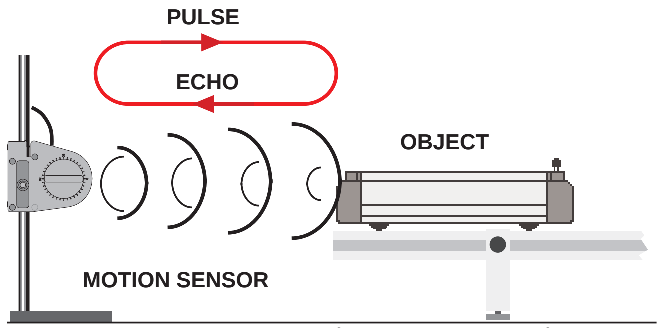
SAFETY REMINDER.

- Follow directions for using the equipment.

For You To Do

Use the Motion Sensor to measure the motion of a ball as it falls and bounces. Use *DataStudio* or *ScienceWorkshop* to record and display the position and velocity of the ball. Examine the slope of the line on a velocity versus time graph to find the acceleration of the ball.

About the Motion Sensor



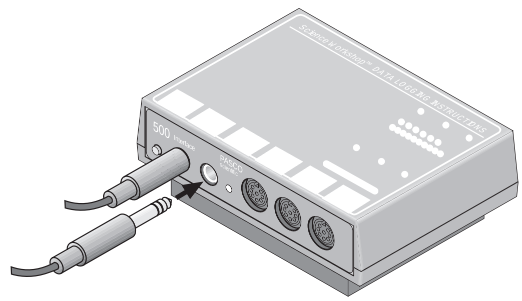
The Motion Sensor sends out pulses of ultrasound and picks up the echoes of ultrasound that bounce back from objects in front of it.

The software program keeps track of the time when the pulses go out and the time when the echoes come back. One-half of the round trip time is the time that it took for the ultrasound to reach the object. Since ultrasound travels at the speed of sound, or about 344 meters per second (or about 700 miles per hour), the program figures out how far away the object is as follows:

$$\textbf{distance to object} = \frac{\textbf{round} - \textbf{trip time}}{\textbf{2}} \times \textbf{speed of sound}$$

The speed of sound through air depends on several factors, including the temperature of the air. Because the temperature of air can change, the speed of sound can change. You can calibrate the Motion Sensor so it uses an accurate measurement of 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. Plug the modular connector on one end of the interface cable into the side of the Motion Sensor. Connect the stereo phone plugs of the Motion Sensor to Digital Channels 1 and 2 on the interface. Connect the yellow plug to Digital Channel 1 and the other plug to Digital Channel 2.
3. Open the file titled as shown:

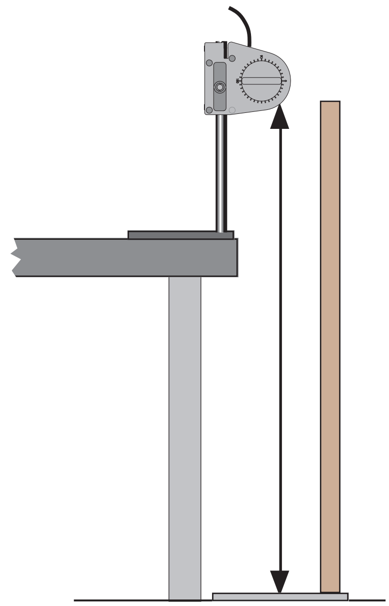
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P06 Gravity.ds	G14 Gravity	G14_GRAV.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Position and Velocity versus Time.
- The Trigger Rate for the Motion Sensor is 60 times per second (60 Hz).

Name ____________________ Class _____________ Date _________

PART II: Sensor Calibration and Equipment Setup

Sensor Calibration



- Calibrate the Motion Sensor so it can use an accurate measurement of the speed of sound in air. You will need a meter stick and a flat surface that can be used as a target to reflect the pulses from the Motion Sensor.

Set Up the Sensor

1. Place the Motion Sensor so it is exactly one meter away from a flat surface that can reflect the pulses from the Motion Sensor.

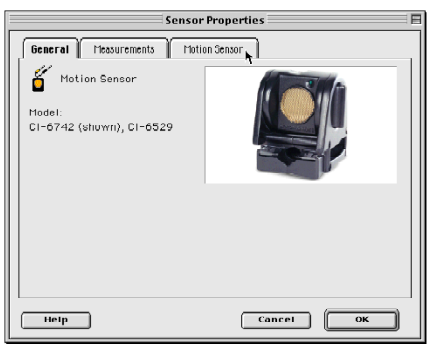
- For example, put the Motion Sensor on a support rod near the edge of a table. Aim the Motion Sensor so it sends pulses down to the floor. If the floor has a rug or carpet on it, put a flat, smooth piece of wood or some other flat surface on the floor directly below the Motion Sensor.

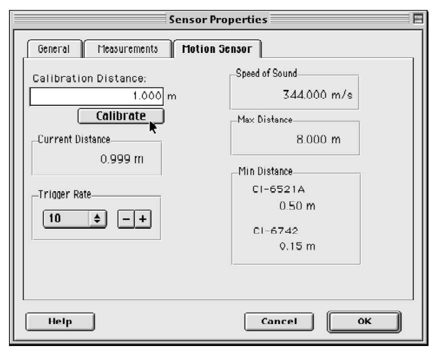
(• NOTE: Remove the meter stick after you use it to measure the distance from the Motion Sensor to the reflector.)

Calibrate the Software

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

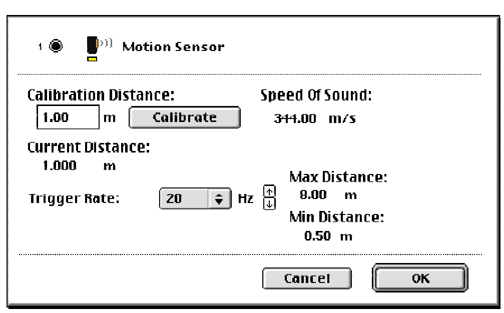
- **Result**: In *DataStudio*, the Sensor Properties window opens.





Click the 'Motion Sensor' tab. **Result**: The calibration window opens and the sensor begins to click a few times per second.

- **Result**: In *ScienceWorkshop*, the sensor's calibration window opens and the sensor begins to click a few times per second.

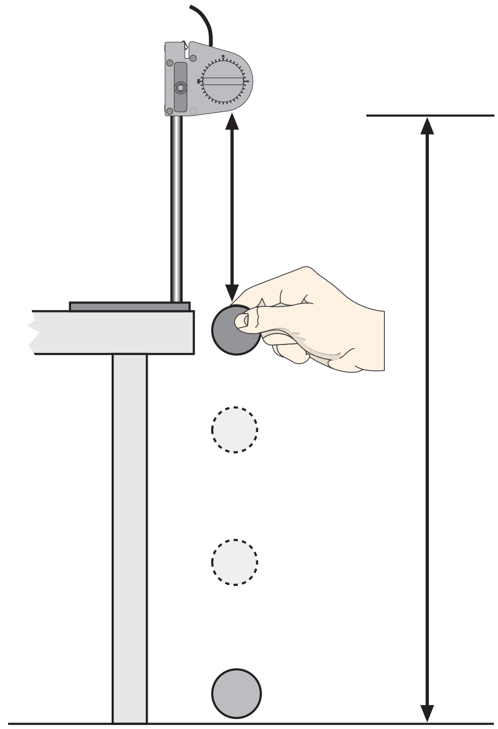


3. Calibrate the software.

- **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.

Equipment Setup



- Make sure that the floor is level. If it is not, put a hard flat surface on the floor and put pieces of paper or shims under the edges of the hard flat surface to level it.

1. Put a base and support rod near the edge of a table. Mount the Motion Sensor on the support rod so the Motion Sensor is aimed downward at the floor.
2. Adjust the position of the Motion Sensor on the support rod so that there is about 1.5 meters between the Motion Sensor and the floor.

PART III: Data Recording

1. Prepare to drop the ball so it falls straight down beneath the Motion Sensor. Hold the ball between your finger and thumb under the Motion Sensor no closer than 15 cm (about 6 inches) below the Motion Sensor.
2. Start recording data. (Hint: In *DataStudio*, click 'Start'. In *ScienceWorkshop*, click 'REC'.) Drop the ball. Let the ball bounce several times.

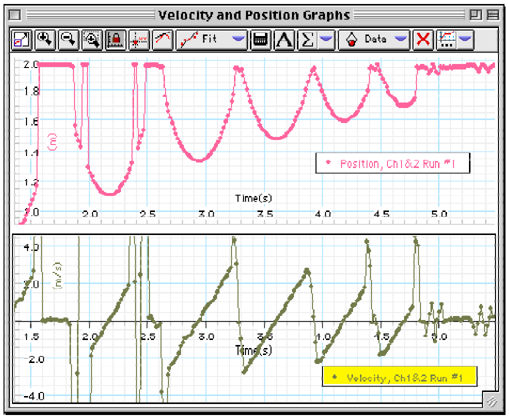
- NOTE: Be sure to move your hand out of the way as soon as you release the ball.

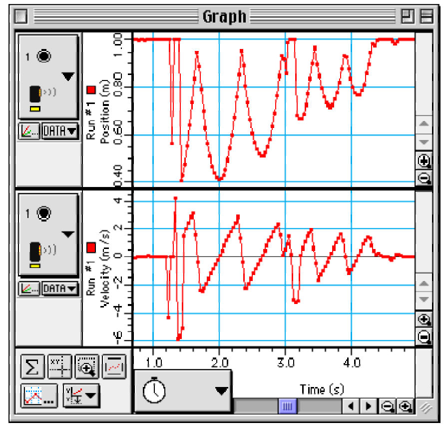
3. After the ball bounces several times on the floor, stop recording data.

Name ____________________ Class _____________ Date _________

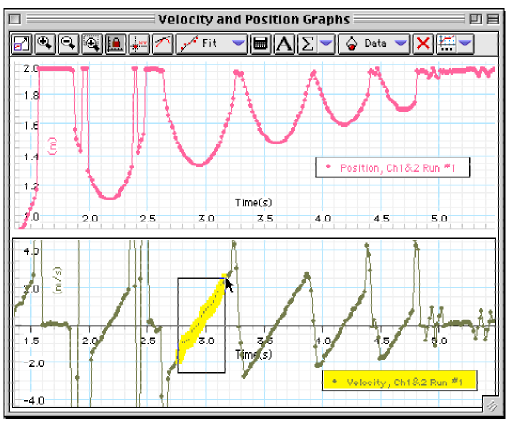
Analyzing the Data

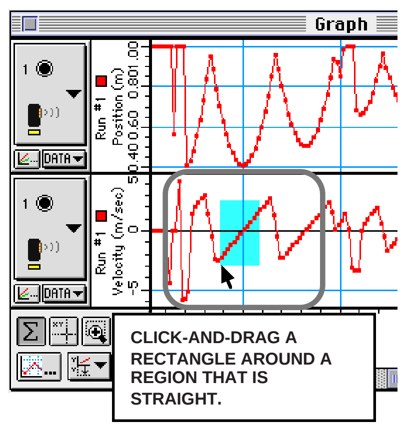
- The position plot of the Graph shows a “mirror image” of a ball bouncing on a flat surface. The velocity plot shows a “sawtooth” pattern. Notice in the velocity plot that the velocity of the ball is positive part of the time and negative part of the time. The Motion Sensor records motion away from it as positive and motion towards it as negative.



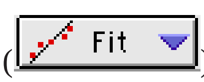


1. In the plot of Velocity versus Time, use the cursor to click-and-draw a rectangle around a region that is relatively straight.





2. Use the Graph display’s built-in analysis tools to determine the slope of the region you selected.

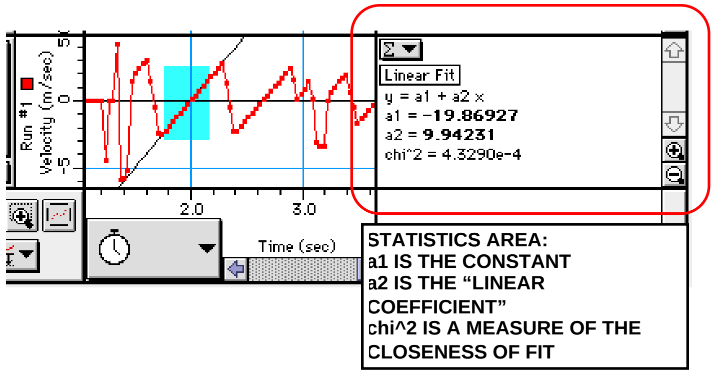
- Hint: In *DataStudio*, select ‘Linear’ from the ‘Fit’ menu ().

- Hint: In *ScienceWorkshop*, click the ‘Statistics’ button () to open the statistics area. Select ‘Curve Fit, Linear Fit’ from the ‘Statistics Menu’ ().

3. Record the value of the slope in the Data Table. This is the value for the acceleration due to gravity on the falling object.

- Hint: In *DataStudio*, the slope appears in the 'Fit' window.
- Hint: In *ScienceWorkshop*, the Statistics area shows the general formula for a line (y = a1 + a2 x), the constant a1, and the linear coefficient a2. The linear coefficient is the slope of the line.

Linear Fit	
m (Slope)	9.7239
b (Y Intercept)	-28.5941
r	0.9976
Standard Deviation m	0.1379
Standard Deviation b	0.4109



Record your results in the Lab Report section.

Name ______________________ Class _______________ Date _________

Lab Report - Activity P06: Acceleration Due to Gravity

What Do You Think?

How can a Motion Sensor be used to measure the acceleration due to gravity of a falling object?

Data Table

'g' (slope of velocity versus time) = _________

Questions

1. How does your value for 'g' (slope of velocity versus time) compare to the accepted value of the acceleration of a free falling object (9.8 m/s^2)?

- Reminder: percent difference = $\left| \frac{accepted\ value - experimental\ value}{accepted\ value} \right| x100\%$

2. What factors do you think may cause the experimental value to be different from the accepted value?

Name ____________________   Class _____________   Date _________

Activity P07: Acceleration of a Cart (Acceleration Sensor, Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Linear motion	P07 Accelerate Cart.ds	(See end of activity)	(See end of activity)

Equipment Needed	Qty	Equipment Needed	Qty
Acceleration Sensor (CI-6558)	1	**Dynamics Cart (inc. w/ Track)**	1
Motion Sensor (CI-6742)	1	Protractor	1
Block (or book)	1	**1.2 m Track System (ME-9429A)**	1

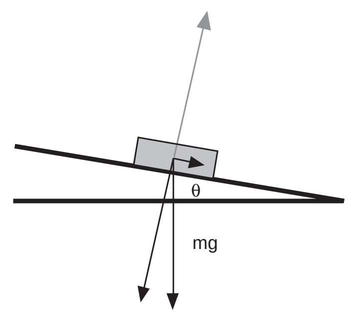
What Do You Think?

What happens to the acceleration of a cart as it moves up and down an inclined plane?

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

Background

If a cart moves on a plane that is inclined at an angle θ, the component of force acting on the cart in a direction that is parallel to the surface of the plane is mg sin θ, where m is the mass of the cart, and g is the acceleration due to gravity.



The acceleration of the cart should be g sin θ, both up and down the inclined plane.

$$a = g \sin\theta$$

SAFETY REMINDER

- Follow all safety instructions.

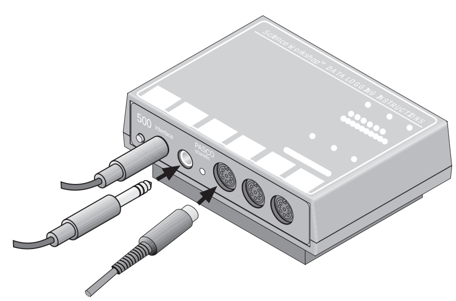
THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use a Motion Sensor to measure the motion of a cart that is pushed up an inclined plane. Use *DataStudio* or *ScienceWorkshop* to record the motion and calculate the velocity and acceleration of the cart as it moves up and down the inclined plane. Compare the calculations to data from an Acceleration Sensor mounted on the cart.

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 Motion Sensor's phone plugs to Digital Channels 1 and 2 on the interface. Plug the yellow-banded (pulse) plug into Digital Channel 1 and the second plug (echo) into Digital Channel 2.
3. Connect the DIN plug of the Acceleration Sensor to Analog Channel A.



4. Open the file titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P07 Accelerate Cart.ds	(See end of activity)	(See end of activity)

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- Data recording is set so the Trigger Rate for the Motion Sensor is 10 samples per second (10 Hz). Data from the Acceleration Sensor is measured 50 times per second (50 Hz).
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.

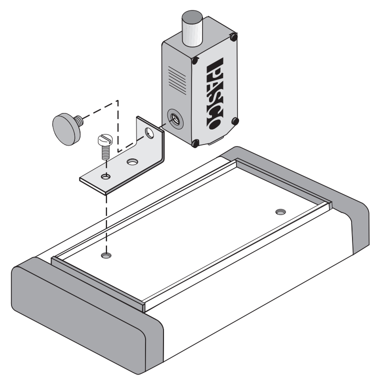
PART II: Sensor Calibration and Equipment Setup

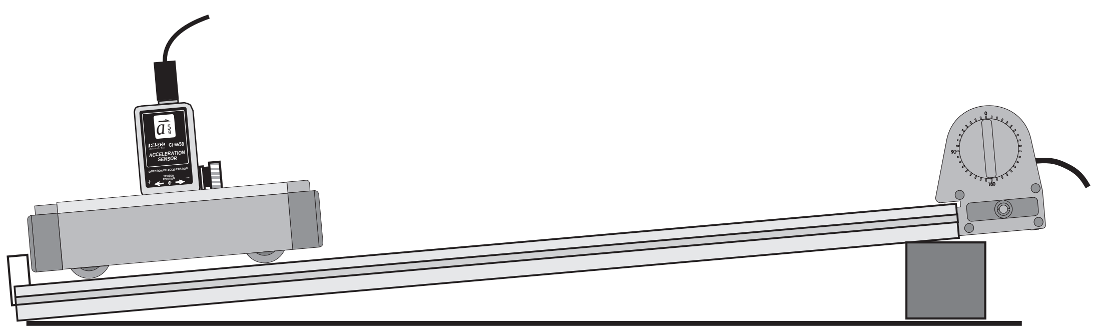
- You do not need to calibrate the sensors for this activity.

1. Place the track on a horizontal surface. Use a block or book at one end of the track to raise that end.
2. Use the protractor to measure the incline angle of the track. Record the angle in the Data Table.
3. Mount the Acceleration Sensor onto the 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.

4. Set the 'SENSOR RESPONSE' switch to 'SLOW'.
5. Mount the Motion Sensor at the high end of the track. Put a mark on the track 15 cm from the Motion Sensor.

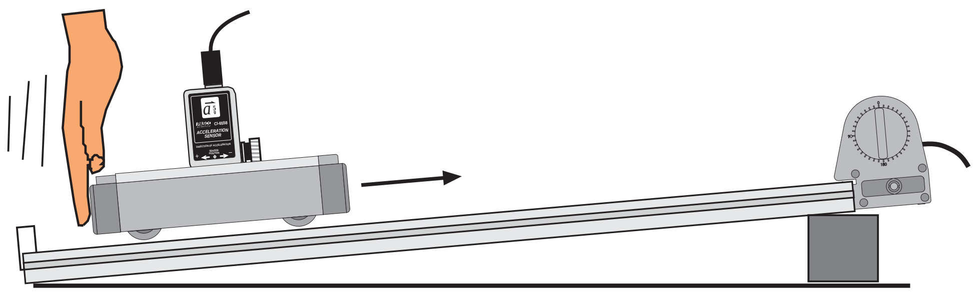




Name ____________________ Class ______________ Date _________

Preparing to Record Data

1. Before recording any data for later analysis experiment with the Motion Sensor to make sure it is aligned and can "see" the cart as it moves.
2. Place the cart on the low end of the track (i.e., the end opposite to the Motion Sensor).
3. When everything is ready, start recording data.
4. Give the cart a firm push up the track so the cart will move up the inclined plane toward and then away from the Motion Sensor.



- **BE CAREFUL! Don't push the cart so firmly that it gets closer than 15 cm to the sensor.**

Remember: The minimum distance between the cart and the Motion Sensor should be 15 cm.

5. Stop recording when the cart returns to the bottom of the track.

- **You may want to rescale the Graph.**

6. If the plot of data is not smooth, check the alignment of the Motion Sensor and repeat the above procedure until the plot is smooth.
7. Erase your sample run of data.

PART III: Data Recording

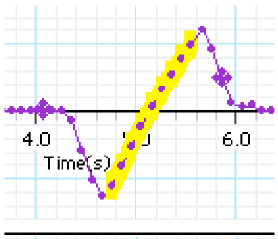
1. Prepare to measure the motion of the cart as it moves toward the Motion Sensor and then back down the track. Place the cart at the low end of the track.
2. When everything is ready, start recording data. Give the cart a firm push toward the Motion Sensor. Continue collecting data until the cart has returned to the bottom of the track.

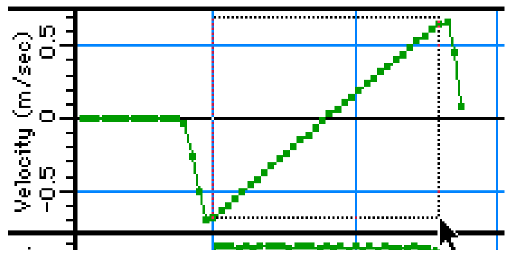
- **If the data points do not appear on the graph, check the alignment of the Motion Sensor and try again.**

3. Set the track to a steeper angle (e.g., 10 degrees) and repeat the data recording.

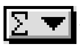
Analyzing the Data

1. In the Motion Sensor's plot of <u>velocity</u>, use the cursor to select the region of the plot that shows the cart's motion <u>after</u> the push and <u>before</u> it stopped at the bottom of the track.



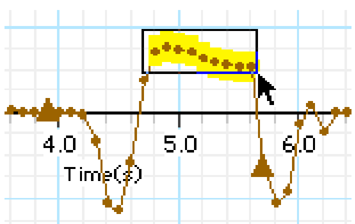


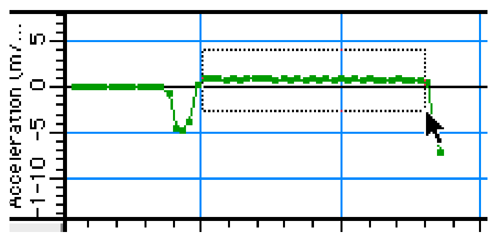
2. Use the Graph display's built-in analysis tools to apply a linear curve fit.

- Hint: In *DataStudio*, select 'Linear' from the 'Fit' menu. In *ScienceWorkshop*, click the 'Statistics' button and then select 'Curve Fit, Linear Fit' from the 'Statistics' menu ().

3. The slope of the best-fit line is the average acceleration. Record the value in the Data Table.

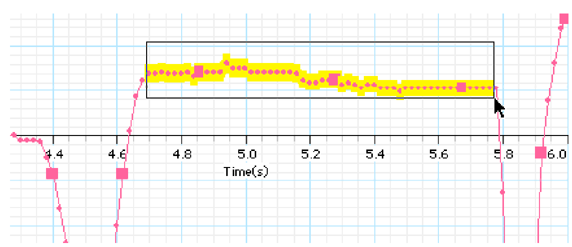
4. In the *Motion Sensor's* plot of <u>acceleration</u>, select the region of the plot that corresponds to the cart's motion <u>after</u> the push and <u>before</u> it stopped at the bottom of the track.





5. Use the 'Statistics' tool to find the mean value of the acceleration *as measured by the Motion Sensor* for your selected region. Record the mean of the acceleration in the Data Table.

6. In the *Acceleration Sensor's* plot of <u>acceleration</u>, select the region of the plot that corresponds to the cart's motion <u>after</u> the push and <u>before</u> it stopped at the bottom of the track.



7. Use the 'Statistics' tool to find the mean value of the acceleration *as measured by the Acceleration Sensor* for your selected region. Record the mean of the value in the Data Table.

8. Calculate the <u>theoretical</u> value for the acceleration of the cart based on the track's angle and record it in the Data Table.

$$a = g \sin\theta$$

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P07: Acceleration of a Cart

What Do You Think?

What happens to the acceleration of a cart as it moves up and down an inclined plane?

Data Table

Item	Run #1	Run #2
angle of track	degrees	degrees
acceleration (slope)	m/sec^2	m/sec^2
acceleration (mean)	m/sec^2	m/sec^2
acceleration (theoretical)	m/sec^2	m/sec^2

Questions

1. Describe the position versus time plot of the Graph display. Why does the distance begin at a maximum and decrease as the cart moves up the inclined plane?

2. Describe the velocity versus time plot of the Graph display.

3. Describe the acceleration versus time plot of the Graph display.

4. How does the acceleration determined in the plot of velocity compare to the mean value of acceleration from the plot of acceleration?

5. What is the percent difference between the acceleration determined in the plot of velocity and the theoretical value for acceleration?

Remember, $\textbf{percent difference} = \left|\dfrac{\textbf{theoretical} - \textbf{actual}}{\textbf{theoretical}}\right| \times \mathbf{100\%}$

6. How did the acceleration change when the track became steeper?

Name ____________________ Class _____________ Date _________

Appendix: Modify a *ScienceWorkshop* File

Modify an existing*ScienceWorkshop* file to add the Acceleration Sensor.

Open the *ScienceWorkshop* File

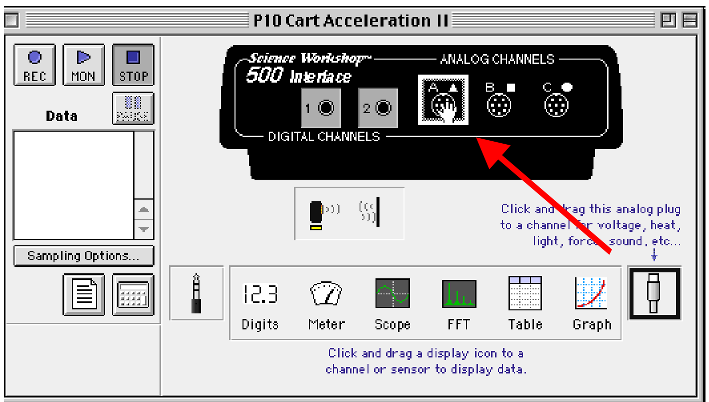
Open the file titled as shown:

ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P10 Accelerate Cart 2	P10_CAR2.SWS

- The *ScienceWorkshop* file has a Graph display of position, velocity, and acceleration for the Motion Sensor. You need to add an Acceleration Sensor to the Experiment Setup window, set the sample rate, and create a Graph display for the new sensor.

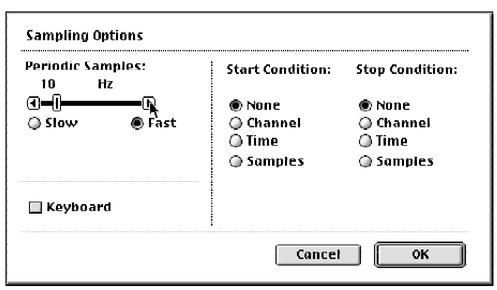
Set Up the Acceleration Sensor

In the Experiment Setup window, click and drag the analog sensor plug to Channel A. Select 'Acceleration Sensor' from the list of sensors. Click 'OK' to return to the Experiment Setup window.



Set the Sampling Options

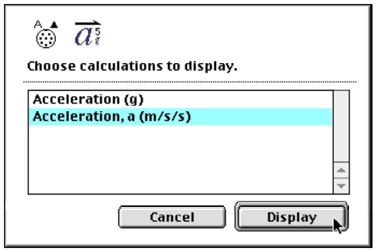
Click the 'Sampling Options' button in the Experiment Setup window or select 'Sampling Options' from the Experiment menu to open the Sampling Options window. Under 'Periodic Samples' click the right arrow to set the sample rate at '50 Hz' (50 measurements per second).



Set Up the Display

In the Experiment Setup window, click and drag the Graph display icon to the Acceleration Sensor icon.

Select 'Acceleration (m/s/s)' from the list of calculations and click 'Display'. **Result**: A Graph display opens for the Acceleration Sensor showing Acceleration versus Time.



Name ____________________ Class _____________ Date _________

Activity P08: Newton's Second Law - Constant Force (Force Sensor, Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Newton's Laws	P08 Constant Force.DS	P11 Constant Force	P11_CONF.SWS

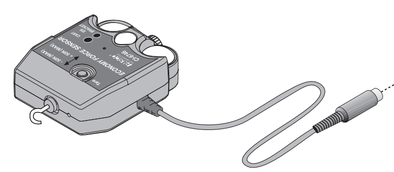
Equipment Needed	Qty	Equipment Needed	Qty
Economy Force Sensor (CI-6746)	1	**Mass and Hanger Set (ME-8967)**	1
Motion Sensor (CI-6742)	1	**String (SE-8050)**	1 m
Balance (SE-8723)	1	**Super Pulley w/ Clamp (ME-9448A)**	1
Dynamics Cart (inc. w/ Track)	1	**1.2 m Track System (ME-9435A)**	1

What Do You Think?

The purpose of this activity is to study Newton's Second Law. Using Newton's Second Law, what happens to an object's acceleration if the force applied to the object is increased but the object's mass remains constant?

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

Background



Newton described the relationship between acceleration, force, and mass as follows:

The acceleration of an object is directly proportional to and in the same direction as the net force, and inversely proportional to the mass of the object:

$$a = \frac{F_{net}}{m}$$

a is acceleration, F_{net} is net force, and m is mass.

Applying Newton's Second Law to the static setup used in this activity for an object accelerated by the weight of a hanging mass, neglecting friction, the acceleration of the object and hanging mass can be written as:

$$a = \frac{F_{net}}{m} = \frac{m_{hanging}g}{m_{object} + m_{hanging}}$$

SAFETY REMINDER

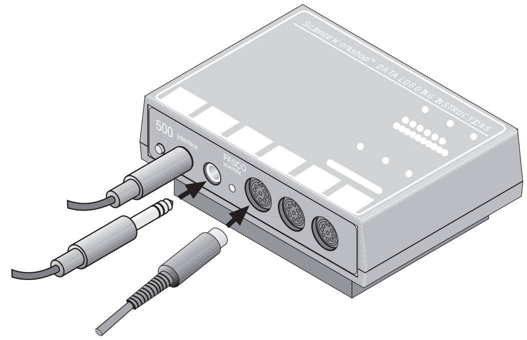
- Do not let the cart run away from the user. Catch the cart before the cart crashes into the bumper or travels off the table.
- Follow directions for using equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

For this activity, use a Motion Sensor to measure the motion of a cart that is pulled by string attached to a hanging mass that is suspended over a pulley. Use a Force Sensor mounted on the cart to measure the force that accelerates the cart. Next, use *DataStudio or ScienceWorkshop* to plot and analyze the data.

PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Motion Sensor's phone plugs to Digital Channels 1 and 2 on the interface. Plug the yellow-banded (pulse) plug into Digital Channel 1 and the second plug (echo) into Digital Channel 2.
3. Connect the DIN plug of the Force Sensor to Analog Channel A.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P08 Constant Force.DS	P11 Constant Force	P11_CONF.SWS

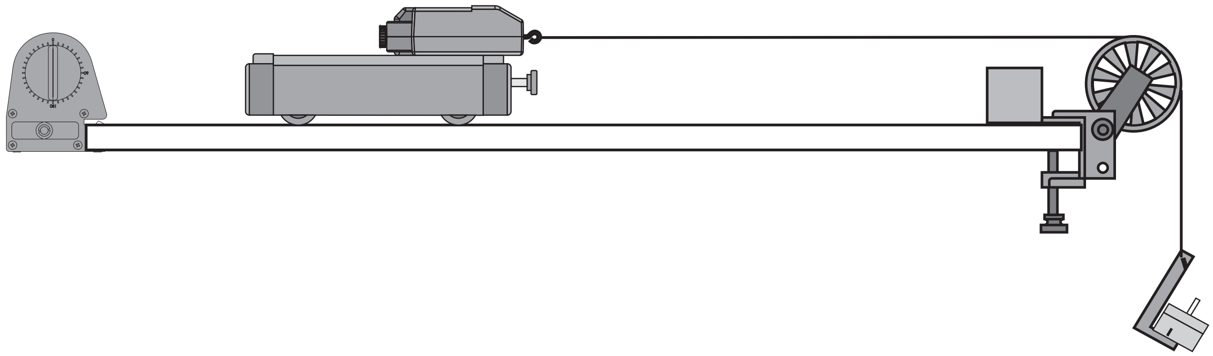
- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display with Velocity versus Time and a Table display of Force.
- Data recording is set for 200 samples per second (200 Hz) for the Force Sensor.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Motion Sensor.
- To calibrate the Force Sensor, refer to the description in the Force Sensor Manual.

1. Place the Dynamics Track on a horizontal surface. Level the Dynamics Track by placing the Dynamics Cart on the Dynamics Track. If the cart rolls one way or the other, use the Adjustable Feet at one end of the Dynamics Track to raise or lower that end until the Dynamics Track is level and the cart does not roll one way or the other.
2. Attach a pulley to the right end of the Dynamics Track. Place the Motion Sensor at the left end of the track.
3. Use the thumbscrew included with the Force Sensor to mount the sensor onto the accessory tray of the cart.
4. Carefully measure and record the total mass of the cart and Force Sensor in the Lab Report section.
5. Place the cart on the Dynamics Track so the hook end of the Force Sensor points away from the Motion Sensor. The cart will be pulled away from the sensor. The cart must remain a minimum distance away from the sensor. The minimum distance from the sensor to its target is dependent upon the motion sensor used. Refer to the Motion Sensor Manual to determine the minimum distance. Put a mark on the Dynamics Track the minimum distance from the motion sensor (15 or 40 cm).
6. Use a string that is 10 cm longer than the length needed to reach the floor when the cart is next to the pulley. Attach one end to the Force Sensor's hook.
7. Add 20 or 30 grams of mass to the mass hanger.

8. Carefully measure and record the total mass of the mass and mass hanger in the Lab Report section.
9. Attach the mass hanger to the other end of the string, and put the string in the pulley's groove. Adjust the height of the pulley so the string is parallel to the Dynamics Track.



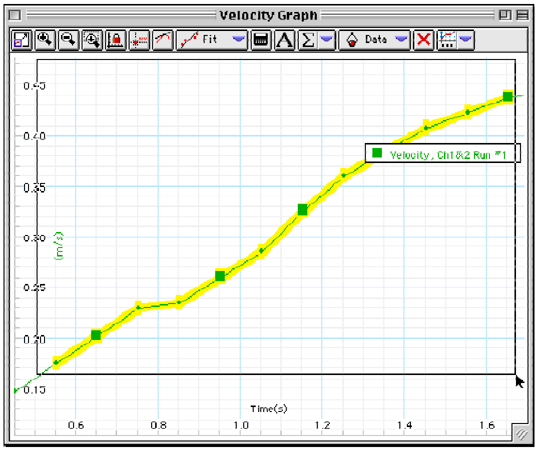
- To fasten the string to the mass hanger, wrap the string four or five turns around the notched area of the mass hanger.

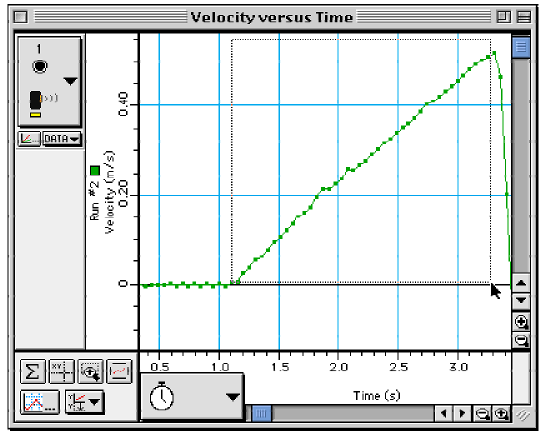
PART III: Data Recording

1. Pull the cart toward the left end of the Dynamics Track but keep the cart at least the minimum distance from the Motion Sensor. Do not let the mass hanger bump into the pulley.
2. Prior to each data run, support the hanging mass so that the string is not pulling on the Force Sensor. Push the tare button on the Force Sensor to zero the Force Sensor.
3. Start recording data and then release the cart.
4. Stop data recording before the cart reaches the pulley.
5. Stop the cart before it collides with the pulley.

Analyzing the Data

1. Click and drag the cursor to draw a rectangle around the region of the velocity vs. time plot that shows the movement of the cart. **Result**: The area will be highlighted.

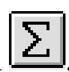




2. Select the Linear curve fit. The slope of the velocity vs. time plot is the average acceleration of the cart.

- In *DataStudio*, click the 'Fit' menu button (). Select 'Linear'.
- In *ScienceWorkshop* click the 'Statistics' button to open the Statistics area on the right side of the Graph. In the Statistics area, click the Statistics Menu button (). Select **Curve Fit, Linear Fit** from the Statistics Menu.

3. Record the slope of the linear fit in the Data Table in the Lab Report section.
4. Using the measured mass values, calculate and record the theoretical acceleration of the system in the Lab Report section.
5. Use the Statistics tool to find the average (mean) force from the Table display.

- In the Force Table, click on the statistics button . Record the mean value of the force in the Data Table in the Lab Report section.

6. Using the measured mass value, calculate and record the force exerted on the cart and Force Sensor. Record the result in the Data Table.

Record your results in the Lab Report section.

Name ____________________ Class _____________ Date _________

Lab Report - Activity P08: Newton's Second Law – Constant Force

What Do You Think?

Using Newton's Second Law, what happens to an object's acceleration if the force applied to the object is increased but the object's mass remains constant?

Data Table

Item	Value
Mass of Cart and Sensor	
Mass of Hanger and Masses	
Acceleration (Measured)	
Acceleration (Calculated)	
Force (Mean)	
Force (Calculated)	

Questions

1. What is the percentage difference between the measured and calculated values of acceleration?

   Remember, $$\textbf{\% difference} = \left|\frac{\textbf{\textit{measured}} - \textbf{\textit{theoretical}}}{\textbf{\textit{theoretical}}}\right| \times \textbf{100\%}$$

2. What is the percentage difference between the measured and calculated values of force?

3. What are some possible reasons for any differences between the measured and calculated or theoretical values?

Name ____________________ Class _____________ Date _________

Activity P09: Newton's Second Law - Push and Pull a Cart (Force Sensor, Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Newton's Laws	P09 Push Pull.ds	P12 Push-Pull a Cart	P12_PUSH.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Economy Force Sensor (CI-6746)	1	**Dynamics Cart (inc. w/ Track)**	1
Motion Sensor (CI-6742)	1	**1.2 m Track System (ME-9429A)**	1
Balance (SE-8723)	1		

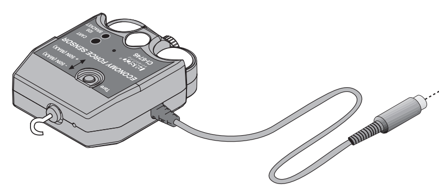
What Do You Think?

The purpose of this activity is to explore Newton's Second Law. Can erratic pushing and pulling of an object produce a linear relationship?

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

Background

Isaac Newton described the relationship of acceleration to net force and mass of an object as follows:



The acceleration of an object is directly proportional and in the same direction as the net force on the object, but inversely proportional to the mass of the object.

$$a = \frac{F_{net}}{m}$$

- For this activity we will be verifying Newton's Second Law in the form $m = \frac{F_{net}}{a}$.

SAFETY REMINDER

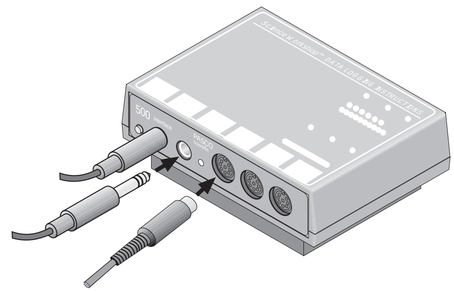
- Do not let the cart hit the Motion Sensor.
- Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

For this activity, push and pull a Dynamics Cart back-and-forth on a level Dynamics Track. Use the Motion Sensor to measure the motion of a cart, and the Force Sensor to measure the force you exert on the cart. Use *DataStudio* or *ScienceWorkshop* to calculate the acceleration of the cart as it moves. (Hint: The slope of the graph of force versus acceleration is the mass of the moving object.)

PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Motion Sensor's phone plugs to Digital Channels 1 and 2 on the interface. Plug the yellow-banded (pulse) plug into Digital Channel 1 and the second plug (echo) into Digital Channel 2.
3. Connect the DIN plug of the Force Sensor to Analog Channel A.
4. Open the document titled as shown:

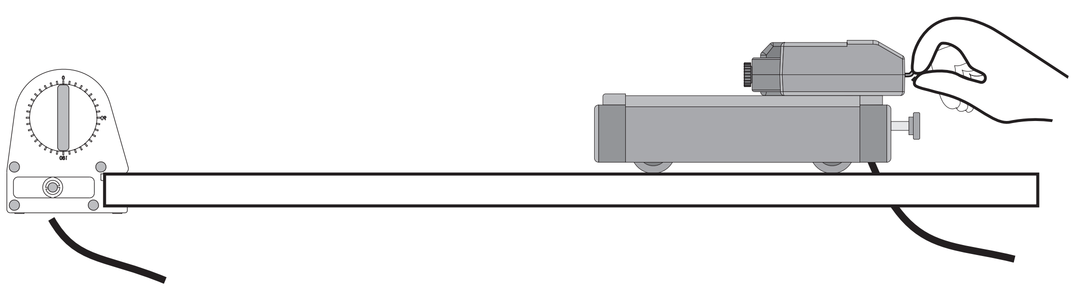
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P09 Push Pull.DS	P12 Push-Pull a Cart	P12_PUSH.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorksho*p document has a Graph display of Force versus Acceleration.
- Data recording is set at 100 Hz for the Force Sensor and the Trigger Rate for the Motion Sensor is 20 times per second.
- The calibration for the Force Sensor has been changed so that a push to the left is negative and a pull to the right is positive.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Motion Sensor.
- To calibrate the Force Sensor, refer to the description in the introduction of this manual.

1. Place the track on a horizontal surface. Level the track by placing the 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 does not roll one way or the other.
2. Mount the Force Sensor onto the accessory tray of the cart.
3. Measure and record the mass of the cart plus Force Sensor in the Data Table in the Lab Report section.
4. Position the Motion Sensor at the left end of the track. Place the cart on the track so the hook end of the Force Sensor points away from the Motion Sensor. The cart must remain a minimum distance away from the sensor (15 cm for the Motion Sensor II). Put a mark on the track at the minimum distance from the Motion Sensor (15 cm).



Name ____________________ Class _____________ Date _________

Trial Run of Data

1. Before recording data for later analysis, record a trial run with the Motion Sensor to make sure it is aligned and can "see" the cart as it moves.
2. Place the cart on one end of the Dynamics Track. Press the tare button on the side of the Force Sensor to zero the Force Sensor.
3. Firmly grasp the hook of the Force Sensor and pull and push the Force Sensor to make the cart move back and forth. Make sure the cart does not come too close to the Motion Sensor.
4. Start recording data.
5. After about 10 seconds, stop recording data.
6. Adjust the position of the Motion Sensor if necessary.

PART III: Data Recording

1. Prior to recording each data run, press the tare button on the side of the Force Sensor to zero the Force Sensor.
2. After the Force Sensor has been zeroed, begin pulling and pushing on the hook of the Force Sensor to make the cart move back and forth.
3. Start recording data.
4. Push and pull the cart back and forth four or five times, then stop the recording.

• Run #1 will appear in the Data list. If the data points do not appear on the graph, check the alignment of the Motion Sensor and try again.

Analyzing the Data

1. Click-and-draw a rectangle around the region of the force versus acceleration plot that shows the movement of the cart. Release the mouse button, and the area will be highlighted.
2. Select the Linear curve fit.

• In *DataStudio*, click the 'Fit' menu button (Fit ▼). Select 'Linear'.

• In *ScienceWorkshop* click the 'Statistics' button to open the Statistics area on the right side of the Graph. In the Statistics area, click the Statistics Menu button (Σ ▼). Select 'Curve Fit, Linear Fit' from the Statistics Menu.

3. Record the slope of the linear fit in the Data Table in the Lab Report section.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P09: Newton's Second Law - Push and Pull a Cart

What Do You Think?

Can erratic pushing and pulling of an object produce a linear relationship?

Data Table

Item	Value
Mass of cart and Force Sensor (measured)	
Mass of cart & Force Sensor (slope)	

Questions

1. What are the appropriate units for the slope of the force vs. acceleration plot?

2. Why does the slope of the force versus acceleration plot equal the object's mass?

3. What is the percentage difference between the actual and experimental mass? Remember,

$$\textbf{percent difference} = \left|\frac{\textbf{theoretical} - \textbf{actual}}{\textbf{theoretical}}\right| \times \textbf{100\%}$$

4. What are some possible reasons for any differences between the measured and calculated or theoretical values?

Name ____________________ Class _____________ Date _________

Activity P10: Atwood's Machine (Photogate/Pulley System)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Newton's Laws	P10 Atwood's.DS	P13 Atwood's Machine	P13_ATWD.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Photogate/Pulley System (ME-6838)	1	**String (SE-8050)**	1
Mass and Hanger Set (ME-8967)	1	**Universal Table Clamp (ME-9376B)**	1

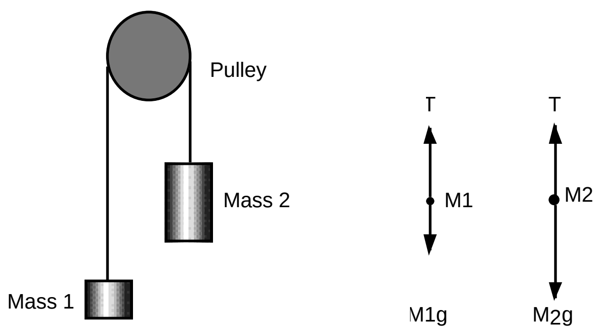
What Do You Think?

The purpose of this activity is to study the relationship among force, mass, and acceleration using an Atwood's Machine apparatus. What is a real world application of Atwood's Machine?

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

Background

The acceleration of an object depends on the net applied force and the object's mass. In an Atwood's Machine, the difference in weight between two hanging masses determines the net force acting on the system of both masses. This net force accelerates both of the hanging masses; the heavier mass is accelerated downward, and the lighter mass is accelerated upward.



Based on the above free body diagram, T is the tension in the string, $M_2 > M_1$, and g is the acceleration due to gravity. Taking the convention that up is positive and down is negative, the net force equations for M_1 and M_2 are:

$$T_1 - M_1 g = F_{net} = M_1 a$$

$$T_2 - M_2 g = F_{net} = M_2(-a)$$

Assuming that the pulley is massless and frictionless, and the string has no mass and doesn't stretch, let $T_1 = T_2$. Solving for a, the acceleration of the system of both masses, the theoretical acceleration is g times the difference in mass divided by the total mass:

$$a = g\left(\frac{M_2 - M_1}{M_1 + M_2}\right)$$

SAFETY REMINDERS

- Follow all directions for using the equipment.

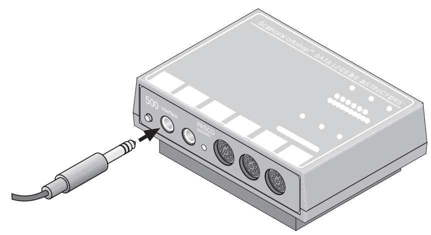
THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the Photogate/Pulley System to measure the motion of both masses as one moves up and the other moves down. Use *DataStudio* or *ScienceWorkshop* to record the changing speed of the masses as they move. The slope of the graph of velocity vs. time is the acceleration of the system.

PART I: Computer Setup

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



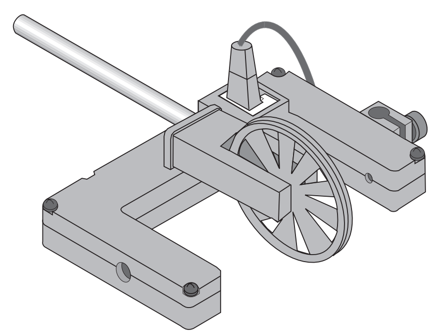
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P10 Atwood's.DS	P13 Atwood's Machine	P13_ATWD.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of velocity versus time.
- Note: The spoke arc length for the Pulley is set at 0.015 m. If you are using a different pulley, change the spoke arc length in the sensor window by double clicking on the sensor's icon in the Experiment Setup window.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the sensor.

1. Mount the clamp to the edge of a table.
2. Use the Pulley Mounting Rod to attach the Pulley to the tab on the Photogate.
3. Place Photogate/Pulley in the clamp so that the rod is horizontal.
4. Use a piece of string about 10 cm longer than the distance from the top of the pulley to the floor. Place the string in the groove of the pulley.

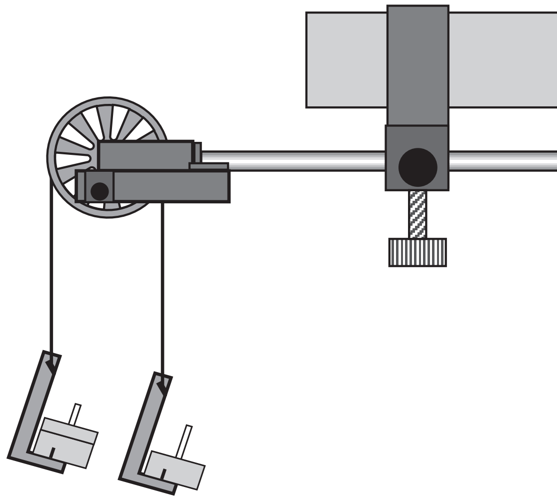


5. Fasten mass hangers to each end of the string.

- To attach the string to the hanger, form a loop at the end of the string and tie it back on itself to 'knot it' or wrap the string about 5 times around the notch in the mass hanger.

6. Place five to six masses from your mass set, totaling (roughly) 100 grams of mass on one mass hanger and record the total mass as M_1 in the Data Table in the Lab Report section. Be sure to include the 5 grams from the mass hanger in the total mass. On the other mass hanger, place about six masses, totaling slightly more mass than M_1. Record this total mass of the masses and mass hanger as M_2 in the Data Table in the Lab Report section.

7. Move the M_2 mass hanger of upward until the M_1 mass hanger almost touches the floor. Hold the M_2 mass hanger to keep it from falling. Turn the pulley so that the Photogate beam is unblocked (the red light-emitting diode (LED) on the Photogate does not light).



PART IIIA: Data Recording – Constant Total Mass

1. Release the M_2 mass hanger and let it fall. Start recording data.
2. Stop recording just before the M_2 mass hanger reaches the floor.

- Do not let the upward moving mass hit the Pulley.
- "Run #1" will appear in the Data list.

3. For Run #2, move a mass from the M_2 mass hanger to the M_1 mass hanger. This process changes the net force without changing the total system mass. Record the new total mass for each hanger with masses in the Data Table in the Lab Report section. Allow the mass to fall. Begin data recording. Stop recording data just before the hanger reaches the floor.
4. Repeat the above step to create three more mass combinations. For each run, the net force changes but the total mass of the system remains constant.

PART IIIB: Data Recording – Constant Net Force

1. Arrange the masses as they were for Run #1. Now, change the total mass of the system but keep the net force the same. To do this, add exactly the same amount of additional mass to both mass hangers.

- Make sure that the difference in mass is the same as it was for the beginning of Part IIIA.

2. Add approximately 10 grams to each mass hanger. Record the new total mass for each hanger with masses in the Data Table in the Lab Report section. Release the M2 mass hanger and let it fall. Start data recording. Stop recording just before the M2 mass hanger reaches the floor.
3. Repeat the above step to create three more data runs. For each data run, the net force remains the same, but the total mass of the system changes.

Analyzing the Data

1. Determine the experimental acceleration for each of the data runs.

- Click in the Graph display to make it active. Find the slope of the velocity vs. time plot, the average acceleration of the masses.
- In *DataStudio*, select Run #1 from the Data Menu ( ) in the Graph display. If multiple data runs are showing, first select No Data from the Data Menu and then select Run #1. Click the "Scale to fit" button ( ) to rescale the Graph axes to fit the data. Next, click the 'Fit' menu button ( ). Select 'Linear'.
- In *ScienceWorkshop*, select Run #1 from the Data Menu ( ) in the Graph display. If multiple data runs are showing, first select No Data from the Data Menu and then select Run #1. Click the "Autoscale" button ( ) to rescale the Graph axes to fit the data. Click the 'Statistics' button to open the Statistics area on the right side of the Graph. In the Statistics area, click the Statistics Menu button ( ). Select 'Curve Fit, Linear Fit' from the Statistics Menu.
- Record the slope of the linear fit in the Data Table in the Lab Report section. Repeat the above procedure for each of the remaining 9 data runs.

2. For each of the data runs, using the measured mass values, calculate and record the net force in the Data Table in the Lab Report section.

$$F_{net} = (M_2 - M_1)g$$

3. Calculate and record the total mass in the Data Table.

4. Using the total mass and net force, calculate the theoretical acceleration using:

$$a = \frac{F_{net}}{M_1 + M_2}$$

5. For each data run, calculate and record the percent difference between the experimental acceleration and the theoretical acceleration.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P10: Atwood's Machine

What Do You Think?

What is a real world application of Atwood's Machine?

Data Table: Constant Total Mass

Run	M_1 (kg)	M_2 (kg)	a_{exp} (m/s^2)	F_{net} (N)	$M_1 + M_2$ (kg)	a_{theory} (m/s^2)	Percent difference
Run #1							
Run #2							
Run #3							
Run #4							
Run #5							

Data Table: Constant Net Force

Run	M_1 (kg)	M_2 (kg)	a_{exp} (m/s^2)	F_{net} (N)	$M_1 + M_2$ (kg)	a_{theory} (m/s^2)	Percent difference
Run #6							
Run #7							
Run #8							
Run #9							
Run #10							

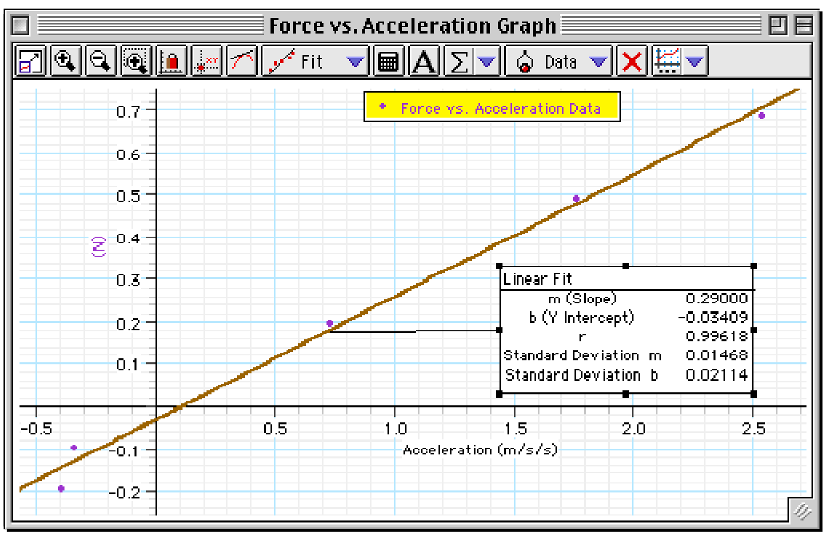
Questions

1. Compare the experimental acceleration with the theoretical acceleration by determining the percentage difference. What are some reasons that would account for this percent difference?

2. For the Constant Total Mass data, plot a graph of Fnet vs. aexp. Note: Include a negative sign for acceleration values when M1 > M2. Attach your plot to the Lab Report.

3. Draw the best-fit line on your plot. What does the slope of the best-fit line represent?

4. How does the Force vs. Acceleration plot relate to Newton's Second Law?



Name ____________________ Class ______________ Date _________

Activity P11: Collision – Impulse and Momentum (Force Sensor, Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Newton's Laws	P11 Impulse.DS	P14 Collision	P14_COLL.SWS

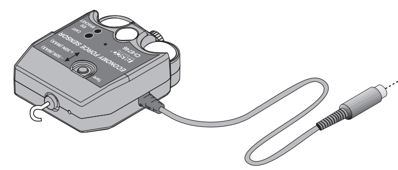
Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Economy Force Sensor (CI-6746)	1	**Balance (SE-8707)**	1
Motion Sensor (CI-6742)	1	**Collision Cart (ME-9454)**	1
Accessory Bracket (CI-6545)	1	**2.2 m Track System (ME-9452)**	1

What Do You Think?

How is the force felt during a collision related to the duration of the collision?

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

Background



When an object strikes a barrier, the force on the object varies as the collision occurs. Changes in the momentum of the object (the *impulse*) can be calculated in two ways:

- Using the velocities before (v_i) and after (v_f) the collision:

$$\Delta \boldsymbol{p} = \boldsymbol{m}\boldsymbol{v}_f - \boldsymbol{m}\boldsymbol{v}_i$$

- Using the net force and time of impact: $\Delta \boldsymbol{p} = \int \boldsymbol{F}d\boldsymbol{t} = \boldsymbol{F}_{net}\,\Delta \boldsymbol{t}$

It is possible for the object to undergo the same change in momentum whether it is involved in an abrupt hard collision or a cushioned collision. We want to determine the difference between how a hard or soft collision affects the force felt by the object.

SAFETY REMINDER

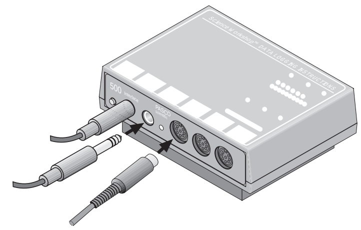
- Follow the directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the Motion Sensor to measure the motion of a cart as it collides with a bumper. Use a Force Sensor mounted on the track to measure the force of the collision over the same interval of time. Use *DataStudio or ScienceWorkshop* to compare the change in momentum of the cart with the integral of the measured force vs. time graph.

PART I: Computer Setup



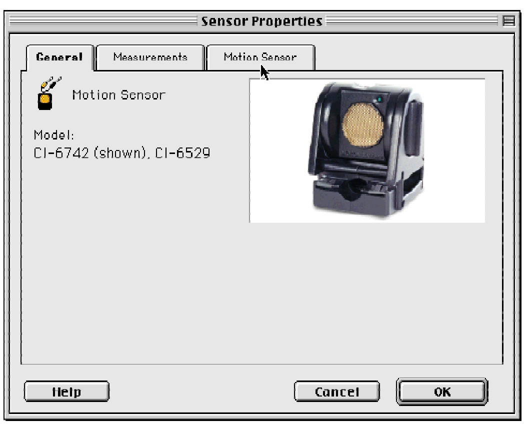
1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Motion Sensor's phone plugs to Digital Channels 1 and 2 on the interface. Plug the yellow-banded (pulse) plug into Digital Channel 1 and the second plug (echo) into Digital Channel 2.
3. Connect the DIN plug of the Force Sensor to Analog Channel A.
4. Open the document titled as shown:

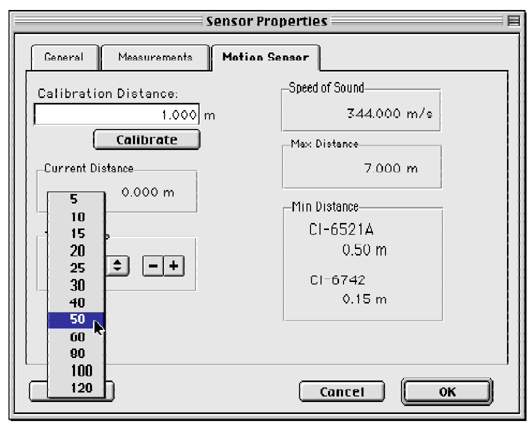
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P11 Impulse.DS	P14 Collision	P14_COLL.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display with Force versus Time and Velocity versus Time.
- Data recording is set for 500 samples per second (500 Hz) for the Force Sensor.

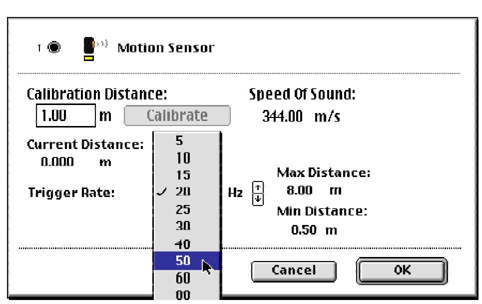
5. Set the Trigger Rate for the Motion Sensor to 50 Hz.

- In *DataStudio*, double-click the Motion Sensor icon in the Experiment Setup window. **Result**: The Sensor Properties window opens. Click the 'Motion Sensor' tab. Select '50' from the Trigger Rate menu. Click 'OK' to return to the Experiment Setup window.





- In *ScienceWorkshop*, double-click the Motion Sensor icon in the Experiment Setup window. **Result**: The Motion Sensor setup window opens. Select '50' from the Trigger Rate menu. Click 'OK' to return to the Experiment Setup window.



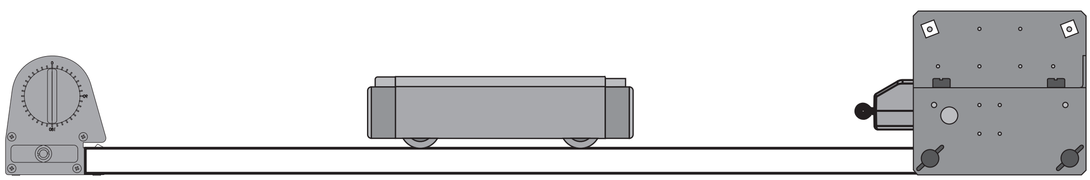
Name ____________________ Class ______________ Date _________

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Motion Sensor.
- To calibrate the Force Sensor, refer to the tutorial in the introduction of this manual.

1. Place the Dynamics Track on a horizontal surface.
2. Mount the Economy Force Sensor on the Accessory Bracket. Mount the Accessory Bracket in the T-slot on the side of the Dynamics Track.
3. Use a book or other method to raise the end of the Dynamics Track that is opposite to the end with the Force Sensor about 1.5 cm so the cart will have approximately the same speed for each trial.
4. Place the Motion Sensor at the raised end of the Dynamics Track so it can measure the motion of the cart. Put a mark on the Dynamics Track at least the minimum distance away from the Motion Sensor. For all trials start the cart at this place.
5. Brace the Force Sensor end of the Dynamics Track against a heavy mass so the Dynamics Track will not move during the collision.
6. Measure the mass of the cart. Record the mass value in the Data Table in the Lab Report section.

7. Unscrew the hook attachment from the front of the Force Sensor. In its place, put the magnetic bumper from the Accessory Bracket with Bumpers.



PART III: Data Recording

1. Prior to each data run, press the tare button on the side of the Force Sensor to zero the sensor.
2. Place the cart on the Dynamics Track at the starting mark made during setup.
3. Release the cart so that it rolls toward the Force Sensor. Begin data recording.
4. End data recording after the cart has rebounded from the collision with the Force Sensor's magnetic bumper.

- The data will appear as Run #1.

Analyzing the Data

1. Zoom in about the peak in the force vs. time plot.

- In the Graph display, click on the zoom button (). While holding down on the mouse button, move the cursor to draw a rectangle around the peak in the force vs. time plot. Make sure that the entire peak is in the rectangle. **Result**: The points will be highlighted. Release the mouse button and the Graph axes will rescale to zoom in about the region.

2. Select the region in the graph window that corresponds to the collision.

- Hold down on the mouse button and move the cursor to draw a rectangle around the region of the force vs. time plot that shows the collision. Release the mouse button, and the area will be highlighted.

3. Integrate to find the area under the curve.

- In *DataStudio*, click the ‘Statistics’ menu button () and select ‘Area’.
- In *ScienceWorkshop*, click the Statistics button () to open the Statistics area on the right side of the graph. In the Statistics area, click the ‘Statistics Menu’ button () and select ‘Integration’.

4. Record the value of the area under the curve in the Data Table in the Lab Report section.
5. Find the velocity just before the collision and the velocity just after the collision from the velocity versus time plot.

- In *DataStudio*, select the velocity window. Click the ‘Smart Tool’ button () and move the Smart Tool to the velocity data points. If needed, zoom in about the region during which the collision took place using the zoom tool.
- In *ScienceWorkshop*, click the ‘Smart Cursor‘ () and move the Smart Cursor to the velocity data points. If needed, zoom in about the region during which the collision took place using the zoom tool.

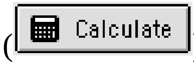
6. Record the two velocity values in the Data Table in the Lab Report section.
7. Use the mass and velocity values to compute the momenta before and after the collision.

Record your results in the Lab Report section.

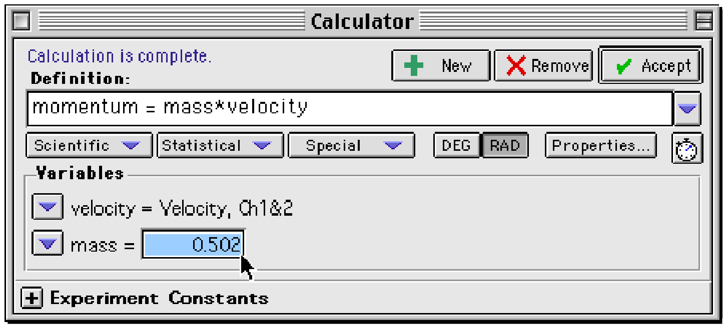
Name ____________________ Class _____________ Date ________

Optional

1. Use the Calculator to make a calculation for linear momentum with units of kg m/sec.

- In *DataStudio*, click the 'Calculate' button () in the main toolbar.

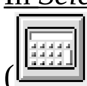
  The Calculator window will open. The window shows the calculation for Momentum that was created as part of this activity.



  If the mass value for your cart is different than 0.502 kg, highlight the "0.502" in the 'mass' window and type in the mass of your cart.

  Click the 'Accept' button to save your change.

  Close the Experiment Calculator window. Display the momentum calculation by dragging a Graph display icon to the calculator.

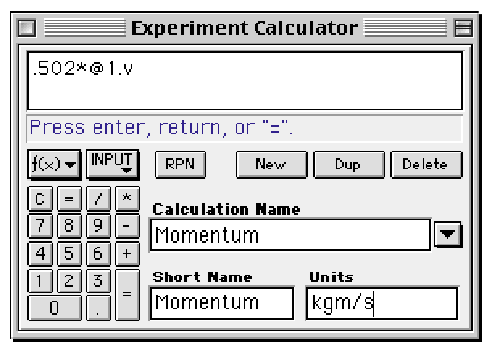
- In *ScienceWorkshop*, to create a calculation for momentum, click the Calculator button () in the Experiment Setup window.

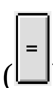
  The Experiment Calculator window will open.

  Enter the mass of the cart and then '*' for multiplication.

  From the Input menu select Digital 1, Velocity.

  Enter a Calculation Name, Short Name, and Units.



  Click the **equals** button () or press <ENTER> or <RETURN> on the keyboard.

  Close the Experiment Calculator window. Display the momentum calculation in the Graph display by selecting Calculations from the Data Input menu.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P11: Collision – Impulse and Momentum

What Do You Think?

How is the force felt during a collision related to the duration of the collision?

Data Table

Item	Value
Mass of cart	
Impulse (from integration)	
Velocity before collision	
Velocity after collision	
Momentum before collision	
Momentum after collision	
Change in momentum	

Questions

1. Why is it desirable to have the same initial speed for each data run?

2. How will raising the end of the Dynamics Track give the cart the same acceleration each time?

3. For your data, how does the change in momentum compare to the impulse?

4. What are possible reasons why the change in momentum is different from the measured impulse?

5. Compare the impulse and force for an abrupt (hard) and a cushioned (soft) collision. Use words and also sketch the force vs. time graphs.

6. Use the above comparison to explain why airbags in cars can help to prevent injuries to the occupants during a frontal collision.

Name ____________________ Class ______________ Date _________

Activity P12: Newton's Third Law – Collision and Tug-of-War (Force Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Newton's Laws	P12 Tug of War.DS	P15 Tug-of-War	P15_TUG.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Economy Force Sensor (CI-6746)	2	PASCO Cart (inc. w/ Track)	2
Accessory Bracket (CI-6545)	1	2.2 m Track System (ME-9452)	1
Balance (SE-8723)	1		

What Do You Think?

What forces act on two carts as they interact during a collision?

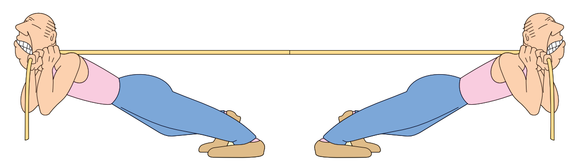
Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

Newton's Third Law states that for every action there is an equal and opposite reaction.

$$F_{12} = -F_{21}$$

If we measure the forces between two objects as they interact, we can verify this relationship.



SAFETY REMINDER

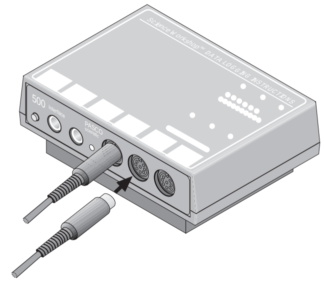
- Follow the directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

For this activity, use Force Sensors attached to carts to measure the force of interaction during collisions and a "tug-of-war". Use *DataStudio* or *ScienceWorkshop* to display and analyze the measured forces.

PART I: Computer Setup



1. Connect the interface to the computer, turn on the interface, and turn on the computer.
2. Connect one Force Sensor DIN plug to Analog Channel A on the interface, and the other Force Sensor DIN plug to Analog Channel B.
3. Open the document titled as shown:

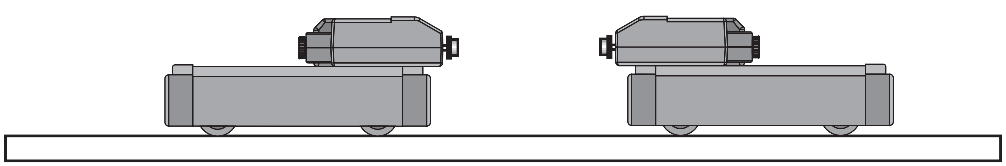
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P12 Tug of War.DS	P15 Tug-of-War	P15_TUG.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display with two plots of Force versus Time and Meter displays of Force for each Force Sensor.
- Data recording is set at 100 Hz.
- The sensors are calibrated so that the Force Sensor connected to Analog Channel B will react in the opposite way as the Force Sensor connected to Analog Channel A. For example, a pull will be a negative force for Sensor A and a pull will be a positive force for Sensor B.

PART II: Sensor Calibration and Equipment Setup

- To calibrate the Force Sensor, refer to the description in the Force Sensor Manual. When calibrating the Channel B Force Sensor, enter a positive force for a pull.

1. Place the Dynamics Track on a horizontal surface. Level the Dynamics Track by placing the Dynamics Cart on the Dynamics Track. If the cart rolls one way or the other, use the Adjustable Feet at one end of the Dynamics Track to raise or lower that end until the Dynamics Track is level and the cart does not roll one way or the other.
2. Use the thumbscrew that comes with the Force Sensor to mount the sensor onto the accessory tray of each cart.
3. Place the carts on the track so that the hooks on the Force Sensors face each other.



4. Unscrew the hook attachments from the front of each of the Force Sensors. In their place, put the magnetic collision bumpers from the Accessory Bracket with Bumpers.

Name ____________________ Class ______________ Date _________

PART IIIA: Data Recording - Collision

1. Move the carts to opposite ends of the track. Push the tare button on each sensor to zero the sensor.

• It is important to tare the Force Sensors prior to each data run.

2. Begin data recording.

3. Push the two carts together, allowing them to collide at approximately equal speeds near the center of the track.

4. End data recording after the carts have collided.

• The data will appear as Run #1.

5. Add additional mass to one of the carts. Repeat the data recording procedure.

• Remember to push the tare button to zero each sensor before recording data.

6. Repeat the data recording procedure again, but allow the lighter cart to remain stationary and push only the heavier cart.

7. Repeat the data recording procedure for two mass and velocity combinations. Describe each combination in the Lab Report section.

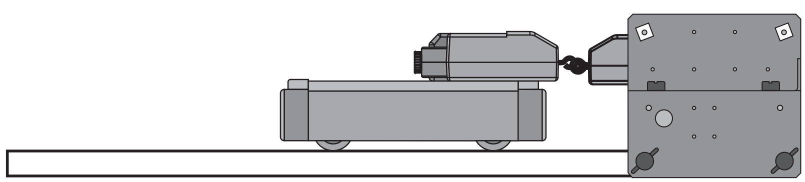
PART IIIB: Data Recording – Tug-of-War

1. Remove one Force Sensor from a cart.

2. Mount the Force Sensor on the Accessory Bracket. Mount the Accessory Bracket in the T-slot on the side of the Dynamics Track. The Force Sensor should be at the same height as the Force Sensor that is still on the cart.

3. Remove the magnetic bumpers from the front of each of the Force Sensors. In their place, put the hooks.

4. Connect the two Force Sensors together with their hooks. Use a rubber band, piece of string, or piece of tape to connect the hooks together.



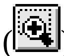
5. Push the tare button on each sensor to zero the sensor.

6. Begin data recording.

7. Push and pull the free cart back-and-forth and observe how the force readings for the two sensors change. End data recording.

Analyzing the Data – Collision

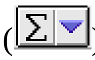
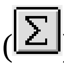
1. For each of the Force Sensors, integrate to find the area under the force vs. time plot (the impulse) that corresponds to the collision.

- Zoom in about the peak in the force vs. time plot with the 'Zoom Select' Magnifier tool ().

2. Select the region in the graph window that corresponds to the collision.

- Hold down on the mouse button and move the cursor to draw a rectangle around the region of the force vs. time plot that shows the collision. Release the mouse button, and the area will be highlighted.

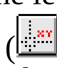
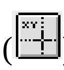
3. Integrate to find the area under the curve.

- In *DataStudio*, click the Statistics menu button () and select 'Area'.
- In *ScienceWorkshop*, click the Statistics button () to open the Statistics area on the right side of the graph. In the Statistics area, click the Statistics Menu button (). Select 'Integration'.

4. Record the value of the area under the curve in the Data Table in the Lab Report section.
5. Repeat this procedure for the other force vs. time plot and for each of the data runs.

Analyzing the Data –Tug-of-War

1. Compare local maxima and minima for the force vs. time plots for the two Force Sensors.

- In *DataStudio*, in the Graph display in the legend click on the channel and data run to be analyzed. Click the 'Smart Tool' button () and move the Smart Tool to the force data points. Next, in the legend, click on the other channel and the same data run. A second Smart Tool will appear. Use the two tools to read the values. If needed, zoom in about a region using the 'Zoom Select' tool.
- In *ScienceWorkshop*, in the Graph display, click the 'Smart Cursor' () and move the Smart Cursor to the force data points. Hold down the Shift key to "freeze" the horizontal position of the cursor. Move the cursor/cross-hair vertically to the plot of force for the other sensor. The force at that point is displayed next to the vertical axis of the plot. If needed, zoom in about the region during which the collision took place using the Magnifier tool.

2. Record the two corresponding force values in the Data Table in the Lab Report section. Repeat this procedure for two other areas (four other data points) on the force vs. time plots. In the Data Table record the force values.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P12: Newton's Third Law – Collision and Tug-of-War

What Do You Think?

What forces act on two carts as they interact during a collision?

Data Tables

Trial	Impulse (Channel A)	Impulse (Channel B)	Notes
#1			
#2			
#3			
#4			
#5			

Force (Channel A)	Force (Channel B)

Questions

1. Which cart experiences more force when one of them is not moving?

2. Which cart experiences more force when both carts are moving and have unequal masses?

3. What is the overall effect of the cart's velocity on the measured force?

4. What is the effect of the mass of a cart on the force it experiences?

Optional

- Repeat Part IIIA, however, instead of using the magnetic bumpers, use the hook attachment on one Force Sensor. Put the cup shaped bumper on the other Force Sensor, and apply a small piece of stick clay to the cup shaped bumper. Make the sticky clay into a cone shape. Start data recording and push the carts towards each other. The hook should stick into the clay, creating an inelastic collision.
- Integrate the area under the force vs. time plots as described in the analysis section. Record your results below.

Impulse (Channel A)	Impulse (Channel B)	Notes

Optional Question

1. How did changing the collision from elastic to inelastic affect the outcome?

Name ______________________ Class _______________ Date __________

Activity P13: Buoyant Force (Force Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Archimedes' Principle	P13 Buoyant Force.DS	P18 Buoyant Force	P18_BUOY.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Economy Force Sensor (CI-6746)	1	**Mass and Hanger Set (ME-9348)**	1
Base and Support Rod (ME-9355)	1	Ruler, metric	1
Beaker, 1000 mL	1	**String (SE-8050)**	1 m
Calipers (SF-8711)	1	**Support rod (ME-8736)**	1
Clamp, right-angle (SE-9444)	1		
Cylinder, w/ hook (from ME-8569)	1	**Other**	**Qty**
Graduated cylinder	1	Water	800 mL
Lab Jack (SE-9373)	1	*Vegetable oil (optional)*	800 mL

What Do You Think?

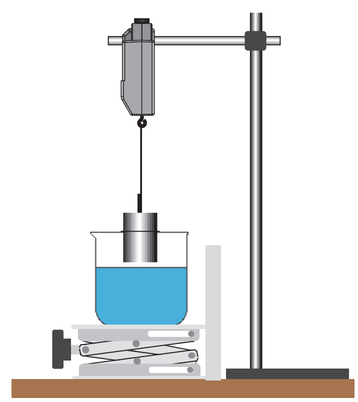
Why is it easy to float in the ocean? In which would you feel a stronger buoyant force: a swimming pool filled with oil or with syrup?

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

Background

Archimedes' Principle states that the buoyant upward force on an object entirely or partially submerged in a fluid is equal to the weight of the fluid displaced by the object.

$$F_b = m_f g = \rho_f V g$$



where ρ_f is the density of the fluid, V is the submerged volume of the object, and g is the acceleration due to gravity.

The submerged volume is equal to the cross-sectional area, A, multiplied by the submerged height, h. So the buoyant force can be written as:

$$F_b = \rho_f (Ah) g$$

If the object is lowered into the fluid while the buoyant force is measured, the slope of the graph of F_b versus h is proportional to the density of the fluid.

SAFETY REMINDER

- Follow the directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the Force Sensor to measure the force on an object as it is lowered into water. Use 'Keyboard Sampling' to enter the depth values. Use *DataStudio or ScienceWorkshop* to plot the force versus submerged depth to obtain the density of the fluid.

PART I: Computer Setup

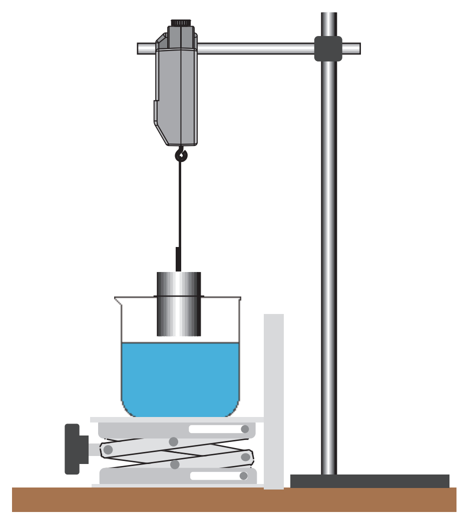
1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the DIN plug of the Force Sensor to Analog Channel A.
3. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P13 Buoyant Force.DS	P18 Buoyant Force	P18_BUOY.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display with Force versus Depth.
- Data recording is set for 1 Hz. Keyboard Sampling allows the user to enter the submerged depth in meters.

PART II: Sensor Calibration and Equipment Setup

- To calibrate the Force Sensor, refer to the description in the Force Sensor Manual.



1. Mount the Force Sensor on a horizontal rod with the hook end down.
2. Using the calipers, measure the diameter of the metal cylinder. From the diameter, calculate the radius and the cross-section area. Record the cross-section area in the Data Table in the Lab Report section. Recall:

$$A = \pi R^2$$

3. Hang the metal cylinder from the Force Sensor hook with a string.
4. Put about 800 mL of water into the beaker and place the beaker on the lab jack below the hanging cylinder. The bottom of the cylinder should be touching the water.
5. Position the metric ruler next to the edge of the lab jack. Note the initial height of the top of the lab jack.

Name ____________________ Class _____________ Date ________

PART III: Data Recording

- Before recording data for later analysis, you may wish to practice using keyboard sampling to collect data.

1. With the cylinder attached to the Force Sensor hook, press the <u>tare</u> button on the Force Sensor to zero the sensor.
2. Record Force vs. Depth data as you submerge the cylinder.

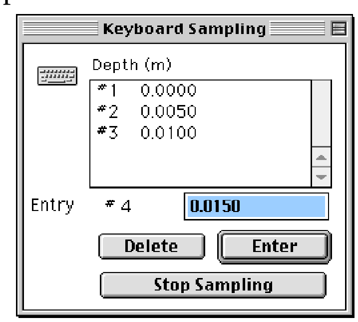
<u>In *DataStudio*</u>, move the Table display so you can see it clearly.

- Click on the ‘Start’ button to start recording data. The ‘Start’ button changes to a ‘Keep’ and a ‘Stop’ button (

). The Force will appear in the first cell in the Table display. Click the ‘Keep’ button to record the force value.
- Immerse the cylinder 5 millimeters (5 mm or 0.005 m) by <u>raising</u> the beaker of water 5 mm with the lab jack. Use the metric ruler to measure the distance that you raise the lab jack.
- Click the Keep button to record the next Force value at the depth of **0.005** m.
- Increase the depth of submersion by increments of 5 mm. After each increase in the submersion, wait for the force reading in the display to stabilize, then click the Keep button to record a Force value at the appropriate depth.
- Repeat the data recording procedure until the top of the cylinder is submerged. Stop data recording by clicking on the ‘Stop’ button. Run #1 will appear in the Summary window.

<u>In *ScienceWorkshop*</u>, click the ‘REC’ button to begin collecting data.

- The ‘Keyboard Sampling’ window will open. Move it so you can also see the Digits display. The default value for ‘Entry #1’ is 10.000.
- Because the cylinder is not submerged, type in ‘0’ as the depth. Click ‘Enter’ to record the depth and force values. The entered depth value will appear in the Data list.



- Immerse the cylinder 5 millimeters (5 mm or 0.005 m) by <u>raising</u> the beaker of water 5 mm with the lab jack. Use the metric ruler to measure the distance that you raise the lab jack.
- For ‘Entry #2’, type in ‘0.005’ (5 millimeters). Click ‘Enter’ to record the depth and force values.
- Increase the depth of submersion by increments of 5 mm. After each increase in the submersion, wait for the force reading in the Digits display to stabilize, then click the Enter button to record a Force value at the appropriate depth.
- Repeat the data recording procedure until the top of the cylinder is submerged. Stop data recording by clicking the ‘Stop Sampling’ button in the ‘Keyboard Sampling’ window.
- The ‘Keyboard Sampling’ window will disappear. ‘Run #1’ will appear in the Data List in the Experiment Setup window.

Analyzing the Data

1. Determine the slope of the Force vs. Depth Graph.

- In *DataStudio*, click the 'Scale to Fit' button ( ) to rescale the Graph axes to fit the data. Next, click the 'Fit' menu button ( ). Select 'Linear'.
- In *ScienceWorkshop*, click the 'Autoscale' button ( ) to rescale the Graph axes to fit the data. Click the 'Statistics' button to open the Statistics area on the right side of the Graph. In the Statistics area, click the Statistics Menu button ( ). Select 'Curve Fit, Linear Fit' from the Statistics Menu.

2. Record the slope of the linear fit in the Data Table in the Lab Report section.
3. Calculate the density of water by setting the slope equal to $\rho A g$ and solving for ρ. Record the value for the density in the Data Table in the Lab Report section.
4. Compare the calculated value to the accepted value by calculating the percent difference.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P13: Buoyant Force

What Do You Think?

Why is it easy to float in the ocean? In which would you feel a stronger buoyant force: a swimming pool filled with oil or with syrup?

Data Table

Item	Value
Area of Cylinder	
Slope (from graph)	
Density of water (calculated)	
Density of water (accepted)	

Questions

1. How does your experimental value compare to the accepted value for the density of water? What is the percent difference?

2. Why was the Force Sensor zeroed after the cylinder was attached to the hook?

Optional

Substitute vegetable oil for the water in the beaker and repeat the experiment. Compare the result for the density of oil to a value calculated by weighing a known volume of oil.

Data Table

Item	Value
Area of Cylinder	
Slope (from graph)	
Density of oil (from slope)	
Mass of beaker	
Mass of beaker and oil	
Volume of oil	
Density of oil (mass/volume)	

Optional Questions

1. How does the experimental value for the density of oil compare to the value determined by the mass/volume method? What is the percent difference?

2. Is vegetable oil less, more, or equally as dense as water?

Name ____________________ Class _____________ Date _________

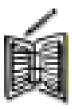
Activity P14: Simple Harmonic Motion - Mass on a Spring (Force Sensor, Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Harmonic motion	P14 SHM.DS	P19 SHM Mass on a Spring	P19_MASS.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Economy Force Sensor (CI-6746)	1	**Mass and Hanger Set (ME-9348)**	1
Motion Sensor (CI-6742)	1	Meter stick	1
Balance (SE-8723)	1	**Support 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		

What Do You Think?

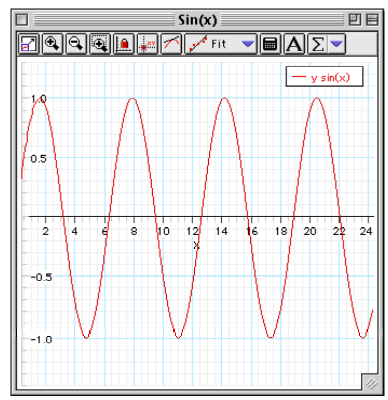
What is the motion of a mass oscillating on a spring? What other motions can you think of that are similar?



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

Background

A spring that is hanging vertically from a support with no mass at the end of the spring has a length L (called its rest length). When a mass is added to the spring, its length increases by ΔL. The equilibrium position of the mass is now a distance L + ΔL from the spring's support. What happens when 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 displaced from equilibrium and **k** is the force constant of the spring (also called the 'spring constant'). 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 depends on the mass and the spring constant.



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

As the mass oscillates, the energy continually interchanges between kinetic energy and some form of potential energy. If friction is ignored, the total energy of the system remains constant.

SAFETY REMINDER

- Follow the directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

Pre-Lab For You To Do

In the Pre-lab use the Force Sensor to measure the weight of a hanging mass. Use 'Keyboard Sampling' to enter the displacement of the spring from equilibrium. Use *DataStudio or ScienceWorkshop* to determine the spring constant k for the spring.

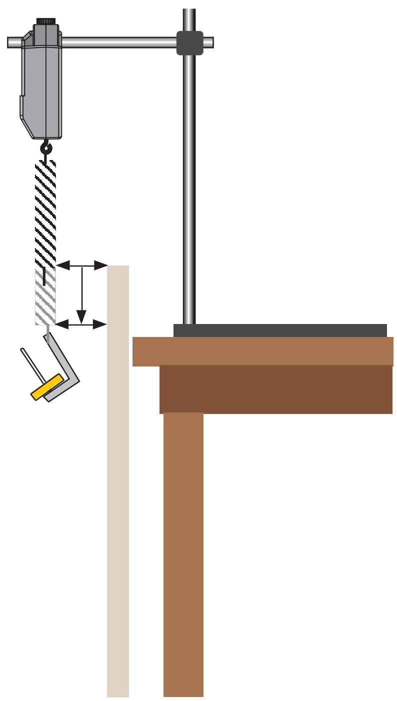
Pre-Lab PART I: Computer Setup

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

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P14 Prelab SHM.DS	X19 Spring Constant	X19_SPNG.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Force versus Stretch and a Digits display of Force.
- Data recording is set for 5 Hz. Use 'Keyboard Sampling' to enter the distance stretched in meters.

Pre-Lab PART II: Sensor Calibration and Equipment Setup



- To calibrate the Force Sensor, refer to the description in the Force Sensor Manual.

1. Using the rod and support stand, the clamp, and the second rod, 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). For your reference, record this measurement as the spring's equilibrium position in the Data Table in the Lab Report section.

Name ____________________ Class _____________ Date _________

Pre-Lab PART II: Data Recording

1. Press the tare button on Force Sensor to zero the Force Sensor.
2. Start data recording. The program will begin Keyboard Sampling. Enter **0.000** in units of meters (m) because the spring is unstretched.

In *DataStudio*, move the Table display so you can see it clearly.

- Click on the 'Start' button to start recording data. The 'Start' button changes to a 'Keep' and a 'Stop' button (). The Force will appear in the first cell in the Table display. Click the 'Keep' button to record the force value.

In *ScienceWorkshop*, click the 'REC' button to begin collecting data.

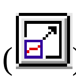
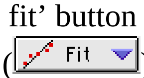
- The 'Keyboard Sampling' window will open. Move it so you can also see the Digits display. The default value for 'Entry #1' is 10.000. Type in '0' as the stretch. Click 'Enter' to record the stretch and force values. The entered stretch value will appear in the Data list.

3. Add 20 grams of mass to the end of the spring (be sure to include the mass of the hanger).
4. Measure the new position of the end of the spring. Enter the difference between the new position and the equilibrium position as the $\Delta \mathbf{x}$, 'Stretch' (in meters), and record a Force value for this Stretch value by clicking on 'Keep' in *DataStudio*, or 'Enter' in *ScienceWorkshop*.
5. Add 10 grams to the spring (for a total of 30 g additional mass). Measure the new position of the end of the spring, enter the stretch value and click 'Keep' or 'Enter' to record the force value.
6. Continue to add mass in 10 gram increments until you have added 70 grams. Each time you add mass, measure and enter the new displacement value from equilibrium. Click 'Keep' in *DataStudio*, or 'Enter' in *ScienceWorkshop* to record the force value.
7. End data recording.

- In *DataStudio*, stop data recording by clicking on the 'Stop' button.
- In *ScienceWorkshop*, stop data recording by clicking the 'Stop Sampling' button in the Keyboard Sampling window.
- The data will appear as Run #1.

Pre-Lab Analyzing the Data

1. Determine the slope of the Force vs. Stretch Graph.

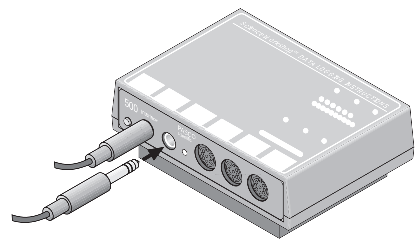
- In *DataStudio*, click the 'Scale to fit' button () to rescale the Graph axes to fit the data. Next, click the 'Fit' menu button (). Select 'Linear'.
- In *ScienceWorkshop*, click the 'Autoscale' button () to rescale the Graph axes to fit the data. Click the 'Statistics' button to open the Statistics area on the right side of the Graph. In the Statistics area, click the Statistics Menu button (). Select 'Curve Fit, Linear Fit' from the Statistics Menu.

2. Record the slope of the linear fit in the Data Table in the Lab Report section.

For You To Do

Use the Motion Sensor to record the motion of a mass on the end of the spring. Use *DataStudio or ScienceWorkshop* to determine the period of oscillation and compare the value to the theoretical period of oscillation.

PART I: Computer Setup



1. Unplug the Force Sensor's DIN plug from the interface.
2. Connect the Motion Sensor's stereo phone plugs into Digital Channels 1 and 2 of the interface. Plug the yellow-banded (pulse) plug into Digital Channel 1 and the second plug (echo) into Digital Channel 2.
3. Open the document titled as shown:

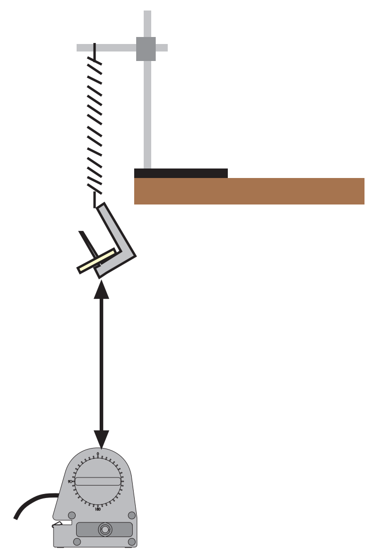
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P14 SHM.DS	P19 SHM Mass on a Spring	P19_MASS.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Position and Velocity vs. Time.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Motion Sensor.

1. Using a support rod and clamp, suspend the spring so that it can move freely up-and-down. Put a mass hanger on the end of the spring.



2. 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 in the Data section. Return the hanger and masses to the end of the spring.
4. Place the Motion Sensor on the floor directly beneath the mass hanger.
5. Adjust the position of the spring so that the minimum distance from the mass hanger to the Motion Sensor is greater than the Motion Sensor's minimum distance at the maximum stretch of the spring.

Name ____________________ Class ______________ Date _________

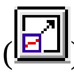
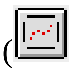
PART III: Data Recording

1. Pull the mass down to stretch the spring about 20 cm. Release the mass. Let it oscillate a few times so the mass hanger will move up-and-down without much side-to-side motion.
2. Begin recording data.
3. The plots of the position and velocity of the oscillating mass will be displayed. Continue recording for about 10 seconds.
4. End data recording.

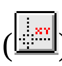
- The data will appear as 'Run #1'.
- The position curve should resemble the plot of a sine function. If it does not, check the alignment between the Motion Sensor and the bottom of the mass hanger at the end of the spring. You may need to increase the reflecting area of the mass hanger by attaching a circular paper disk (about 2" diameter) to the bottom of the mass hanger.
- To erase a run of data, select the run in the Data list and press the "Delete" key.

Analyzing the Data

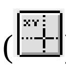
1. Rescale the Graph axes to fit the data.

- In *DataStudio*, click on the 'Scale to Fit' button ().
- In *ScienceWorkshop*, click on the 'Autoscale' button ().

2. Find the average period of oscillation of the mass.

In *DataStudio*, click the 'Smart Tool' button ().

- Move the Smart Tool to the first peak in the plot of position versus time and read the value of time. Record the value of time in the Data Table in the Lab Report section.
- Move the Smart Tool to each consecutive peak in the plot and record the value of time shown for each peak.

In *ScienceWorkshop*, in the Graph display, click the 'Smart Cursor' ().

- Move the Smart Cursor to the first peak in the plot of position versus time and read the value of time (shown below the horizontal axis). Record the value of time in the Data Table in the Lab Report section.
- Move the Smart Cursor to each consecutive peak in the plot and record the value of time shown below the horizontal axis for each peak.

3. Find the period of each oscillation by calculating the difference between the time for each successive peak. Find the average of the periods. Record your result in the Data Table.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P14: Simple Harmonic Motion - Mass on a Spring

What Do You Think?

What is the motion of a mass oscillating on a spring? What other motions can you think of that are similar?

Pre-Lab Data Table

Item	Value
Equilibrium Position	
Spring Constant (slope)	

Data Table

Mass = ___________kg

Peak	1	2	3	4	5	6	7
Time (s)							
Period (s)							

Average period of oscillation = ________sec

Questions

1. Calculate the theoretical value for the period of oscillation based on the measured value of the spring constant of the spring and the mass on the end of the spring.

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

2. How does your calculated value for oscillation compare to the measured value of the period of oscillation? What is the percent difference?

3. When the position of the mass is farthest from the equilibrium position, what is the velocity of the mass?

4. When the absolute value of the velocity of is greatest, where is the mass relative to the equilibrium position?

Name ____________________ Class _____________ Date _________

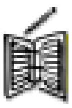
Activity P15: Simple Harmonic Oscillation (Force Sensor, Photogate)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Harmonic motion	P15 Oscillation.DS	P21 Harmonic Oscillation	P21_HARM.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Economy Force Sensor (CI-6746)	1	Picket fence for cart (648-04704)	1
Photogate/Pulley System (ME-6838)	1	*Meter stick (optional)*	1
Balance (SE-8723)	1	Photogate Bracket (003-04662)	1
Base and Support Rod (ME-9355)	1	Spring, k ~ 2 - 4 N/m (inc. w/ Track)	2
Collision Cart (inc. w/ Track)	1	1.2 m Track System (ME-9429A)	1

What Do You Think?

Is there any way to determine how often an object on a spring will bounce up and down? Does it matter how heavy the object is? Does it matter how stiff or soft the spring is? Explain.

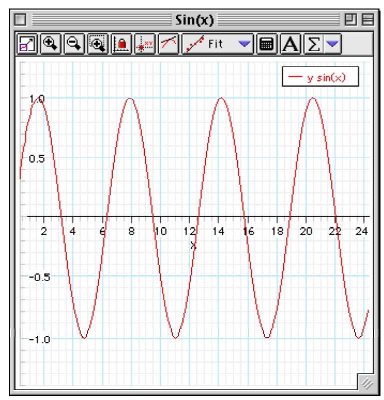


Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background

For an object with mass m attached to a single spring, the theoretical period of oscillation is given by:

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



where T is the time for one complete back-and-forth motion (i.e., one cycle), m is the mass of the object that is oscillating, and k is the spring constant.

The direction of the force and the direction of the distance stretched are opposite (e.g., if the stretch is to the right, the force of the spring is to the left.) As described by Hooke's Law, the force exerted by the spring is proportional to the distance the spring is compressed or stretched from its equilibrium position (i.e., F = -kx), where k is the proportionality or "spring" constant.

The spring constant can be experimentally determined by applying different forces to stretch the spring different distances. When the force is plotted versus the distance stretched, the slope of the resulting straight line is equal to the spring constant, 'k'.

This activity uses two springs; one end of each spring is attached at each end of an object, and the other end of each spring is attached to fixed supports. For an object of mass m between two springs with spring constants k_1 and k_2, the period of oscillation is:

$$T = 2\pi\sqrt{\frac{m}{k_1 + k_2}}$$

SAFETY REMINDER

- Follow the directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

Pre-Lab For You To Do

In the Pre-lab use the Force Sensor to measure the weight of a hanging mass. Use 'Keyboard Sampling' to enter the displacement of the spring from equilibrium. Use *DataStudio or ScienceWorkshop* to determine the spring constants k_1 and k_2 for the springs.

Pre-Lab PART I: Computer Setup

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

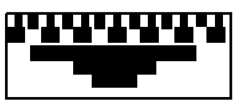
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P15 Prelab Oscillation.DS	X21 Spring Constant	X21_HARM.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Force versus Stretch and a Digits display of Force.
- Data recording is set for 5 Hz. Keyboard Sampling allows the user to enter the distance stretched in meters.

Pre-Lab PART II: Sensor Calibration and Equipment Setup

- To calibrate the Force Sensor, refer to the description in the Force Sensor Manual.

1. Put the five-pattern picket fence into the slots of the accessory tray on top of the Dynamics Cart. Put the picket fence on the cart so the 2.5-centimeter opaque band is at the top.



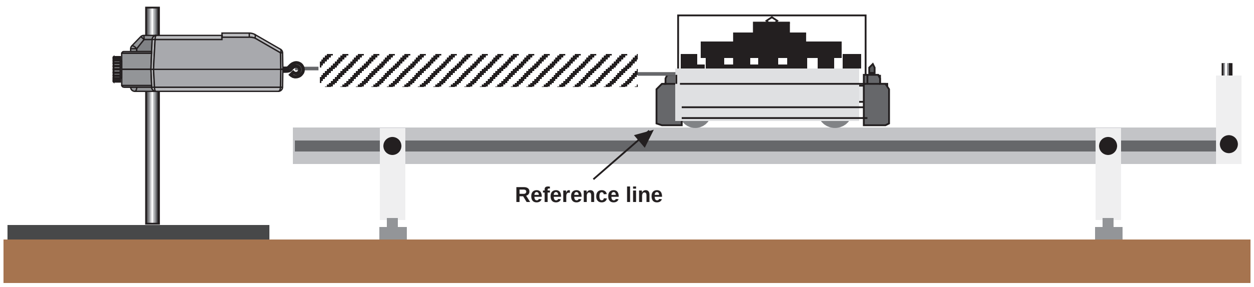
Five-pattern picket fence

Edge-to-edge spacing: 1 cm or 2 cm
Band lengths: 10 cm, 5 cm, or 2.5 cm

2. Measure the mass of the cart plus picket fence. Record the mass in the Data Table.
3. Put the Adjustable Feet on both ends of the 1.2 meter Dynamics Track and place the Dynamics Track on a horizontal surface. Put the cart near the middle of the Dynamics Track and level the Dynamics Track by raising or lowering one end so the cart will not roll one way or the other.
4. Put one end-stop at the right end of the Dynamics Track.
5. Mount the Force Sensor horizontally on a support rod and base. Position the Force Sensor at the left end of the Dynamics Track so the hook is even with the end of the Dynamics Track and is at the same height as the top of the end-stop that is at the right end of the Dynamics Track.

6. Connect springs to both ends of the Dynamics Cart. Use the small holes that are on the top of the black plastic end caps. Connect the spring on the <u>left</u> end of the cart to the Force Sensor's hook. Lay the other spring in the accessory tray on top of the cart.
7. Pull the cart away from the Force Sensor so the left end of the cart is 20 centimeters from the end of the Force Sensor. This should stretch the spring slightly. Hold the cart in place. Put a mark on the Dynamics Track to indicate the initial setup position of the left end of the cart.

- Use the mark as a reference line during the data recording process.



Pre-Lab PART III: Data Recording

1. Press the tare button on Force Sensor to zero the Force Sensor.
2. Start data recording. The program will begin Keyboard Sampling. Enter **0.000** in units of meters (m).

<u>In *DataStudio*</u>, move the Table display so you can see it clearly.

- Click on the 'Start' button to start recording data. The 'Start' button changes to a 'Keep' and a 'Stop' button (). The Force will appear in the first cell in the Table display. Click the 'Keep' button to record the force value.

<u>In *ScienceWorkshop*</u>, click the 'REC' button to begin collecting data.

- The 'Keyboard Sampling' window will open. Move it so you can also see the Digits display. Type in '0' as the stretch. Click 'Enter' to record the stretch and force values. The entered stretch value will appear in the Data list.

3. Pull the cart 2 additional centimeters (0.02 meters) away from the Force Sensor. Use the mark on the Dynamics Track at the left end of the cart as your reference line. Hold the cart at the new position.
4. Enter 0.02 m in the software. Record a Force value for your second Stretch position by clicking 'Keep' in *DataStudio*, or 'Enter' in *ScienceWorkshop*.
5. Pull the cart so it is 4 centimeters (0.04 m) away from the reference line and hold the cart at the new position. Enter 0.04 m in the software. Record a Force value at this position.
6. Continue to move the cart in 2-cm increments until the left edge of the cart is 24 cm from the reference line. Enter the stretch and record a Force value at each new position.
7. End data recording.

- In *DataStudio*, stop data recording by clicking on the 'Stop' button.
- In *ScienceWorkshop*, stop data recording by clicking the Stop Sampling button in the Keyboard Sampling window.
- The data will appear as Run #1.

8. When you are finished, do not let go of the cart. Move the cart gently toward the Force Sensor until the spring is not stretched.
9. Disconnect the first spring from the Force Sensor's hook. Turn the cart around.
10. Connect the second spring to the Force Sensor's hook. Lay the first spring in the accessory tray on top of the cart, but don't disconnect it from the cart.
11. Repeat the data recording process for the second spring.

Pre-Lab Analyzing the Data

1. Determine the slope of the Force vs. Stretch Graph.

- In *DataStudio*, select Run #1 from the Data Menu () in the Graph display. If multiple data runs are showing, first select 'No Data' from the Data Menu and then select Run #1. Click the "Scale to fit" button () to rescale the Graph axes to fit the data. Next, click the 'Fit' menu button (). Select 'Linear'.
- In *ScienceWorkshop*, select Run #1 from the Data Menu () in the Graph display. If multiple data runs are showing, first select No Data from the Data Menu and then select Run #1. Click the 'Autoscale' button () to rescale the Graph axes to fit the data. Click the 'Statistics' button to open the Statistics area on the right side of the Graph. In the Statistics area, click the Statistics Menu button (). Select 'Curve Fit, Linear Fit' from the Statistics Menu.

2. Record the slope of the linear fit in the Data Table in the Lab Report section as k_1.
3. Repeat the analysis for Run #2 and record the slope for k_2 in the Data Table.

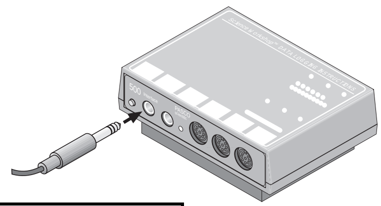
For You To Do

Use the Photogate to measure the motion of a cart that is oscillating back-and-forth as it is pulled by springs attached at each end of the cart. The *DataStudio* or *ScienceWorkshop* program calculates and displays the period of oscillation. The measured period is compared to the theoretical period.

Name ____________________ Class ______________ Date _________

PART I: Computer Setup

1. Unplug the Force Sensor's DIN plug from the interface.
2. Connect the Photogate digital plug to Digital Channel 1 on the interface.
3. Open the document titled as shown:



DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P15 Oscillation.DS	P21 Harmonic Oscillation	P21_HARM.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Table display of period.
- Data recording is set at 10 kHz.

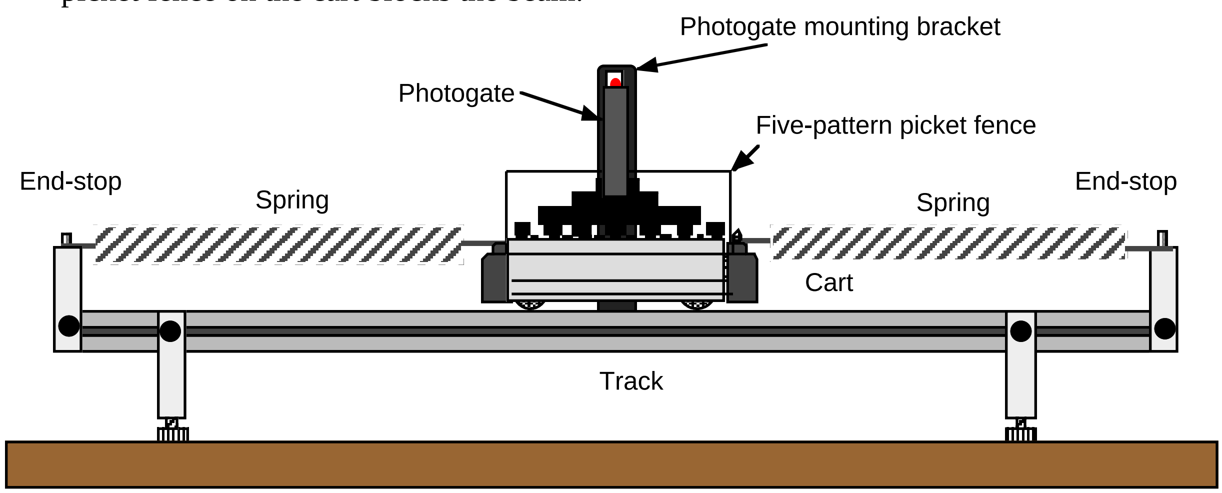
PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Photogate.

1. Disconnect the spring on the left end of the cart from the Force Sensor's hook. Remove the Force Sensor and its support rod and base.
2. Put an end stop on the left end of the Dynamics Track.
3. Connect the unattached end of each spring to the peg on top of an end stop.

- When the springs are attached at opposite ends of the Dynamics Track, the cart should be near the middle of the Dynamics Track.

4. Attach the Photogate to the Photogate Mounting Bracket. Mount the bracket on the side of the Dynamics Track.
5. Position the bracket so the Photogate is aligned with the center of the cart when the cart is at rest near the middle of the Dynamics Track.
6. Adjust the height of the Photogate so the 2.5-centimeter opaque band at the top edge of the picket fence on the cart blocks the beam.



PART III: Data Recording

1. Pull the cart about 25 centimeters from its equilibrium position at the middle of the Dynamics Track.
2. Begin recording data
3. Release the cart so that it can move back-and-forth through the Photogate.
4. After the cart completes eight or nine oscillations, end data recording.

¥ The data will appear as ‘Run #1’.

5. Measure the mass of the cart’s extra mass bar. Record the mass in the Data section.
6. Add the extra mass bar to the cart. Repeat the data recording process as described above.

- The data will appear as ‘Run #2’.

Analyzing the Data

1. From the Table display, determine the mean of the Period for Run #1, and record this in the Data Table.

- In the Force Table, click on the statistics button Σ.

2. Find the mean of the Period for Run #2, and record this value in the Data section.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P15: Simple Harmonic Oscillation

What Do You Think?

Is there any way to determine how often an object on a spring will bounce up and down? Does it matter how heavy the object is? Does it matter how stiff or soft the spring is? Explain.

Pre-Lab Data Table

Mass of Cart and Picket Fence = _________kg

Item	Value
Spring Constant k_1 (slope)	
Spring Constant k_2 (slope)	

Data Table

Mass of Mass Bar = _________kg

Item	Value
Period (cart)	
Period (cart with mass bar)	

Questions

1. Calculate the theoretical period using the values of the spring constants and the mass of the cart and picket fence. Recall:

$$T = 2\pi\sqrt{\frac{m}{k_1 + k_2}}$$

2. What is the percent difference between the measured and theoretical values for the period?

3. Calculate the theoretical period for Run #2 using the values of the spring constants and the mass of the cart and picket fence and mass bar.

4. What is the percent difference between the measured and theoretical values for the period?

5. Does the period of oscillation increase or decrease as the mass is increased?

6. Is the spring constant value, k, the same for a spring when the spring is vertical as when the spring is horizontal? How can you test this?

Optional

- Change the initial displacement of the cart from equilibrium (for example, try 15 cm) and repeat the data collection and analysis.

Optional Question

1. How does the period of oscillation change?

Amplitude = cm	Mass (kg)	Period (s)	Theoretical (s)	% difference
Cart alone				
Cart plus mass				

Amplitude = cm	Mass (kg)	Period (s)	Theoretical (s)	% difference
Cart alone				
Cart plus mass				

Name ____________________ Class _____________ Date _________

Activity P16: Heat versus Temperature (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	P16 Heat v Temperature.DS	G22 Heat v. Temperature	G22_TEMP.SWS

Equipment Needed	Qty	Other	Qty
Temperature Sensor (CI-6505A)	1	Styrofoam cup with lid	1
Graduated cylinder, 100 mL	1	Water	300 mL
Heating resistor, 10 Ω, 1 W	1		
Power Supply, DC, 10 W (SE-9720)	1		
Protective gear	1 set		

(*such as the heating resistor that is part of the PASCO CI-6514 Thermodynamics Kit)

What Do You Think?

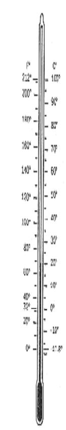
What is the relationship between **heat**, **thermal energy**, and **temperature**?

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

Background

Heat is energy in transit between two or more objects. When the energy is inside an object, it is sometimes called internal energy or thermal energy. The **thermal energy** in an object is the total kinetic energy of all the particles that make up the object.

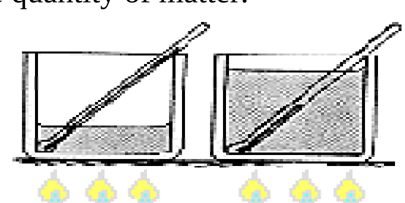
Temperature is a measure of the average kinetic energy of all the particles in the object. The number for the temperature of an object doesn't tell you much about the actual kinetic energy of a particle inside the object. The number comes from a temperature scale such as the kind found on a common thermometer.



A thermometer measures temperature by means of the expansion and contraction of a liquid, usually mercury or colored alcohol. The reason that this works is that the liquid in a thermometer expands or contracts in a predictable, repeatable way when it gains or loses thermal energy. For example, the mercury in a thermometer always expands to the same level when the end of the thermometer is in boiling water. It always shrinks to the same level when the end of the thermometer is in ice-cold water. The number on the temperature scale is a way to make comparisons. If we say that a certain liquid has a temperature of 0˚ C, it means that the mercury in a thermometer put into this liquid would shrink to the same level as it did when the thermometer was put into ice-cold water.

The amount of thermal energy in an object is related to temperature, but temperature by itself can't tell you have much thermal energy is in an object. For example, a bed of glowing coals in a fireplace might have a temperature of 600 ˚C while a single spark from the fire might have a temperature of 2000˚ C. The single "hot" spark gives off very little heat while the bed of relatively "cool" coals gives off a large amount of heat. The difference between the bed of coals and the single spark has to do with both the temperature and the quantity of matter.

Identical thermometers in two pots of water on a hot stove will show different temperatures even if the pots have been on the stove for the same time if the amount of water in one pot is different than the amount in the other.



SAFETY REMINDERS

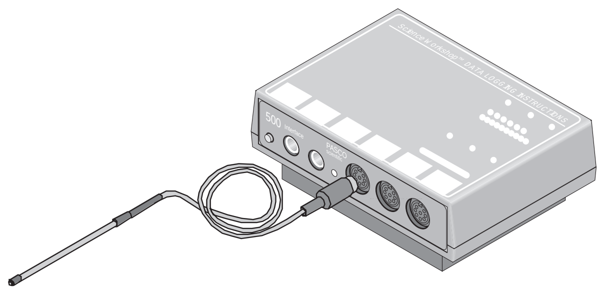
- Wear protective gear.
- Follow directions for using the equipment.
- Be sure that the heating resistor is in the water before you turn on the power supply.

For You To Do

Use the Temperature Sensor to measure the temperature of 100 mL water as a heating resistor heats it for a set amount of time. Then use the sensor to measure the temperature of 200 mL of water as the same resistor heats it for the same amount of time. Both measurements start at the same temperature.

Use *DataStudio* or*ScienceWorkshop* to record and display the data. Compare the final temperature of the 100 mL sample of water to the final temperature of the 200 mL sample of water.

PART I: Computer Setup



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

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P16 Heat v Temp.DS	G22 Heat v. Temperature	G22_TEMP.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document will open with a Graph display of Temperature versus Time, a Digits display of Temperature, and a Table display of Temperature.
- Data recording is set so there is 1 second per measurement, a ‘Start Condition’ = Channel A at 0.20 volts, and a ‘Stop Condition’ = Time at 600 seconds (or 10 minutes).

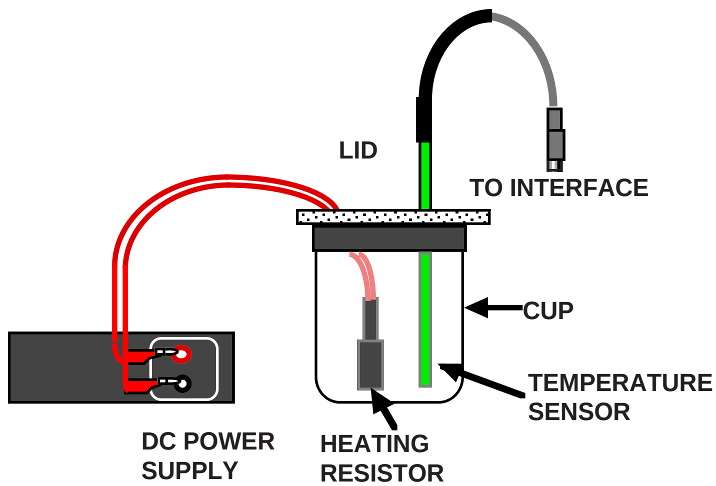
Name ____________________ Class _____________ Date _________

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.
2. Put 100 mL of water in the foam cup.

- NOTE: Start with water that is about two degrees below 20 ˚C. The program will begin recording data when the water warms up to 20 ˚C.



3. Connect the banana plugs of the heating resistor into the output jacks of the power supply.
4. Put the heating resistor through its hole in the lid. Submerge the resistor in the water.
5. Put the Temperature Sensor through its hole in the lid of the cup.

- CAUTION: Be sure the resistor is submerged in water when the current is flowing through it. Otherwise it can burn up!

PART IIIA: Data Recording – 100 mL

1. Set the DC power supply to output 10 volts at 1 amp. Turn on the power supply.
2. Start recording data (Click 'Start' or click 'REC'). Data recording begins when the temperature of the water reaches 20 ˚C.

- Watch the Digits display of the temperature.

IMPORTANT: While the power supply is ON, gently swirl the water in the cup so the water will be heated evenly.

3. Data recording stops automatically at ten minutes. When data recording stops, turn off the DC power supply.
4. Remove the sensor and heating resistor from the cup. Pour out the 100 mL of warmed water.

PART IIIB: Data Recording – 200 mL

1. Put 200 mL of water into the cup. Use water that is about two degrees below 20 ˚C.
2. Put the sensor and heating resistor back into the cup.
3. Turn on the power supply.
4. Start recording data to begin the second measurement. Data recording begins when the temperature of the water reaches 20 ˚C.
5. Watch the Digits display of the temperature.

- IMPORTANT: While the power supply is ON, gently swirl the water in the cup so the water will be heated evenly.

6. Data recording stops automatically at ten minutes. When data recording stops, turn off the DC power supply.
7. Remove the sensor and heating resistor from the cup. Pour out the 200 mL of warmed water.

Analyzing the Data

1. Set up the Graph to show statistics such as Minimum and Maximum.

- Hint: In *DataStudio*, select from the ‘Statistics’ menu. In *ScienceWorkshop,* click the ‘Statistics’ button to open the Statistics area on the right side of the Graph. Then select from the ‘Statistics Menu’ in the Statistics area.

2. Set up the Table to show statistics such as Minimum and Maximum
3. Record the Minimum and Maximum temperatures for the first run of data.
4. Record the Minimum and Maximum temperatures for the second run of data.
5. Record the amount of water used for each run.
6. Find the change in temperature for each run and record it.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P16: Heat vs. Temperature

What Do You Think?

What is the relationship between **heat**, **thermal energy**, and **temperature**?

Data Table

Item	Run #1	Run #2
Amount of Water		
Temperature (maximum)		
Temperature (minimum)		
Change in Temperature (ΔT)		

Questions

1. What is the change in temperature for the 100 mL of water in Run #1?

2. What is the change in temperature for the 200 mL of water in Run #2?

3. How does the change in temperature for Run #1 compare to the change in temperature for Run #2?

4. Did the 100 mL of water receive the same, more than, or less thermal energy than the 200 ml of water? Why?

5. Why is the final temperature for the 200 mL of water different than the final temperature for the 100 mL of water?

Name ____________________ Class ______________ Date _________

Activity P17: Pressure versus Temperature
(Pressure Sensor, Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Gas laws	P17 Pres v Temp.DS	(See end of activity)	(See end of activity)

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Pressure Sensor (CI-6532A)	1	Rubber stopper, one-hole	1
Temperature Sensor (CI-6505A)	1	Tongs	1
Base and support rod (ME-9355)	1	**Tubing, plastic (w/sensor)**	1
Beaker, 1 L	4	Protective gear	PS
Clamp, buret (SE-9446)	1		
Connector, rubber stopper (w/sensor)	1	**Other**	**Qty**
Coupling, quick-release (w/sensor)	1	Glycerin	1 mL
Flask, Erlenmeyer, 125 mL	1	Ice, crushed	1 L
Hot plate (for hot water bath)	1	Water	3 L

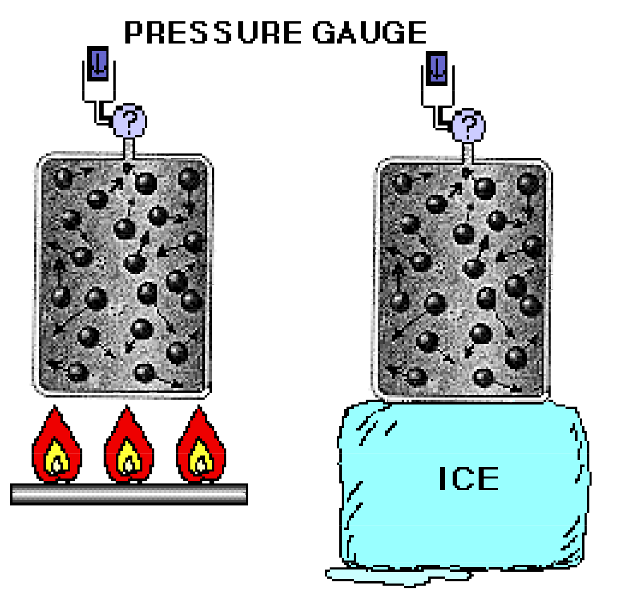
What Do You Think?

What is the relationship between the pressure of a gas and the temperature of a gas if its volume remains constant as the temperature changes? Could you use this relationship to determine the value of Absolute Zero, the theoretical limit of low temperature?

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

Background

Solid, liquid and gas are the most common states of matter found on this planet. The only difference among all these states is the amount of movement of the particles that make up the substance.



Temperature is a measure of the relative movement of particles in a substance because temperature is a measure of the average kinetic energy of the particles. At any specific temperature the total kinetic energy is constant. Particles with a large kinetic energy tend to collide frequently and move apart. Intermolecular forces tend to pull particles toward each other. The forces that bind some molecules together at a particular temperature are greater than the kinetic energy of the molecules.

In an "ideal gas" there are NO intermolecular forces. (In fact, the "Ideal gas" has no mass and occupies no volume!) While the "ideal gas" is fictional, real gases at room temperature and pressure behave as if their molecules were ideal. It is only at high pressures or low temperatures that the kinetic energy of molecules is overcome by intermolecular forces and the molecules can "grab onto" one another.

In the “ideal gas”, the volume of the gas is inversely proportional to the pressure on the gas at a constant temperature. In other words, the product of the volume and pressure for the gas is a constant when the gas is at a constant temperature.

$$P * V = k$$

For example, imagine that the gas pressure in a balloon is one atmosphere and has a volume of twelve liters. The value of k is 12 liter • atmospheres. If the balloon were to rise to a point in the atmosphere where the pressure is 0.5 atmospheres, the balloon would expand to 24 liters and the value of k is still 12 liter • atmospheres.

At the same time, the volume of a gas is directly proportional to the temperature. If a gas is heated, the volume of the gas increases. If it is cooled, the volume of the gas decreases, thus:

$$V = T \cdot k_2$$

or

$$\frac{V}{T} = k_2$$

What happens at very low temperatures? For real gases the molecules become closer, the intermolecular forces overcome kinetic energy, and the gas turns into a liquid. At still lower temperatures and higher pressures, the liquid is forced into a rigid structure we call a solid. For the “ideal gas”, the gas would continue to have a constant pressure-volume relationship. For the “ideal gas”, as the temperature decreases, the volume and the pressure of the gas also decrease. The pressure and volume maintain a constant relationship.

In this activity the volume of the gas is a constant because you will use a rigid container that will not change in volume as the temperature is changed. At a constant volume then,

P is proportional to T

or

$$P = T \cdot k_3$$

Theoretically, you can use a graph of pressure versus temperature to estimate the value of Absolute Zero by finding the temperature at which the pressure reaches zero.

SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Be very careful when you heat water.

For You To Do

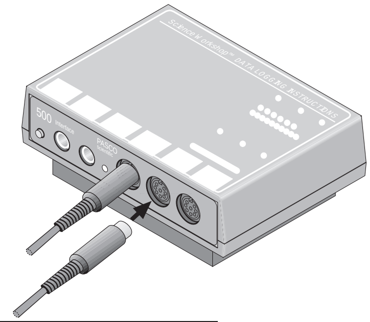
Set Up a Boiling Water Bath

- Put about 600 mL of water into a 1 L beaker and put the beaker on a hot plate. Start to heat the water to boiling. Check the water bath occasionally as you set up the rest of the equipment.

Use the Pressure Sensor to measure the pressure inside a flask and use the Temperature Sensor to measure the temperature of the water bath in which the flask is immersed. Use *DataStudio* or *ScienceWorkshop* to plot the pressure-temperature data onto a graph. Use the graph to determine the relationship of pressure and temperature and to estimate the value of Absolute Zero.

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 DIN plug of the Temperature Sensor to Analog Channel A on the interface. Connect the DIN plug of the Pressure Sensor to Analog Channel B on the interface.
3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P17 Pres v Temp.DS	(See end of activity)	(See end of activity)

- The *DataStudio* file has a Table display and a Graph display of the gas pressure and the temperature of the water bath.
- For *ScienceWorkshop*, refer to the pages at the end of this activity.
- Data recording is set at ten measurements per second (10 Hz). Use 'Manual Sampling' (*DataStudio*) or 'Keyboard Sampling' (*ScienceWorkshop*) to record the pressure and temperature data for each different temperature.

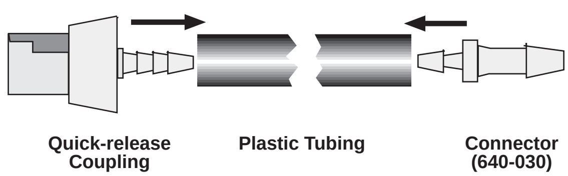
PART II: Sensor Calibration and Equipment Setup

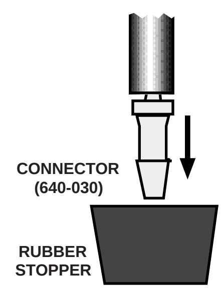
You do not need to calibrate the sensors.

Set Up the Equipment

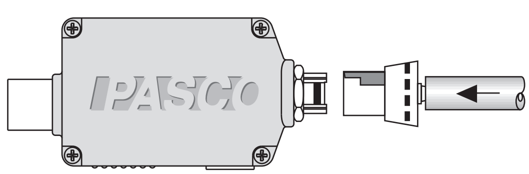
- For this part you will need the following: glycerin, quick-release coupling, connector, plastic tubing, rubber stopper, flask, and Pressure Sensor

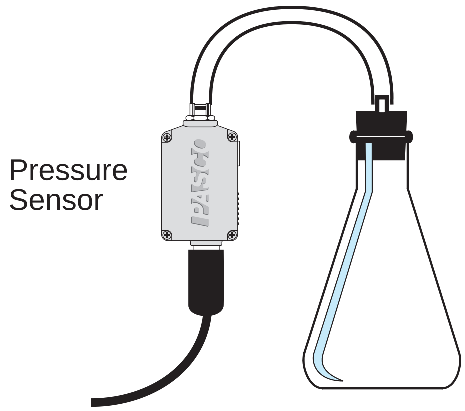
1. Put a drop of glycerin on the barb end of a quick release coupling. Put the end of the quick release coupling into one end of a piece of plastic tubing (about 15 cm) that comes with the Pressure Sensor.





2. Put a drop of glycerin on the barb end of the connector. Push the barb end of the connector into the other end of the plastic tubing.
3. Fit the end of the connector into the one-hole rubber stopper.
4. Push the rubber stopper firmly into the flask.
5. Align the quick-release coupling on the end of the plastic tubing with the pressure port of the Pressure Sensor. Push the coupling onto the port, and then turn the coupling clockwise until it clicks (about one-eighth turn).





Set Up the Other Water Baths

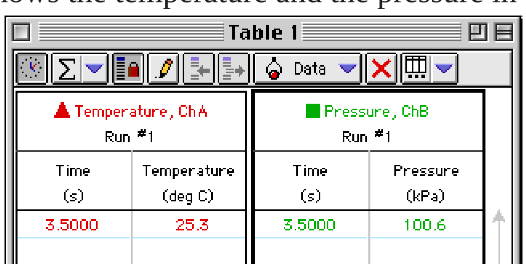
- For this part you will need the following: 1-L beakers (3), water, and ice.

1. Fill one beaker with about 600 mL of cold tap water and add ice.
2. Fill a second beaker with about 600 mL of room temperature water (approximately 20 ˚C).
3. Fill the third beaker with about 600 mL of hot tap water.

PART III: Data Recording

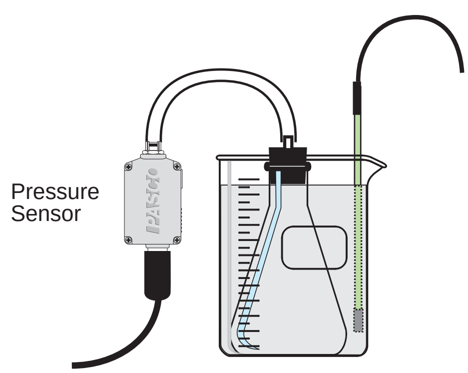
1. When you are ready, record pressure and temperature measurements.

- (Hint: For *ScienceWorkshop*, see the Appendix at the end of this write-up. In *DataStudio*, click 'Start'. The 'Start' button changes to a 'Keep' button (
))
- The Table display shows the temperature and the pressure in the first row.



2. Put the flask into the ice water bath so the flask is covered. Put the Temperature Sensor into the ice water and stir gently.
3. When the temperature and pressure values stabilize in the Table display, click 'Keep' to record the data.

- The recorded values of temperature and pressure will appear in the first row of the Table display.

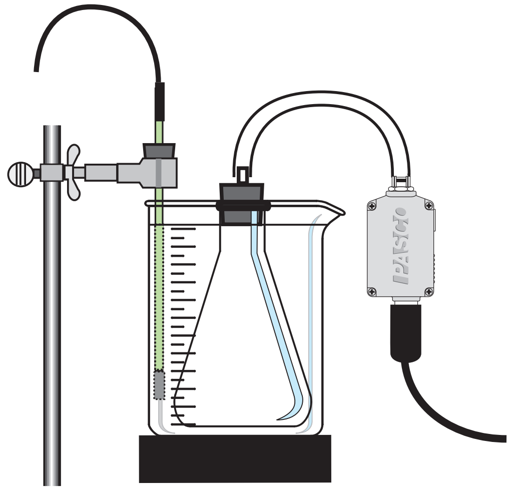


Name ____________________ Class _____________ Date ________

4. Move the flask and Temperature Sensor to the water bath with the room temperature water. Stir gently with the sensor. When the temperature and pressure values stabilize, click 'Keep'.

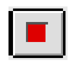
5. Repeat the process in the water bath with the hot tap water.

- For the next part, use a base and support rod, clamp, and slit stopper to hold the Temperature Sensor in the water bath with the boiling water. Use a pair of tongs to hold the flask.



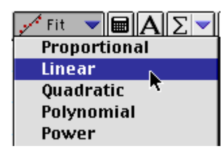
SAFETY ALERT! Be careful not to touch the beaker, the boiling water, or the hot plate.

6. When the temperature and pressure values stabilize in the Table display, click 'Keep' to record the data.

7. Stop recording data (click the  button). Turn off the hot plate. Remove the flask and sensor.

Analyzing the Data

1. Use the Graph display to determine whether or not the relationship of pressure and temperature is linear.



- Click 'Fit' and select 'Linear' from the menu.

2. Use your data to determine whether or not the relationship of pressure and temperature is direct or inverse.

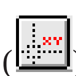
   (Hint: If the relationship is direct, the *ratio* of pressure (measured in atmospheres) to temperature (measured in Kelvins) is constant. If the relationship is inverse, the *product* of pressure and temperature is a constant. In other words, if P/T is a constant, the relationship is direct. If P•T is a constant, the relationship is inverse.)

- Convert the pressure data from kilopascals to atmospheres (1 atm = 101 kPa) and record in the Data Table. Convert the temperature data from Celsius to Kelvin (K = ˚C + 273). Record in the data table.

- Calculate the ratio of pressure (atm.) and temperature (K). Calculate the product of pressure and temperature. Compare.

3. Use the Graph display to estimate the value of Absolute Zero.

- Use the 'Zoom Out' tool () to expand your view of the Graph display. Continue to expand the view until you can see where the 'Linear' fit line crosses the negative X-axis.

- Use the 'Smart Tool' () to find the coordinates of the point where the 'Linear' fit line intersects the X-axis. The X-coordinate is the approximate value of Absolute Zero.

4. Compare your value for Absolute Zero to the accepted value (-273 ˚C).

5. Use your observations and data to answer the questions in the Lab Report.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P17: Pressure versus Temperature

What do you think?

What is the relationship between the pressure of a gas and the temperature of a gas if its volume remains constant as the temperature changes? Could you use this relationship to determine the value of Absolute Zero, the theoretical limit of low temperature?

Data Table

Water bath	Press. (kPa)	Press. (atm)	Temp. (˚C)	Temp. (K)	P/T	P•T
Ice-water						
Room temp						
Hot tap						
Boiling						

Questions

1. Is the relationship between the pressure of a gas and the temperature a linear relationship when the volume is constant?

2. Based on your data and calculations, is the relationship between the pressure and temperature direct or inverse?

3. Based on your data, what is the value of Absolute Zero?

4. How does your value of Absolute Zero compare to the accepted value (-273 ˚C)?

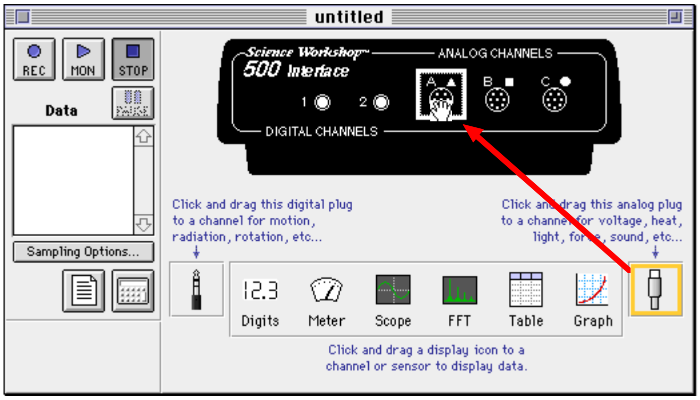
Name ____________________ Class ______________ Date _________

Appendix: Set Up *ScienceWorkshop*

Create a *ScienceWorkshop* file to measure and display temperature and pressure.

Set Up the Sensors

1. In the Experiment Setup window, click and drag the analog sensor plug to Channel A.



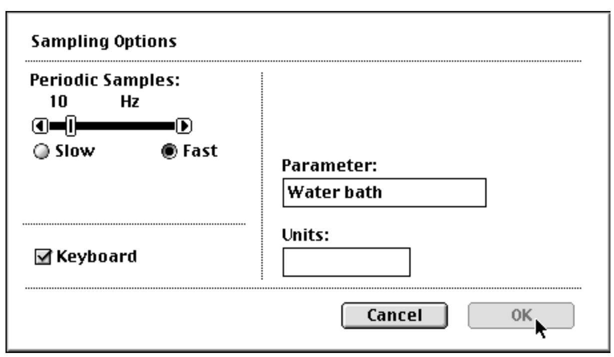
2. Select 'Temperature Sensor' from the list of sensors. Click 'OK' to return to the Experiment Setup window.

3. Repeat the process to set up the Pressure Sensor. Click and drag the analog sensor plug to Channel B. Select 'Pressure Sensor – Absolute' from the list and click 'OK' to return to the Experiment Setup window.

Set Up the Sampling Options

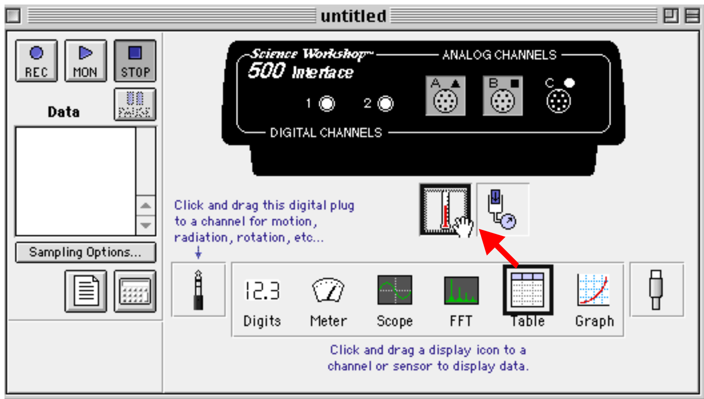
1. In the Experiment Setup window, click the 'Sampling Options…' button (or select it from the Experiment menu).

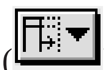
2. In the Sampling Options window, click the check box in front of 'Keyboard'. Enter 'Water bath' as the Parameter. Leave 'Units' blank. Click 'OK' to return to the Experiment Setup window.

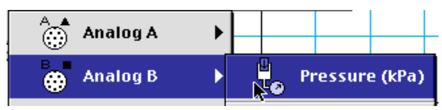


Set Up the Displays

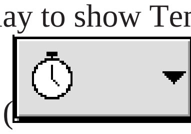
1. In the Experiment Setup window, click and drag the Table display icon to the Temperature Sensor icon.



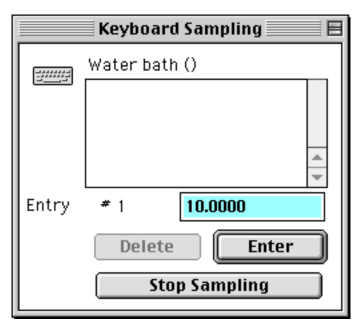
2. In the Table display, add a column for Pressure. Click the Add-a-Column menu button () and select ‘Analog B, Pressure’ from the list.



3. In the Experiment Setup window, click and drag the Digits display icon to the Temperature Sensor icon. Repeat the process to make another Digits display. Click and drag the Digits display icon to the Pressure Sensor icon.
4. In the Experiment Setup window, click and drag the Graph display icon to the Pressure Sensor icon.
5. Change the horizontal axis of the Graph display to show Temperature rather than Time.

   Click the Horizontal Axis Input menu button (). Select ‘Analog A, Temperature’ from the list.

Record Data

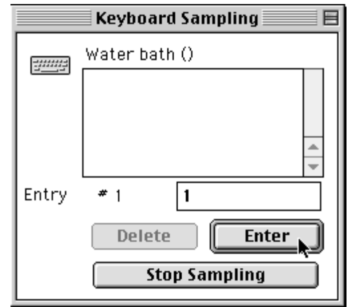


1. Set up the sensors and equipment as described earlier.
2. Put the flask and Temperature Sensor into the first water bath.
3. When you are ready, click ‘REC’ to start recording data.

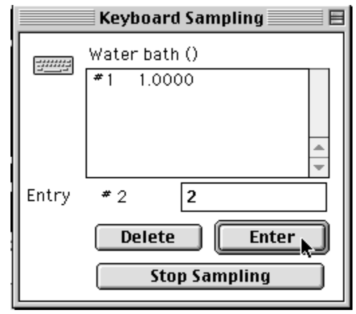
- The ‘Keyboard Sampling’ window will open. Arrange the windows so you can see the two Digits displays.

Name ____________________ Class _____________ Date _________

4. When the readings for temperature and pressure stabilize, type ‘1’ in the Keyboard Sampling window and click ‘Enter’ to record the temperature and pressure for the first water bath.

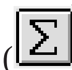
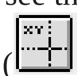


5. Move the flask to the second water bath. When the readings for temperature and pressure stabilize, type ‘2’ in the Keyboard Sampling window and click ‘Enter’ to record the temperature and pressure for the second water bath.
6. Move the flask to the third water bath. When the readings in the Digits displays stabilize, click ‘Enter’ to record the temperature and pressure for the third water bath.



7. Repeat the process for the next water bath.
8. When you are ready to stop recording data, click ‘Stop Sampling’ in the Keyboard Sampling window. The Keyboard Sampling window will automatically close.

Analyze the Data

1. Use the Graph display to determine whether or not the pressure and temperature relationship is linear. In the Graph display, click the ‘Statistics’ button () to open the Statistics area. In the Statistics area, click the ‘Statistics menu’ button () and select ‘Curve Fit, Linear Fit’ from the menu.
2. Use the Graph display to find a value for Absolute Zero. In the Graph display, use the ‘Zoom Out’ buttons () for the vertical and horizontal axes to re-scale the display until you can see the point where the ‘Linear Fit’ line crosses the X-axis. Then use the ‘Smart Cursor’ () to find the coordinates of that intersection point. The x-coordinate is shown below the label of the X-axis.
3. Compare your value for Absolute Zero to the accepted value (-273 ˚C).
4. Use your data to determine whether or not the relationship of pressure and temperature is direct or inverse.

   (Hint: If the relationship is direct, the *ratio* of pressure (measured in atmospheres) to temperature (measured in Kelvins) is constant. If the relationship is inverse, the *product* of pressure and temperature is a constant. In other words, if P/T is a constant, the relationship is direct. If P•T is a constant, the relationship is inverse.)

- Convert the pressure data from kilopascals to atmospheres (1 atm = 101 kPa) and record in the Data Table. Convert the temperature data from Celsius to Kelvin (K = ˚C + 273) and record in the data table.
- Calculate the ratio of pressure (atm.) and temperature (K). Calculate the product of pressure and temperature. Compare.

5. Use your observations and data to answer the questions in the Lab Report.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

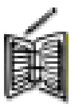
Activity P18: Boyle's Law – Pressure and Volume (Pressure Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Gas laws	P18 Boyle's Law.DS	P37 Boyle's Law	P37_BOYL.SWS

Equipment Needed	Qty	Other	Qty
Pressure Sensor (CI-6532)	1	Glycerin	1 mL
Coupling, quick-release (w/sensor)	1		
Syringe (w/sensor)	1		
Tubing (w/sensor)	1		

What Do You Think?

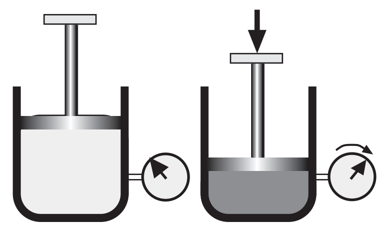
What happens to the pressure in a container of air as its volume is changed while the temperature remains constant?



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

Background

Boyle's Law states that the pressure of a gas in a container is related to the volume of the gas. In other words, as the volume changes, the pressure changes. For a given amount of a gas at a fixed temperature the pressure of the gas is inversely proportional to the volume. One way to verify this is to graph the inverse of gas volume versus gas pressure.



SAFETY REMINDERS

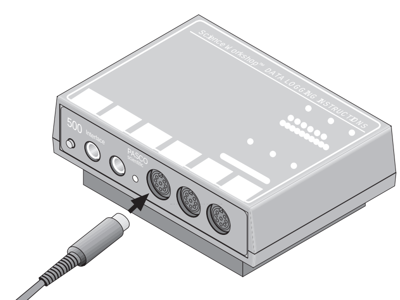
- Wear protective gear.
- Follow directions for using the equipment.

For You To Do

Use the Pressure Sensor to measure the change in pressure of the air in a syringe as you change the volume of the air in the syringe. Use *DataStudio* or *ScienceWorkshop* to record and analyze the data. Determine the relationship of pressure to volume for the air in the syringe

PART I: Computer Setup

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



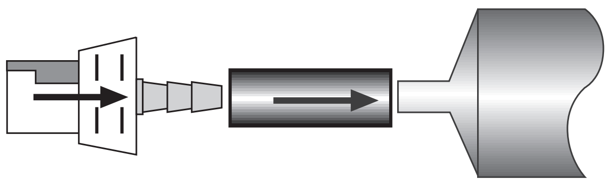
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P18 Boyle's Law.DS	P37 Boyle's Law	P37_BOYL.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Digits display of Pressure, a Graph display of Volume and Inverse Volume versus Pressure, and a Table of Pressure, Volume and Inverse Volume.
- Data recording is set for one measurement per second. Use the keyboard to enter the volume of the air inside the syringe (in milliliters).

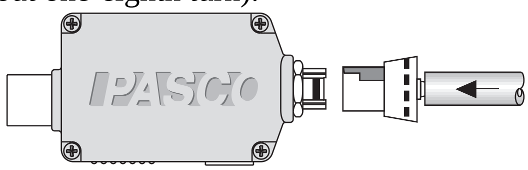
PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensor.

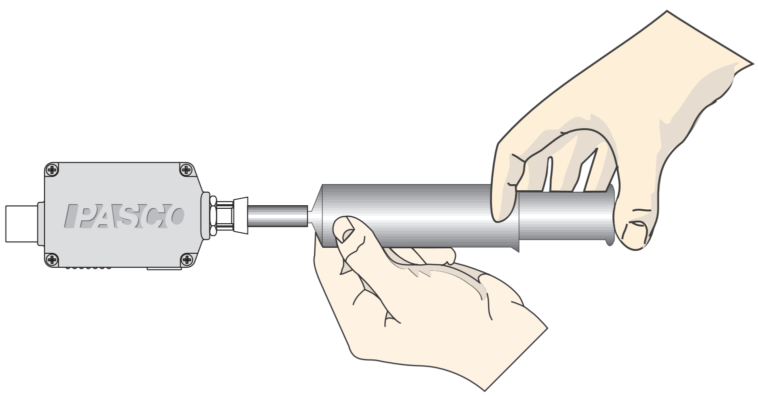
1. Put a drop of glycerin on the barb end of a quick release coupling. Put the end of the coupling into one end of a short piece (about 2.5 cm) of plastic tubing that comes with the Pressure Sensor.
2. Put a drop of glycerin on the end of the syringe. Connect the end of the syringe to the other end of the small piece of plastic tubing.



3. Align the quick-release coupling on one end of the plastic tubing with the pressure port of the Pressure Sensor. Push the coupling onto the port, and then turn the coupling clockwise until it clicks (about one-eighth turn).



4. Check that the syringe and Pressure Sensor have a secure seal by adjusting the volume between 20 mL and 10 mL. It should get harder to push as the volume decreases.

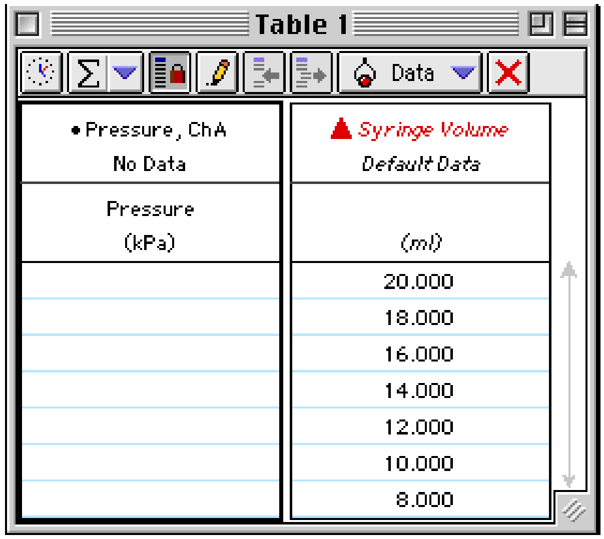


5. Adjust the volume of air in the syringe to 20.0 mL. (Note: To set the initial position of the piston in the syringe, disconnect the quick-release connector from the sensor, move the piston to the first position (20 mL), and then re-connect the quick-release connector to the sensor.)

Name ____________________ Class _____________ Date _________

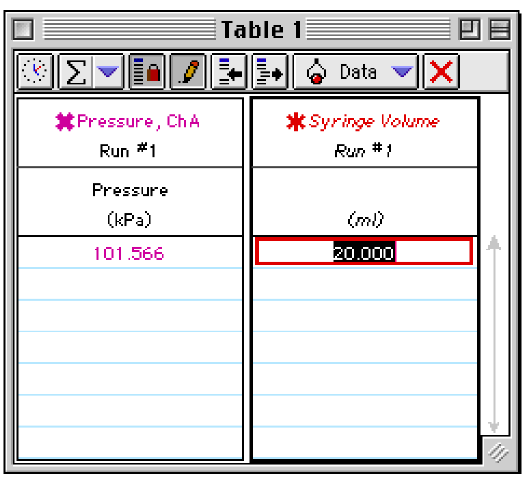
PART III: Data Recording (for *DataStudio*)

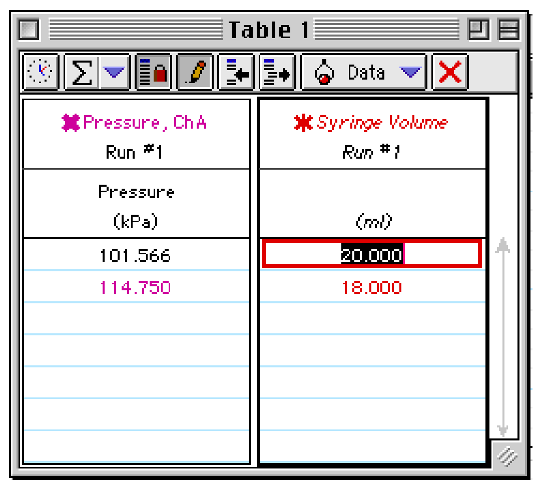
- In *DataStudio*, the Table display shows values for the gas volume in the syringe (for example, 20, 18, 16 and so on).



1. When everything is ready, start recording data. (Hint: In *DataStudio*, click ‘Start’).

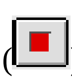
- In *DataStudio*, the ‘Start’ button changes to ‘Keep’ () and the Table display shows the value of pressure next to the first volume (20 mL).





2. Click ‘Keep’ to record the pressure.

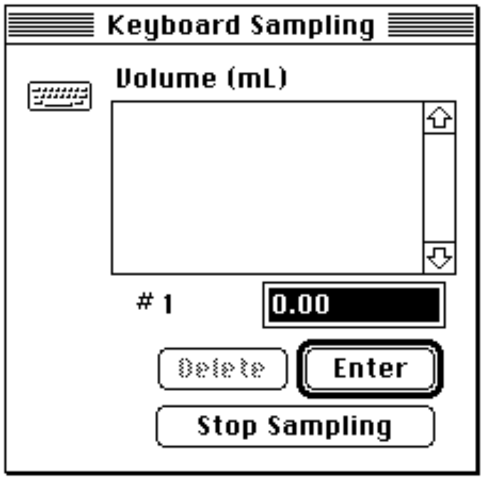
- The Table display changes to show the next value of volume (18 mL).

3. Move the piston to the 18 mL mark and click ‘Keep’ to record the pressure.
4. Continue to move the piston to each new position and then click ‘Keep’ to record the corresponding pressure.
5. After you record the pressure for the last volume, click ‘Stop’ () to end data recording.
6. If time permits, repeat the procedure.

PART III: Data Recording (for *ScienceWorkshop*)

1. In *ScienceWorkshop*, click 'REC' to start recording data.

• The Keyboard Sampling window opens.



2. When the pressure reading stabilizes, type "20" for the volume of air in the syringe and click 'Enter' to record the pressure.
3. Reduce the volume to 18 mL. Type 18 for the volume and click 'Enter'. (Note: *ScienceWorkshop* will prompt you for the third volume based on the pattern of the first two volumes.)
4. Continue reducing the volume by 2.0 mL each time, checking the pressure, and entering the new volume until your last entered volume is 10.0 mL.
5. After you enter the last volume, click 'Stop Sampling' to end data recording.
6. If time permits, repeat the procedure.

Analyzing the Data

1. Set up the Graph display so you can examine the plot of Volume versus Pressure and also the plot of Inverse Volume versus Pressure.
2. Set up the Table display so you can examine the Pressure, Volume and Inverse Volume.

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

Name ____________________ Class _____________ Date ________

Lab Report - Activity P18: Boyle's Law – Pressure and Volume

What Do You Think?

What happens to the pressure in a container of air as its volume is changed while the temperature remains constant?

Questions

1. From looking at your data, do the pressure and volume seem to be directly or inversely proportional? Does this agree with Boyle's Law?

2. What happened to the pressure when the volume went from 20 mL to 10 mL?

3. What are possible sources of error or limitations in this experiment? For each one, try to decide what effect it might have on the experimental results.

Name ____________________ Class _____________ Date _________

Activity P19: Work–Energy Theorem: W = ΔE
(Force Sensor, Photogate/Pulley System)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	P19 Work Energy.DS	P22 Work-Energy Theorem	P22_WORK.SWS

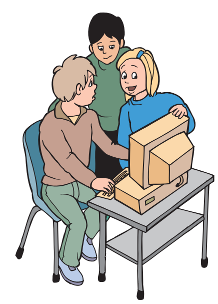
Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Economy Force Sensor (CI-6746)	1	**Mass and Hanger Set (ME-8967)**	1
Photogate/Pulley System (ME-6838)	1	**String (SE-8050)**	1 m
Balance (SE-8723)	1	**Universal Table Clamp (ME-9376)**	1
Dynamics Cart (inc. w/ Track)	1	**1.2 m Track System (ME-9435A)**	1

What Do You Think?

Using the definition of work in the background section, is work done when a person is studying? Is work done when a person lifts a backpack up from the floor?

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

Background



For an object with mass **m** that experiences a net force $\mathbf{F_{net}}$ over a distance **d** that is parallel to the net force, the work done is:

$$W = F_{net}d$$

If the work changes the object's vertical position, the object's gravitational potential energy changes. However, if the work changes only the object's speed, the object's kinetic energy changes as follows:

$$W = \Delta KE = KE_f - KE_i = \tfrac{1}{2}mv_f^2 - \tfrac{1}{2}mv_i^2$$

where **W** is the work, $\mathbf{v_f}$ is the final speed of the object and $\mathbf{v_i}$ is the initial speed of the object.

SAFETY REMINDER

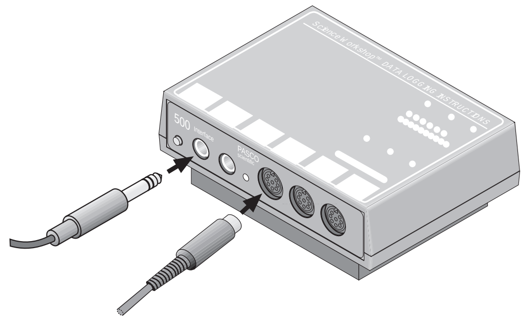
- Do not let the cart run away from the user. Catch the cart before the cart crashes into the bumper or travels off from the table.
- Follow the directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

The purpose of this laboratory activity is to compare the work done on an object and the change in kinetic energy of the object. Use the Force Sensor to measure the force applied to the cart. Use the Photogate/Pulley System to measure the motion of the cart as it is pulled by the weight of the hanging mass. Next, use *DataStudio or ScienceWorkshop* to plot and analyze the data.

PART I: Computer Setup



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

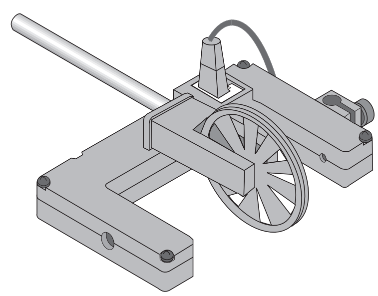
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P19 Work Energy.DS	P22 Work-Energy Theorem	P22_WORK.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Force vs. Distance and a Table display of Speed.
- Data recording is set at 50 Hz for the Force Sensor.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Photogate/Pulley System.
- To calibrate the Force Sensor, refer to the description in the Force Sensor Manual.

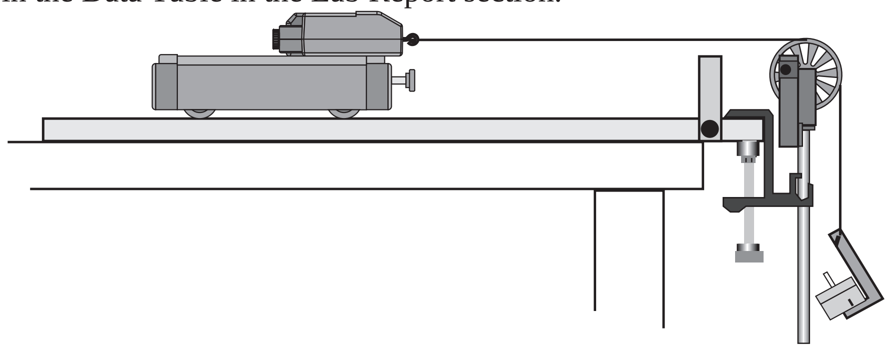
1. Use the thumbscrew that comes with the Force Sensor to mount the sensor onto the accessory tray of the cart.
2. Measure the mass of the cart and Force Sensor, and record the value in the Data Table in the Lab Report section.
3. Place the Dynamics Track on a horizontal surface. Level the Dynamics Track by placing the Dynamics Cart on the Dynamics Track. If the cart rolls one way or the other, use the Adjustable Feet at one end of the Dynamics Track to raise or lower that end until the Dynamics Track is level and the cart does not roll one way or the other.
4. Put one end-stop at the right end of the track. Place the cart next to the end stop.
5. Use the Pulley Mounting Rod to attach the Pulley to the tab on the Photogate.



6. Put a table clamp on the end of the track. Mount the Photogate/Pulley System's rod in the table clamp so that top edge of the pulley is approximately the same height as the hook on the Force Sensor that is mounted on the cart.
7. Use a piece of string that is about 10 centimeters longer than the distance from the top of the Photogate/Pulley System to the floor. Connect one end of a string to the Force Sensor's hook. Place the string in the Pulley's groove.
8. Press the tare button on the Force Sensor.

Name ____________________ Class _____________ Date _________

9. Attach an object of known mass to the end of the string so that the bottom of the object is just above the floor when the end of the cart is against the end-stop. Record the value of the hanging mass in the Data Table in the Lab Report section.

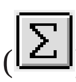


PART III: Data Recording

1. Pull the cart away from the Photogate so the object on the end of the string is just below the pulley.
2. Turn the pulley so the beam of the Photogate is not blocked (the light-emitting diode or LED on top of the Photogate is not lit).
3. Start data recording.
4. Release the cart so that it can move toward the Photogate.
5. End data recording just before the cart reaches the end stop.

- Run #1 will appear in the Data list in the Experiment Setup window.

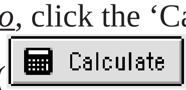
Analyzing the Data

1. Click on the Table display to make it active. Click the "Statistics" button ().

- Statistics will be displayed at the bottom of the Table.

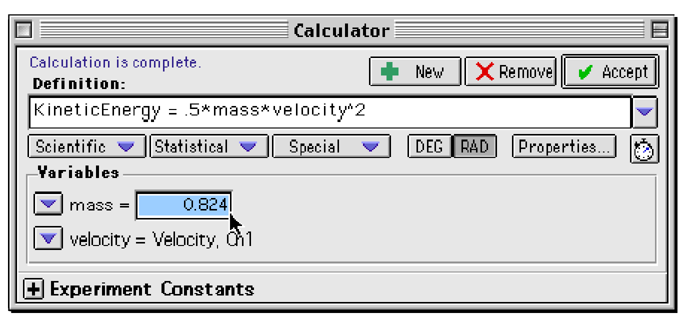
2. Record the value of the maximum velocity for Run #1 in the Data Table in the Lab Report section.
3. Use the Calculator to make a calculation for Kinetic Energy.

<u>In *DataStudio*</u>, click the 'Calculate'

button (

) in the main toolbar.

The Calculator window will open. The window shows the calculation for Kinetic Energy that was created as part of this activity.



If the total mass value for your cart and sensor and hanging mass is different, highlight the mass value in the 'mass' window and type in your total mass value.

Click the 'Accept' button to save your change.

Close the Experiment Calculator window. The Kinetic Energy Calculation should be displayed in the Table. If it is not, drag the Table display icon to the Calculator.

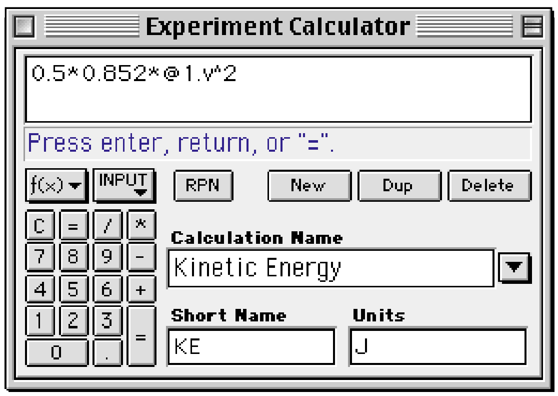
In *ScienceWorkshop*, to create a calculation for Kinetic Energy, click the Calculator button ( ) in the Experiment Setup window.

In the formula area, type '0.5' and then click the multiplication button ( ).

Type the total mass value for the mass of your cart plus sensor plus hanging mass such as 0.852, and click the multiplication button again.

Click the 'INPUT Menu' button ( ). Select 'Digital 1, Velocity (v)' from the INPUT menu. Type **"^2"**.

Type **'**Kinetic Energy' in the Calculation Name area. Type 'KE' in the Short Name area. Type 'J' in the Units area. Press <enter> or <return> on the keyboard.



Click the Table display. Click the 'Add Plot Menu' button ( ). Select 'Calculation, Kinetic Energy' from the Add Plot Menu.

4. From the Table display, find the maximum value for KE. Record this value in the Data Table in the Lab Report section.
5. Click in the Graph display to make it the active window.
6. In the Force vs. Position Graph display, click and drag the cursor to highlight the region of data that corresponds to the motion.
7. Integrate to find the area under the curve of the Force vs. Position Graph.

- In *DataStudio*, click the Statistics menu button ( ) and select 'Area'.
- In *ScienceWorkshop*, click the Statistics button ( ) to open the Statistics area on the right side of the graph. In the Statistics area, click the Statistics Menu button ( ). Select 'Integration'.

8. Record the absolute value of the integration in the Data Table in the Lab Report section.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P19: Work–Energy Theorem: $W = \Delta E$

Using the definition of work in the background section, is work done when a person is studying? Is work done when a person lifts a backpack up from the floor?

Data Table

Item	Value
Mass (hanging)	
Mass (cart and sensor)	
Maximum Velocity	
Maximum Kinetic Energy	
Work (from integration)	

Questions

1. What is the percent difference between the maximum kinetic energy and the work done?

2. What are possible reasons for the difference?

Optional

1. Repeat the data recording and analysis after adding a mass bar to the top of the cart. Prior to collecting data, hold the cart in place, pull the string toward the cart to remove the force from the hanging mass and push the tare button to zero the sensor. After you have tared the sensor, return the hanging mass to its initial position and prepare for data recording.

Optional Data Table

Item	Value
Mass (hanging)	
Mass (cart and sensor and mass bar)	
Maximum Velocity	
Maximum Kinetic Energy	
Work (from integration)	

Optional Questions

1. What is the percent difference between the maximum kinetic energy and the work done?

2. How does the data for the cart with the mass bar added compare with the first run of data?

Name ____________________ Class ______________ Date _________

Activity P20: Conservation of Mechanical Energy (Force Sensor, Photogate)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	P20 Mechanical Energy.DS	P23 Cons. Mechanical Energy	P23_MECH.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Economy Force Sensor (CI-6746)	1	**Photogate Mounting Bracket**	1
Photogate/Pulley System (ME-6838)	1	**Picket fence for cart (648-04704)**	1
Balance (SE-8723)	1	Ruler, metric	1
Base and Support Rod (ME-9355)	1	**String (SE-8050)**	0.5 m
'C'-Clamp	1	**1.2 m Track System (ME-9429A)**	1
Dynamics Cart (inc. w/ Track)	1		

What Do You Think?

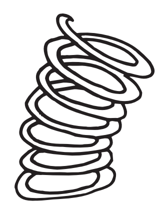
What happens to the elastic potential energy of a spring stored in a compressed spring when it is released? What other form of energy does it become? Is energy conserved in this process?

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

Background

The elastic potential energy of a spring compressed a distance **x** from its equilibrium position is given by

$$PE_{elastic} = \frac{1}{2}kx^2$$



where **k** is the spring constant. As described by Hooke's Law, the force exerted by the spring is proportional to the distance the spring is compressed or stretched from equilibrium, **F = -kx**, where **k** is the proportionality or spring constant. The spring constant can be experimentally determined by applying different forces to compress the spring different measured distances. If force is plotted versus distance, the slope of the resulting straight line is equal to **k**.

If energy is conserved, the elastic potential energy in the compressed spring will be completely converted into kinetic energy when the spring pushes an object of mass **m**.

SAFETY REMINDER

- Follow the directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

Pre-Lab For You To Do

Use the Force Sensor to measure the force that compresses the plunger spring in the Dynamics Cart. Measure the distance that the spring compresses and enter the distance into the computer. Use *DataStudio* or *Science Workshop* to plot force vs. distance. The slope of the best fit line of a graph of force versus distance is the spring constant k.

Pre-Lab PART I: Computer Setup

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

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P20 Prelab Mechanical Energy.DS	X23 Spring Constant	X23_MECH.SWS

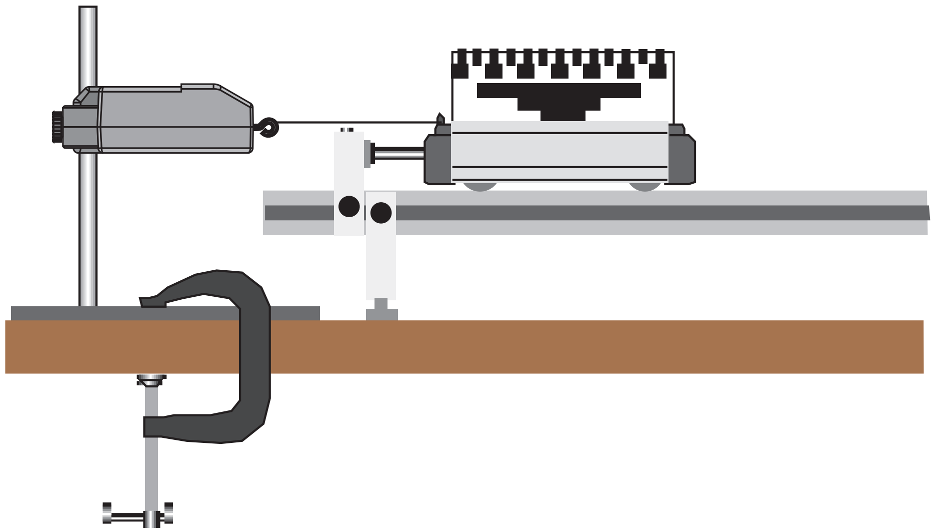
- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Force versus Stretch and a Digits display of Force.
- Data recording is set for 5 Hz. Keyboard Sampling allows the user to enter the distance compressed in meters.

Pre-Lab PART II: Sensor Calibration and Equipment Setup

- To calibrate the Force Sensor, refer to the description in the Force Sensor Manual.

1. Put the five-pattern picket fence in the slots of the accessory tray on top of the Dynamics Cart. Place the picket fence so the pattern of 1 centimeter opaque bands is at the top.
2. Measure the mass of the cart and picket fence. Record the total mass in the Data Table in the Lab Report section.
3. Place the 1.2 meter Dynamics Track on a horizontal surface. Put the cart near the middle of the Dynamics Track and level the Dynamics Track by raising or lowering one end of the track so the cart will not roll one way or the other.
4. Mount the end stop at the left end of the Dynamics Track. Place the cart so the end of its plunger bar is against the end stop. Tie one end of a string to the small hole in end cap of the cart.
5. Mount the Force Sensor horizontally on a support rod and base. Position the Force Sensor at the left end of the Dynamics Track so the hook is at the same height as the top of the end cap of the cart. Use a “C”-clamp to firmly hold the base in position.
6. Tie the other end of the string to the sensor’s hook.
7. Slide the Dynamics Track itself to the right (away from the Force Sensor) so the string is taut, and the end of the plunger is against the end stop, but the plunger spring is NOT compressed.

Name ____________________ Class _____________ Date _________



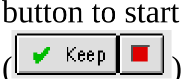
8. Put a mark on the edge of the Dynamics Track to indicate the initial setup position of the left end of the cart.

- You can use the mark as a reference line during the data recording process.

Pre-Lab PART III: Data Recording

1. Press the tare button on Force Sensor to zero the Force Sensor.
2. Start data recording.

In *DataStudio*, move the Table display so you can see it clearly.

- Click on the 'Start' button to start recording data. The 'Start' button changes to a 'Keep' and a 'Stop' button (

). The Force will appear in the first cell in the Table display. Click the 'Keep' button to record the force value.

In *ScienceWorkshop*, click the REC button to begin collecting data.

- The Keyboard Sampling window will open. Move it so you can also see the Digits display. Type in '0' as the compressed value. Click 'Enter' to record the compression and force values. The entered value will appear in the Data list.

3. Slide the Dynamics Track to the right (away from the Force Sensor) so the plunger spring is compressed 5 millimeters (0.005 m) against the end stop. Use the mark on the edge of the Dynamics Track as a reference line. Make sure the string between the sensor and the cart is taut. Hold the Dynamics Track in its new position.

- Note: You may need to hold the sides of the cart so its wheels don't slip sideways out of the grooves in the Dynamics Track.

4. Enter the value 0.005 m in the software. Record a Force value for your second compressed position by clicking 'Keep' in *DataStudio*, or 'Enter' in *ScienceWorkshop*.
5. Slide the Dynamics Track to the right so the plunger spring is compressed 10 millimeters (0.010 m). Hold the Dynamics Track at the new position. Enter the compressed value and record a force value at this position.
6. Continue to slide the Dynamics Track to the right in 5 mm increments until the plunger spring has been compressed 20 millimeters. Record a Force value at each new position.
7. End data recording.

- In *DataStudio*, stop data recording by clicking on the 'Stop' button.
- In *ScienceWorkshop*, stop data recording by clicking the Stop Sampling button in the Keyboard Sampling window.
- The data will appear as Run #1.

8. When you are finished, do not let go of the track. Move the track gently toward the Force Sensor until the plunger is not compressed.

Pre-Lab Analyzing the Data

1. Determine the slope of the Force vs. Compression Graph.

- In *DataStudio*, click the 'Scale to fit' button ( ) to rescale the Graph axes to fit the data. Next, click the 'Fit' menu button (Fit). Select 'Linear'.
- In *ScienceWorkshop*, click the 'Autoscale' button ( ) to rescale the Graph axes to fit the data. Click the 'Statistics' button to open the Statistics area on the right side of the Graph.

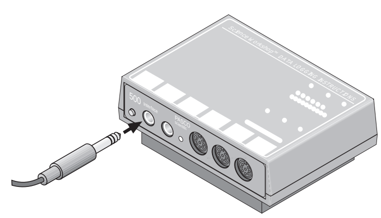
  In the Statistics area, click the Statistics Menu button ( ). Select Curve Fit, Linear Fit from the Statistics Menu.

2. Record the slope of the linear fit as the Spring Constant (k) in the Data Table in the Lab Report section.
3. Disconnect the string from the Force Sensor's hook. Remove the C-clamp from the base and set the Force Sensor aside.

For You To Do

Use a Photogate to measure the motion of a cart as its plunger spring de-compresses. Next, use *DataStudio* or *ScienceWorkshop* to calculate and display the velocity and maximum kinetic energy of the cart. Compare the measured kinetic energy to the calculated elastic potential energy.

PART I: Computer Setup



1. Unplug the Force Sensor's DIN plug from the interface.
2. Connect the Photogate digital plug to Digital Channel 1 on the interface.
3. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P20 Mechanical Energy.DS	P23 Cons. Mechanical Energy	P23_MECH.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Position vs. Time and a Table display of Velocity.
- Data recording is set at 10 kHz.

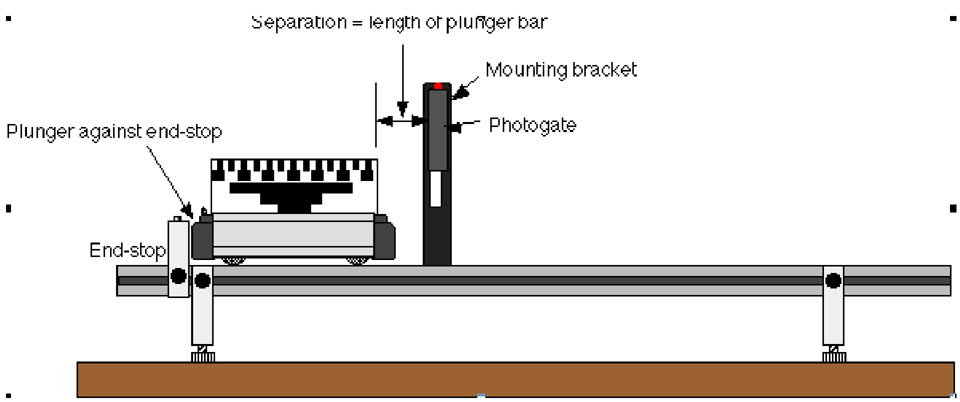
PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Photogate.

1. Attach the Photogate to the Photogate Mounting Bracket. Mount the bracket on the side of the Dynamics Track.
2. Adjust the height of the Photogate so the beam will be blocked by the pattern of 1 centimeter opaque bands at the top edge of the picket fence.
3. Put the cart on the Dynamics Track so the end of the plunger bar is pressed against the end stop, but the plunger spring is not compressed. Position the Photogate bracket so the Photogate is as close as possible to the right edge of the picket fence.
4. Measure the length of the plunger relative to the end cap of the Dynamics Cart. Record the plunger length **x** in the Data Table in the Lab Report section.

- Note: When the cart is placed so the end of the plunger bar is pressed against the end stop, you can measure the length of the plunger by measuring the distance from the end stop to the cart.

5. Completely compress the plunger spring on the cart, and lock the spring in position by pushing the plunger in and then pushing the end of the plunger upward slightly so one of its notches will 'catch' on the metal rail inside the cart's end cap.



6. Put the plunger end of the cart against the end stop.

- The separation between the right edge of the picket fence and the Photogate should be the length of the plunger bar when the spring is not compressed.

PART IIIA: Data Recording

1. Begin data recording.
2. Use the end of a pencil or similar object to tap down on the plunger release knob.

- The cart will be pushed away from the end stop by the plunger spring.

3. End data recording after the entire cart has moved through the Photogate.

- The data will appear as Run #1.

4. Repeat the data recording process two more times to produce Run #2 and Run #3.

PART IIIB: Data Recording

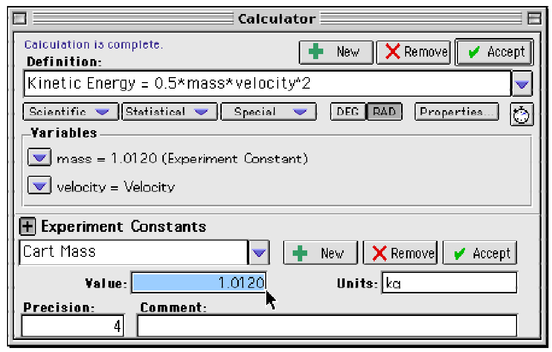
1. Put the mass bar in the accessory tray of the cart and measure the mass of the cart plus bar. Record the total mass value in the Data Table in the Lab Report section.
2. Repeat the data recording process as in Part IIIA.

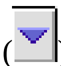
- The three data runs should appear as Run #4, #5 and #6.

Analyzing the Data

1. Use the Calculator to make a calculation for Kinetic Energy.

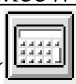
In *DataStudio*, double click on the calculation for Kinetic Energy in the Summary Window. The Calculator window will open. The window shows the calculation for Kinetic Energy that was created as part of this activity



The cart mass is stored as an ‘Experiment Constant’. If the total mass value for your cart is different than the value listed, in the Experiment Constants section, click on the menu button () and select ‘Cart Mass’ from the list. Highlight the mass value in the ‘Value’ window and type in your total mass value.

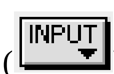
Click the ‘Accept’ button to save your change.

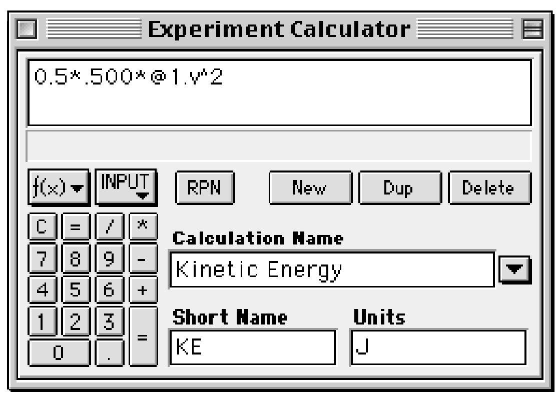
Close the Experiment Calculator window.

In *ScienceWorkshop*, to create a calculation for Kinetic Energy, click the Calculator button () in the Experiment Setup window.

In the formula area, type ‘0.5’ and then click the multiplication button ().

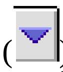
Type the total mass value for the mass of your cart such as 0.500, and click the multiplication button again.

Click the ‘INPUT Menu’ button (). Select ‘Digital 1, Velocity (v)’ from the INPUT menu. Type **“^2”**.



Type ‘Kinetic Energy’ in the Calculation Name area. Type ‘KE’ in the Short Name area. Type ‘J’ in the Units area. Press <enter> or <return> on the keyboard.

2. Open a Graph and Table for your Kinetic Energy data from Run #1.
3. Use the Statistics button to find the Mean value for the KE in Run #1, and record this value in the Data Table in the Lab Report section.
4. Repeat the process for the next two runs of data. Record the Mean value of the KE for Run #2 and Run #3 in the Data section.
5. Change the value of the mass in the formula for kinetic energy (KE) to take into account the extra mass for the three data runs Part IIIB.

In *DataStudio*, double click on the Kinetic Energy calculation in the Summary window. In the 'Experiment Constants' section, click the menu button () and select 'Cart Mass' from the list. Highlight the mass value in the 'Value' window and type in your total mass value. Click the 'Accept' button to save your change. Close the Experiment Calculator window.

In *ScienceWorkshop*, click on the select 'Calculator Window' from the Experiment menu. Highlight the value of the mass of the cart in the formula area. Type in the value of the mass of the cart plus the bar. Click the 'equals' button in the Experiment Calculator to enter the change. Close the Experiment Calculator window.

6. Find the Mean value for the KE of Run #4, and record this value in the Data section.
7. Repeat the process for the last two runs of data.
8. Calculate the elastic potential energy based on k and x. Record the values in the Data Table.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P20: Conservation of Mechanical Energy

What Do You Think?

What happens to the elastic potential energy of a spring stored in a compressed spring when it is released? What other form of energy does it become? Is energy conserved in this process?

Data Table

Item	Value
Mass (cart & fence)	
Spring constant (k)	
Plunger length (x)	
Mass (cart & bar & fence)	

Run #	1	2	3	4	5	6	Average
KE (J)							

Elastic Potential Energy = $PE_{elastic} = \frac{1}{2}kx^2$ = ________J

Questions

1. What is the percent difference between the average kinetic energy and the elastic potential energy?

2. Which energy was larger in each case, the elastic potential energy or the kinetic energy of the cart?

3. What are possible reasons for the differences, if any?

4. When the mass of the cart was increased, why did the elastic potential energy remain the same?

Name ____________________ Class _____________ Date ________

Activity P21: Kinetic Friction (Photogate/Pulley System)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Newton's Laws	P21 Kinetic Friction.DS	P25 Kinetic Friction	P25_KINE.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Photogate/Pulley System (ME-6838)	1	Mass and Hanger Set (ME-8967)	1
Balance (SE-8723)	1	String (SE-8050)	2 m
Friction Block w/ hook (003-04708)	1	Universal Table Clamp (ME-9376)	1

What Do You Think?

In relation to the direction of motion, in which direction does the kinetic frictional force act?

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

Background

The block of mass **M** is placed on a level table connected by a string to a mass (**m**) hanging over a pulley. As the mass is released and starts to fall the block will slide across the table.

Treating both masses together as one system, the free-body diagram includes two forces: the force of gravity pulling on mass **m** and the kinetic friction acting on mass **M**. According to Newton's Second Law, the vector sum of the forces equals the total mass of the system times the acceleration of the system.

$$\sum F = mg - F_k = (M + m)a$$

where F_k is the force of kinetic friction which is given by:

$$F_k = \mu_k N$$

where μ_k is the coefficient of kinetic friction and N is the normal force acting on the block:

$$N = Mg$$

Solving for the coefficient of kinetic friction gives:

$$\mu_k = \frac{mg - (M + m)a}{Mg}$$

In general, the coefficient of kinetic friction for the block depends only on the type of materials that are rubbing together.

SAFETY REMINDER

- Follow the directions for using the equipment.

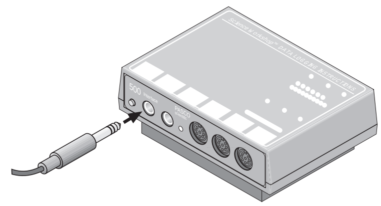
**THINK SAFETY
ACT SAFELY
BE SAFE!**

For You To Do

Use the Photogate/Pulley System to study how the coefficient of kinetic friction for an object depends on the normal force between the surfaces, the area of contact between the surfaces, the types of materials making contact, and the relative speed of the surfaces.

PART I: Computer Setup

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

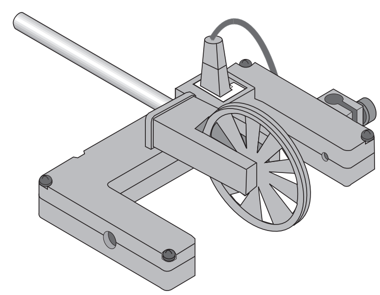


DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P21 Kinetic Friction.DS	P25 Kinetic Friction	P25_KINE.SWS

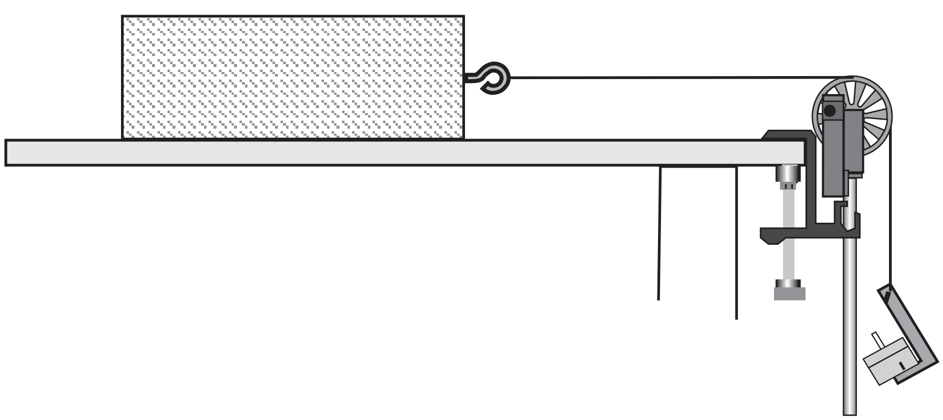
- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Velocity versus Time.
- Note: The spoke arc length for the Photogate/Pulley System is set at 0.015 m. If you are using a different pulley, change the spoke arc length in the sensor window by double clicking on the Smart Pulley icon in the Experiment setup window.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Photogate/Pulley System.



1. Use the Pulley Mounting Rod to attach the Pulley to the tab on the Photogate.
2. Use the Universal Table Clamp to mount the pulley rod vertically at the edge of a horizontal surface, such as a tabletop.
3. Measure the mass of the Friction Block. Record the mass in the Data Table in the Lab Report section.
4. Use a piece of string that is about 10 centimeters longer than the distance from the top of the horizontal surface to the floor. Attach one end of the string to the block.
5. Put the string in the groove of the pulley. Attach the mass hanger to the other end of the string. Set up the block and Photogate/Pulley System as shown. If you are using a PASCO mass hanger, you can attach the string to the mass hanger by wrapping the string through the notch three or four times.



Name ____________________ Class ______________ Date _________

PART IIIA: Data Recording – Large, Smooth Surface

1. Place the block so its largest smooth side is on the horizontal surface.
2. Put enough mass on the mass hanger so that the block will slide on the surface without needing an initial push. Measure and record the value of the TOTAL hanging mass (remember to include the mass of the hanger).
3. Pull the block away from the Photogate/Pulley System until the hanging mass is almost up to the pulley. Hold the block in place. Turn the pulley so the photogate's beam is not blocked (light-emitting diode on the photogate is not lit).
4. Begin data recording.
5. Release the block.
6. End data recording before the block hits the pulley. Do not let the block hit the pulley.

- The data will appear as Run #1.

7. Repeat the procedure to obtain a second run of data for the same hanging mass and surface.

- The data will appear as Run #2.

PART IIIB: Data Recording – Different Mass of Block

1. Double the mass of the block by placing a mass approximately equal to the mass of the block on top of the block.
2. Measure and record the total mass (**M**) of the block and additional mass in the Data Table.
3. Double the hanging mass. Measure and record the total hanging mass (**m**) in the Data Table.
4. Record one run of data as before to see how the different mass affects the coefficient of kinetic friction.

PART IIIC: Data Recording – Different Surface Area

1. Remove the additional mass from the block and from the mass hanger to return the block and mass hanger to their original state from Part IIIA.
2. Place the block so its smallest smooth side is on the horizontal surface.
3. Record data. Compare this run to the data from Part IIIA.

PART IIID: Data Recording – Different Surface Material

1. Place the block so its **largest "rough" side** is on the horizontal surface.
2. Put enough mass on the mass hanger so that the block will slide on the surface without needing an initial push. Measure and record the value of the TOTAL hanging mass in the Data Table in the Lab Report section. Remember to include the mass of the hanger.
3. Record one run of data as before to see how the different material affects the coefficient of kinetic friction.
4. Place the block so its **smallest "rough" side** is on the horizontal surface.
5. Record data using the same hanging mass you used for the largest "rough" side so you can compare this run to the data for the largest "rough" side.

PART IIIE: Data Recording – Different Hanging Mass

1. Return the block to the original orientation as in Part IIIA (largest smooth side down).
2. Put an amount of mass on the hanger that is larger than the amount you used in Part IIIA. Measure and record the total hanging mass in the Data Table.
3. Record data as in Part IIIA.
4. Repeat the process using two larger totals for the hanging mass. Be sure to measure and record the total hanging mass for all three trials.

Data Recording Summary

Run #	PART & DESCRIPTION
1	IIIA, Largest smooth side of block
2	IIIA, Largest smooth side of block
3	IIIB, Larger mass of block and hanging mass
4	IIIC, Smallest smooth side of block
5	IIID, Largest rough side of block
6	IIID, Smallest rough side of block
7	IIIE, Larger hanging mass 1
8	IIIE, Larger hanging mass 2
9	IIIE, Larger hanging mass 3

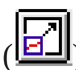
Analyzing the Data

1. Determine the experimental acceleration for each of the data runs.

- Click in the Graph display to make it active. Find the slope of the velocity vs. time plot, the average acceleration of the block.

In *DataStudio*, select Run #1 from the Data Menu (

) in the Graph display. If multiple data runs are showing, first select No Data from the Data Menu and then select Run #1.

Click the "Scale to fit" button () to rescale the Graph axes to fit the data. Next, click the 'Fit' menu button (

). Select 'Linear'.

In *ScienceWorkshop*, select Run #1 from the Data Menu (

) in the Graph display. If multiple data runs are showing, first select No Data from the Data Menu and then select Run #1. Click the "Autoscale" button () to rescale the Graph axes to fit the data. Click the 'Statistics' button to open the Statistics area on the right side of the Graph. In the Statistics area, click the Statistics Menu button (). Select 'Curve Fit, Linear Fit' from the Statistics Menu.

- Record the slope of the linear fit in the Data Table in the Lab Report section. Repeat the above procedure for each of the remaining data runs.

2. Using the mass values and the acceleration value, determine and record the coefficient of kinetic friction for each data run in the Data Table.

Record your results in the Lab Report section.

Name ______________________ Class _______________ Date __________

Lab Report - Activity P21: Kinetic Friction

What Do You Think?

In relation to the direction of motion, in which direction does the kinetic frictional force act?

Data Table:

Run	M total block mass (kg)	m total hanging mass (kg)	a_{exp} acceleration (m/s^2)	μ_k coefficient of friction
Run #1				
Run #2				
Run #3				
Run #4				
Run #5				
Run #6				
Run #7				
Run #8				
Run #9				

Summary:

Run #	Part and Description	μ_k
1	IIIA, Largest smooth side of block	
2	IIIA, Largest smooth side of block	
3	IIIB, Larger mass of block	
4	IIIC, Smallest smooth side of block	
5	IIID, Largest rough side of block	
6	IIID, Smallest rough side of block	
7	IIIE, Larger hanging mass 1	
8	IIIE, Larger hanging mass 2	
9	IIIE, Larger hanging mass 3	

Questions

1. How does the coefficient of kinetic friction vary with the mass of the block?

2. How does the coefficient of kinetic friction vary with the area of contact between the block and the horizontal surface?

3. How does the coefficient of kinetic friction vary with the type of material between the block and the horizontal surface?

4. When you used the different type of material, how does the coefficient of kinetic friction vary with the area of contact between the block and the horizontal surface?

5. How does the coefficient of kinetic friction vary as the speed varied due to the different hanging masses?

6. What is the relationship between the coefficient of kinetic friction and the mass, surface area, or speed of the object?

7. When the mass of the block is increased, does the force of kinetic friction increase? Why?

Name ____________________ Class _____________ Date _________

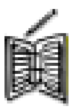
Activity P22: Rotational Inertia (Rotary Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Rotational motion	P22 Rotational Inertia.DS	(See end of activity)	(See end of activity)

Equipment Needed	Qty	Equipment Needed	Qty
Rotary Motion Sensor (CI-6538)	1	**Mass and Hanger Set (ME-9348)**	1
Balance (SE-8723)	1	**Rotational Accessory (CI-6691)**	1
Base and Support Rod (ME-9355)	1	**Thread (inc. w/ CI-6691)**	1 m
Calipers (SF-8711)	1		

What Do You Think?

What is an example of an object or device that depends on rotational inertia? How does the rotational inertia of a ring (or hoop) compare to the rotational inertia of a disk (or cylinder)?



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

Background

A quarterback on an American football team throws the ball so it spirals in flight. A figure skater performs an elegant spin on the ice and increases her rotation rate by moving her outstretched arms closer to her body. Rotational inertia plays an important role in both of these phenomena.

The rotational inertia of an object depends on the mass and the distribution of mass. In general, the more compact an object, the less rotational inertia it has.

Theoretically, the rotational inertia, ***I***, of a ring is given by

$$I = \frac{1}{2}M(R_1^2 + R_2^2) \quad \text{Equation 1}$$

where ***M*** is the mass of the ring, R_1 is the inner radius of the ring, and R_2 is the outer radius of the ring.

Theoretically, the rotational inertia, ***I***, of a solid disk of uniform density is given by

$$I = \frac{1}{2}MR^2 \quad \text{Equation 2}$$

where ***M*** is the mass of the disk, ***R*** is the radius of the disk.

To find the rotational inertia of the ring and disk experimentally, apply a known torque to the ring and disk and measure the resulting angular acceleration.

Since $\tau = I\alpha$

$$I = \frac{\tau}{\alpha} \quad \text{Equation 3}$$

where α is the angular acceleration and τ is the torque.

Torque depends on the force applied and the distance from the pivot point of the rotating object to the point where the force is applied, or

$$\tau = \boldsymbol{r} \times \boldsymbol{F} \quad \text{Equation 4}$$

where $\boldsymbol{r}$ is the distance from the center of the ring or disk to the point where a force is applied (the ‘lever arm’), and $\boldsymbol{F}$ is the applied force. The value of $\boldsymbol{r}$ ***x*** $\boldsymbol{F}$ is $\boldsymbol{r}\ \boldsymbol{F}$ ***sin ø*** where ***ø*** is the angle between $\boldsymbol{r}$ and the direction of $\boldsymbol{F}$, the applied force. The torque is maximum when $\boldsymbol{r}$ and $\boldsymbol{F}$ are perpendicular.

In this case, the applied force is the tension (***T***) in a thread that is attached to a part of a rotational apparatus. Gravity pulls a hanging mass **m** that is attached to the thread. The value of $\boldsymbol{r}$ is the radius of the step pulley on the apparatus. The radius is perpendicular to the applied force (Tension).

Therefore, the torque is:

$$\tau = \boldsymbol{rT} \quad \text{Equation 5}$$

The following solution is derived from the convention that up is positive and down is negative, counter-clockwise is positive and clockwise is negative.

Applying Newton’s Second Law for the hanging mass, ***m***, results in:

$$\sum \boldsymbol{F} = \boldsymbol{T} - \boldsymbol{mg} = \boldsymbol{m}(-\boldsymbol{a})$$

Solving for the tension in the string gives

$$\boldsymbol{T} = \boldsymbol{m}(\boldsymbol{g} - \boldsymbol{a})$$

The torque is:

$$\tau = \boldsymbol{rT} = \boldsymbol{rm}(\boldsymbol{g} - \boldsymbol{a}) \quad \text{Equation 6}$$

The linear acceleration $\boldsymbol{a}$ of the hanging mass is the tangential acceleration, $\boldsymbol{a_T}$, of the rotating apparatus.

The angular acceleration is related to the tangential acceleration as follows:

$$\alpha = \frac{\boldsymbol{a_T}}{\boldsymbol{r}} \quad \text{Equation 7}$$

Substituting Equation 6 and Equation 7 into Equation 3 gives:

$$\boldsymbol{I} = \frac{\tau}{\alpha} = \boldsymbol{rm}(\boldsymbol{g} - \boldsymbol{a}) \div \frac{\boldsymbol{a_T}}{\boldsymbol{r}} = \boldsymbol{rm}(\boldsymbol{g} - \boldsymbol{a})\frac{\boldsymbol{r}}{\boldsymbol{a_T}} = \frac{\boldsymbol{mgr}^2}{\boldsymbol{a_T}} - \boldsymbol{mr}^2 = \boldsymbol{mr}^2\left(\frac{\boldsymbol{g}}{\boldsymbol{a_T}} - \mathbf{1}\right)$$

The system’s rotational inertia, ***I***, can be calculated from the tangential acceleration, $\boldsymbol{a_T}$.

For You To Do

Measure the mass and dimensions of a ring and a disk and calculate the theoretical values of rotational inertia. Use the Rotary Motion Sensor to measure the motion of a hanging mass that is connected by a thread to a step pulley on the rotational apparatus. Use *DataStudio* or *ScienceWorkshop* to record and display velocity versus time. The slope of velocity versus time is the tangential acceleration.

Name ____________________ Class _____________ Date _________

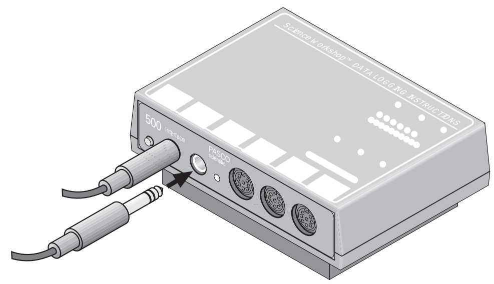
SAFETY REMINDERS

- Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

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's stereo phone plugs into Digital Channels 1 and 2 on the interface. Remove the 'O' ring from the large groove on the step pulley on the sensor.
3. Open the file titled as shown:



DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P22 Rotational Inertia.DS	(See end of activity)	(See end of activity)

- The *DataStudio* file has a Workbook display and a Graph display. Read the instructions in the workbook.
- Data recording is set at 20 Hz. The Rotary Motion Sensor is set for 360 divisions per rotation. The 'Linear Calibration' is set for 'Large Groove (Pulley)'.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.

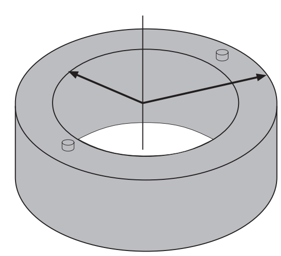
PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the sensor.

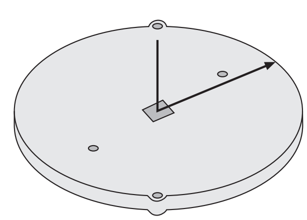
Equipment Setup

For this part you will need the following: ring, disk, clamp-on Super Pulley, thread (all part of the Rotational Accessory), calipers, balance, base and support rod, Rotary Motion Sensor, mass hanger.

1. Complete **DataTable #1** in the Lab Report section.

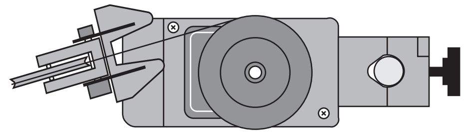


- Measure the diameter of the large groove on the step pulley on Rotary Motion Sensor. Calculate and record the radius of the step pulley**.**
- Measure the inside and outside diameters of the ring. Calculate and record the inside radius and the outside radius of the ring.
- Measure and record the radius of the disk.
- Measure and record the mass of the ring and the mass of the disk.



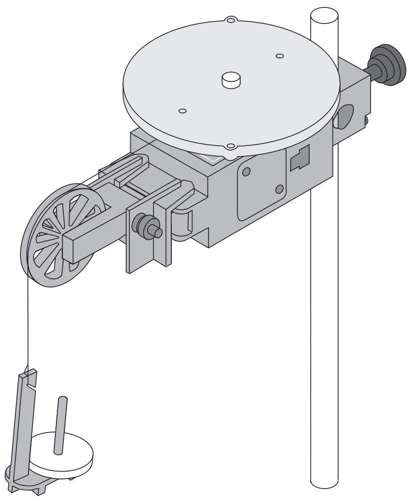
2. Mount the Rotary Motion Sensor on a support rod so the step pulley is on top.
3. Mount the clamp-on Super Pulley on the end of the Rotary Motion Sensor.

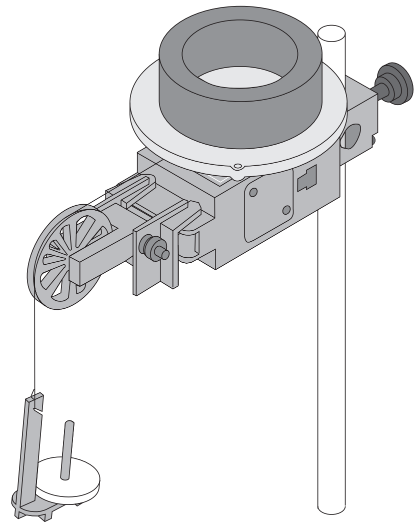
4. Use a piece of thread about 10 cm longer than the distance from the Super Pulley to the ground. Tie one end of the thread to the edge of the large groove on the step pulley on the Rotary Motion Sensor. Drape the thread over the Super Pulley. Tie the other end of the thread to a mass hanger. Adjust the angle of the Super Pulley so the thread is tangent to the step pulley and in the middle of the groove on the Super Pulley.



5. Remove the thumbscrew from the step pulley on top of the Rotary Motion Sensor. Place the disk on the pulley and attach the disk with the thumbscrew.

6. Place the ring on the disk inserting the ring pins into the holes on the disk.





PART IIIA: Data Recording – Acceleration of the Ring and Disk

Measure the acceleration of the ring and disk together.

1. Add about 20 g to the mass hanger attached to the thread. Wind the thread around the large groove on the step pulley of the Rotary Motion Sensor by rotating the disk until the mass hanger is raised almost to the Super Pulley. Hold the disk in place.

2. Start recording data and release the disk.

3. Stop recording data just before the mass hanger reaches the floor.

• "Run #1" will appear in the Data list in the Experiment Setup window.

4. Remove the mass hanger from the thread. Measure the total mass of the hanger and record the value in **Data Table 2**.

Name ____________________ Class _____________ Date _________

PART IIIB: Data Recording – Acceleration of the Disk Alone

Measure the acceleration of the disk alone.

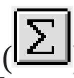
1. Remove the ring from the disk. Add about 20 g to the mass hanger attached to the thread. Wind the thread around the large groove on the step pulley of the Rotary Motion Sensor by rotating the disk until the mass hanger is raised almost to the Super Pulley. Hold the disk in place.
2. When you are ready, start recording data and then release the disk.
3. Stop recording data just before the mass and hanger reaches the floor.

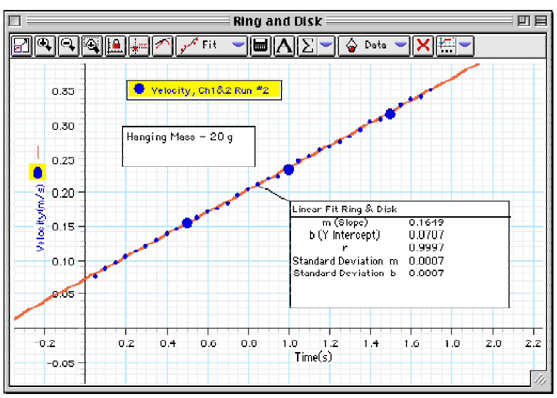
- "Run #2" will appear in the Data list in the Experiment Setup window.

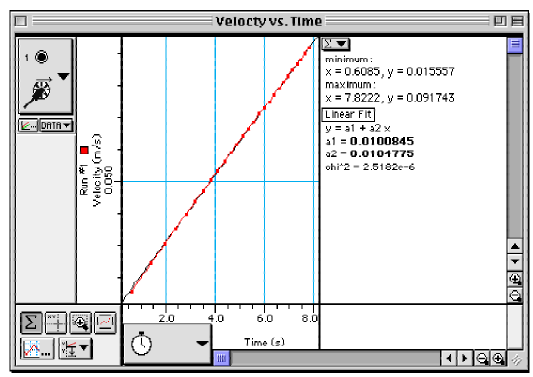
4. Remove the mass hanger from the thread. Measure the total mass of the hanger and record the value in the **Data Table 2**.

Analyzing the Data

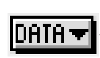
1. Use the Graph display's built-in analysis tools to find the slope of the velocity versus time.

- In *DataStudio*, use the cursor to draw a rectangle around the region of smoothest data in the Graph. Click the 'Fit' menu in the Graph toolbar and select 'Linear'.
- In *ScienceWorkshop* , click the 'Statistics' button () to open the Statistics area on the right side of the Graph. Rescale the display. Use the cursor to draw a rectangle around the region of smoothest data. Select 'Curve Fit, Linear Fit' from the Statistics menu.





2. Record the acceleration for both Run #1 (Ring and Disk) and Run # 2 (Disk alone).

- Hint: Use the 'Data' menu () or ) in the Graph display to select Run #2.

3. Calculate and record the experimental rotational inertia, I, of the Ring and Disk using the measured acceleration "**a_T**", the Step Pulley radius **"r"**, and the mass **"m"** that caused the apparatus to rotate.

$$I = \frac{\tau}{\alpha} = mr^2\left(\frac{g}{a_T} - 1\right)$$

4. Calculate and record the experimental rotational inertia of the Disk using the measured acceleration "**a_T**", the Step Pulley radius **"r"**, and the mass **"m"**.

5. Subtract the rotational inertia of the Disk from the value of the rotational inertia for the Ring and Disk to find the rotational inertia of the Ring alone. Record the experimental value for the Ring.
6. Calculate the theoretical value of the rotational inertia of the Ring based on its dimensions (**R_1** and **R_2**) and mass (**M**). Record the value.

$$I = \frac{1}{2}M(R_1^2 + R_2^2)$$

7. Calculate the theoretical value of the rotational inertia of the Disk based on its dimension (**R**) and mass (**M**). Record the value.

$$I = \frac{1}{2}MR^2$$

8. Calculate the percent difference between the experimental values and the theoretical values for the rotational inertia of the Ring and the rotational inertia of the disk.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report – Activity P22: Rotational Inertia

What Do You Think?

What is an example of an object or device that depends on rotational inertia? How does the rotational inertia of a ring (or hoop) compare to the rotational inertia of a disk (or cylinder)?

Data Table #1: Dimensions

Item	Value
Step Pulley radius (r)	
Ring, inside radius (R_1)	
Ring, outside radius (R_2)	
Disk, radius (R)	
Mass of Ring (M)	
Mass of Disk (M)	

Data Table #2: Mass

Run	Description	Hanging Mass
#1	Ring and Disk	
#2	Disk Alone	

Data Table #3: Measured Accelerations (a_T)

Run	Description	Acceleration
#1	Ring and Disk	
#2	Disk Alone	

Data Table #4: Rotational Inertia (I)

Run	Description	Experimental	Theoretical	% Difference
#1	Ring and Disk			
#2	Disk Alone			
	Ring Alone			

Questions

1. How do the experimental values compare to the theoretical values for rotational inertia?

2. What are some reasons that could account for any differences?

Name ____________________ Class _____________ Date _________

Appendix: Modify a *ScienceWorkshop* File

Modify an existing *ScienceWorkshop* file to add the Rotary Motion Sensor.

Open the *ScienceWorkshop* File

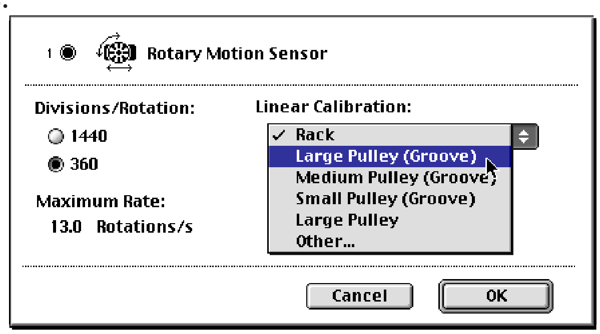
Open the file titled as shown:

ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P26 Rotational Inertia	P26_ROTA.SWS

- The *ScienceWorkshop* file has a Graph display of Velocity versus Time (using data from a Smart Pulley).
- You need to replace the Smart Pulley with the Rotary Motion Sensor in the Experiment Setup window and set up the Rotary Motion Sensor parameters. Then you need to change the Graph display.

Set Up the Rotary Motion Sensor

In the Experiment Setup window, click and drag the digital sensor plug to Channel 1. Select 'Rotary Motion Sensor' from the list of sensors. Click 'OK'. **Result**: The Rotary Motion Sensor setup window opens.



Under Linear Calibration, select 'Large Pulley (Groove). Click 'OK' to return to the Experiment Setup window.

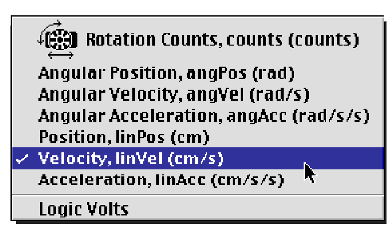
Set the Sampling Options

Click the 'Sampling Options' button in the Experiment Setup window or select 'Sampling Options' from the Experiment menu to open the Sampling Options window. **Result**: The Sampling Options window opens.

Under 'Periodic Samples' click the right arrow to set the sample rate at '20 Hz' (20 measurements per second). Click 'OK' to return to the Experiment Setup window.

Change the Graph Display

Click the 'Y-Axis Input' menu and select 'Digital 1, Velocity, linVel (cm/s)'.



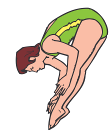
Name ____________________ Class _____________ Date _________

Activity P23: Conservation of Angular Momentum (Rotary Motion Sensor)

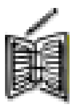
Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Rotational motion	P23 Angular Momentum.DS	(See end of activity)	(See end of activity)

Equipment Needed	Qty	Equipment Needed	Qty
Rotary Motion Sensor (CI-6538)	1	Calipers (SF-8711)	1
Balance (SE-8723)	1	Rotational Accessory (CI-6691)	2
Base and Support Rod (ME-9355)	1		

What Do You Think?



What interesting sporting events can be understood using the concept of conservation of angular momentum?



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

Background

When a net torque τ is applied to an object that is free to rotate, there is a change in the angular momentum (Δ**L**) of the object.

$$\tau = \frac{\Delta L}{\Delta T}$$

When a non-rotating disk is dropped on a rotating disk, there is no net torque on the system since the torque on the non-rotating is equal and opposite to the torque on the rotating disk. If there is no change in angular momentum the angular momentum is conserved:

$$L = I_i \omega_i = I_f \omega_f$$

where I_i is the initial rotational inertia and ω_i is the initial rotational speed. The initial rotational inertia is that of a disk.

$$\frac{1}{2} MR^2$$

If the second disk has the same rotational inertia as the first disk, the final rotational inertia is twice the initial rotational inertia of the first disk.

If angular momentum is conserved, the final rotational speed is half of the initial rotational speed:

$$\omega_f = \frac{I_i}{I_f}\omega_i = \frac{1}{2}\omega_i$$

SAFETY REMINDERS

- Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

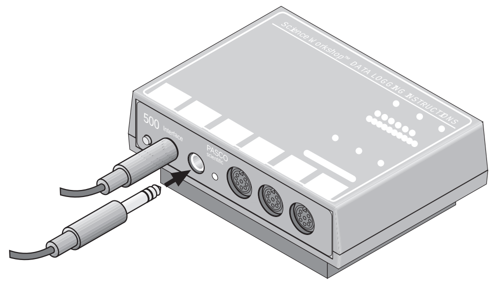
For You To Do

The goal in this activity is to measure the final angular speed of a system consisting of a non-rotating ring that is dropped onto a rotating disk and to compare the measured angular speed to the value predicted using conservation of angular momentum.

Use the Rotary Motion Sensor to measure the angular speed of a rotating disk before and after a second disk that is not rotating is dropped onto the rotating disk. Use *DataStudio* or *ScienceWorkshop* to record and display the angular speed before and after the torque-free collision.

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's stereo phone plugs into Digital Channels 1 and 2 on the interface. Remove the 'O' ring from the large groove on the step pulley on the sensor.
3. Open the file titled as shown:



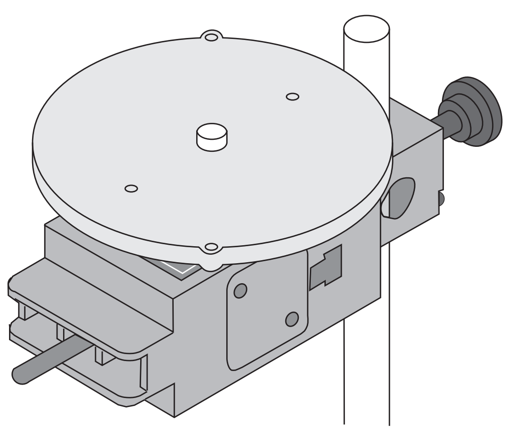
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P23 Angular Momentum.DS	(See end of activity)	(See end of activity)

- The *DataStudio* file has a Workbook display and a Graph display. Read the instructions in the workbook.
- Data recording is set at 20 Hz. The Rotary Motion Sensor is set for 360 divisions per rotation.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the sensor.

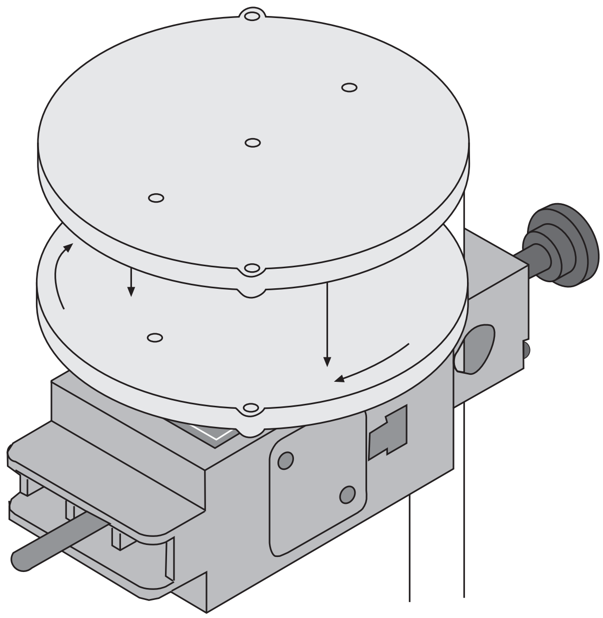
1. Mount the Rotary Motion Sensor on a support rod so the step pulley is on top.
2. Remove the thumbscrew from the step pulley on top of the Rotary Motion Sensor. Place the disk on the pulley and attach the disk with the thumbscrew.



PART III: Data Recording

- In this part of the activity you will drop the second disk onto the disk that is attached to the Rotary Motion Sensor. Hold the second disk so the square indent on one side of the disk is above the thumbscrew on the first disk.

1. Give the first disk a spin using your hand.
2. Start recording data. (Hint: Click ‘Start’ in *DataStudio* or ‘REC’ in *ScienceWorkshop*.)
3. After about 25 data points have been recorded, drop the second disk onto the spinning one.



4. After another 25 or so data points have been recorded, stop data recording.

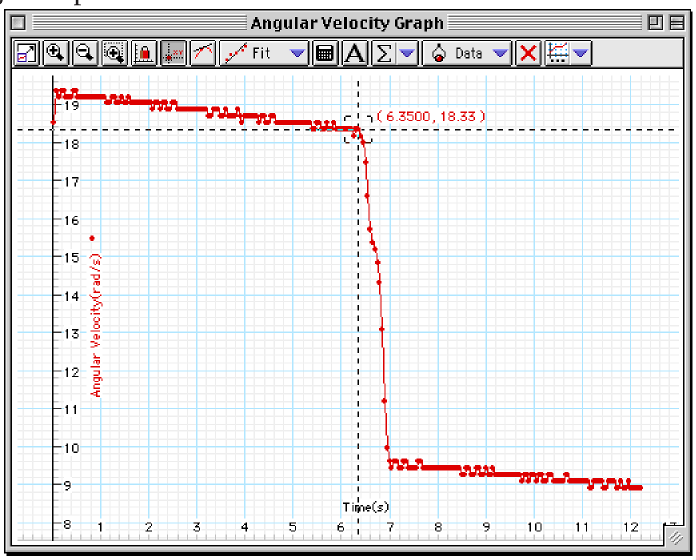
- Run #1 will appear in the Data list.

5. Repeat the data recording procedure a total of three times**.**

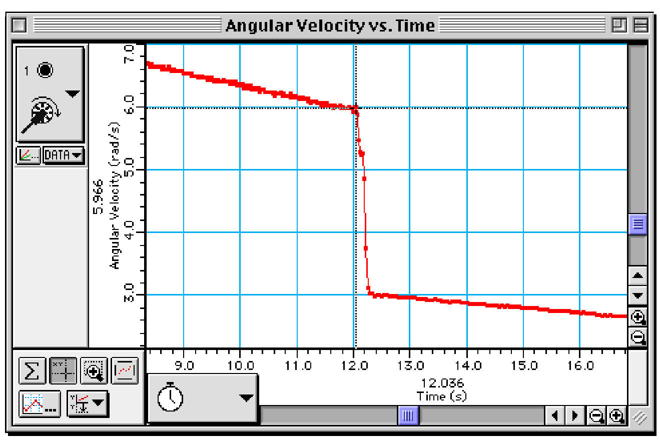
Analyzing the Data

1. Use the Graph display's built-in analysis tools to determine the angular speed just before the disk was dropped and the angular speed just after the disk was dropped. Record the initial angular speed and the final angular speed in the Lab Report.

- In *DataStudio*, use the 'Smart Tool' to find the coordinates of the point on the plot just before the second disk was dropped on the first disk. Then find the coordinates of the point just after the second disk was dropped and the two disks are rotating together. The 'Y-coordinate' is the angular speed.



- In *ScienceWorkshop*, use the 'Smart Cursor' to find the coordinates of the point on the plot just before the second disk was dropped on the first disk. Then find the coordinates of the point just after the second disk was dropped and the two disks are rotating together. The 'Y-coordinate' is the angular speed.



2. Calculate the expected (theoretical) values for the final angular speed ($\omega_f = 0.5\ \omega_i$) and record it in the Lab Report.

3. Repeat the data analysis process for each run, selecting the next run from the data list. Complete the data table by calculating the percent difference between the actual and the theoretical values of the final angular speed.

Record your results in the Lab Report section.

Name ______________________ Class _______________ Date _________

Lab Report – Activity P23: Conservation of Angular Momentum

What Do You Think?

What interesting sporting events can be understood using the concept of conservation of angular momentum?

Data Table

Trial	ω_i (rad/s)	ω_f (actual) (rad/s)	ω_f (theory) (rad/s)	% Difference
Run #1				
Run #2				
Run #3				

Questions

1. How does the experimental value for the final angular velocity agree with the theoretical value for the final angular velocity?

2. What are possible reasons for the difference between the experimental value and the theoretical value, if any?

Appendix: Modify a *ScienceWorkshop* File

Modify an existing *ScienceWorkshop* file to add the Rotary Motion Sensor.

Open the *ScienceWorkshop* File

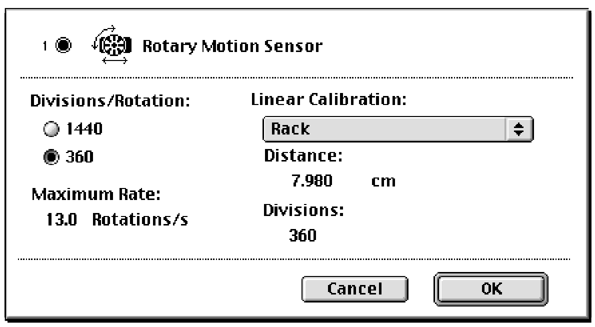
Open the file titled as shown:

ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P27 Cons. Angular Momentum	P27_ANGU.SWS

- The *ScienceWorkshop* file has a Graph display of Angular Velocity versus Time (using data from a Smart Pulley).
- You need to replace the Smart Pulley with the Rotary Motion Sensor in the Experiment Setup window and set up the Rotary Motion Sensor parameters. Then you need to change the Graph display.

Set Up the Rotary Motion Sensor

In the Experiment Setup window, click and drag the digital sensor plug to Channel 1. Select 'Rotary Motion Sensor' from the list of sensors. Click 'OK'. **Result**: The Rotary Motion Sensor setup window opens. Click 'OK' to return to the Experiment Setup window.



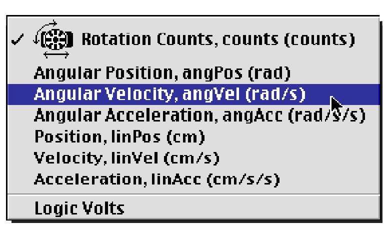
Set the Sampling Options

Click the 'Sampling Options' button in the Experiment Setup window or select 'Sampling Options' from the Experiment menu to open the Sampling Options window. **Result**: The Sampling Options window opens.

Under 'Periodic Samples' click the right arrow to set the sample rate at '20 Hz' (20 measurements per second). Click 'OK' to return to the Experiment Setup window.

Change the Graph Display

Click the 'Y-Axis Input' menu and select 'Digital 1, Angular Velocity, angVel (rad/s)'.



Name ____________________ Class _____________ Date _________

Activity P24: Conservation of Linear and Angular Momentum (Photogate/Pulley System)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Momentum	P24 Linear Angular.DS	P28 Cons Linear & Ang Mom	P28_CLAM.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Photogate/Pulley System (ME-6838)	1	**Projectile Launcher (ME-6800)**	1
Balance (SE-8723)	1	**Rotating Platform (ME-8951)**	1
Calipers (SF-8711)	1	Rubber band, large	1
Mass and Hanger Set (ME-9348)	1	**Spirit Level (SE-8729)**	1
Projectile Catcher (ME-6815)	1	**String (SE-8050)**	1 m

What Do You Think?

What are differences between linear and rotational motion? How is momentum calculated for linear and rotational motion?

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

Background

When an object with linear momentum collides and is captured by a system that is free to rotate, the angular momentum of the system with the captured object after the collision equals the linear momentum of the object before the collision.

$$\vec{L} = I\vec{\omega} = m_b \vec{v}_b R$$

where **L** is the angular momentum of the rotating system, **I** is the rotational inertia, ω is the angular velocity, m_b is the mass of the object, v_b is the velocity of the object, and **R** is the distance from the axis of rotation to the point where the object collides with the rotating system. Solving for the velocity of the object gives:

$$v_b = \frac{I\omega}{m_b R}$$

In the activity, this velocity value will be compared with another measured velocity value. For a ball shot horizontally with initial speed v_0, the horizontal distance, x, traveled by the ball is: $x = v_0 t$ where t is the time of flight for the ball. Assuming no air resistance, the time of flight depends only on the vertical distance, y, where "g" is the acceleration due to gravity: $t = \sqrt{\frac{2y}{g}}$.

SAFETY REMINDER

- Never aim or fire the projectile launcher at a person.
- Follow the directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

Pre-Lab For You To Do

Use the Photogate/Pulley System to measure the motion of the Rotating Platform and Projectile Catcher and the ball as the rotating system is pulled by a hanging mass. Use *DataStudio* or *ScienceWorkshop* to calculate the tangential acceleration. From the results, determine the rotational inertia of the rotating system (consisting of the Rotating Platform and Projectile Catcher with ball).

Pre-Lab Background

To find the rotational inertia of the system, apply a known torque to the system and measure the resulting motion.

Since $\tau = I\alpha$, solving for the rotational inertia, $\boldsymbol{I}$, gives $\boldsymbol{I} = \frac{\tau}{\alpha}$.

where α is the angular acceleration and τ is the torque. Now, $\tau = \boldsymbol{r} \times \boldsymbol{F}$, where $\boldsymbol{r}$ is the distance from the center of the rotating system to the point where a force is applied, and $\boldsymbol{F}$ is the applied force. In this case, the applied force is the tension ($\boldsymbol{T}$) in a string that is tied to a step pulley that is part of the Rotating Platform. A hanging mass $\boldsymbol{m}$ pulls the string. The value of $\boldsymbol{r}$ is the radius of the step pulley on the platform. The radius is perpendicular to the applied force ($\boldsymbol{T}$).

Therefore, for this activity, the torque is: $\tau = \boldsymbol{rT}$.

Applying Newton's Second Law for the hanging mass, $\boldsymbol{m}$, results in: $\sum \boldsymbol{F} = \boldsymbol{ma} = \boldsymbol{mg} - \boldsymbol{T}$
Solving for the tension in the string gives: $\boldsymbol{T} = \boldsymbol{m(g-a)}$. The expression for torque becomes: $\tau = \boldsymbol{rT} = \boldsymbol{rm(g-a)}$

The linear acceleration $\boldsymbol{a}$ of the hanging mass is the <u>tangential</u> acceleration, $\boldsymbol{a_T}$, of the rotating apparatus.

The angular acceleration is related to the tangential acceleration as follows:

$$\alpha = \frac{\boldsymbol{a_T}}{\boldsymbol{r}}$$

Substituting for the torque and angular acceleration gives:

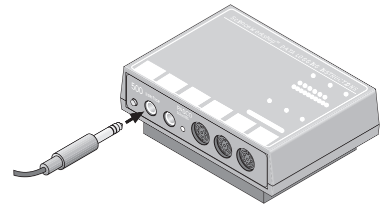
$$\boldsymbol{I} = \frac{\tau}{\alpha} = \boldsymbol{rm(g-a)} \div \frac{\boldsymbol{a_T}}{\boldsymbol{r}} = \boldsymbol{rm(g-a)}\frac{\boldsymbol{r}}{\boldsymbol{a_T}} = \frac{\boldsymbol{mgr^2}}{\boldsymbol{a_T}} - \boldsymbol{mr^2} = \boldsymbol{mr^2}\left(\frac{\boldsymbol{g}}{\boldsymbol{a_T}} - \boldsymbol{1}\right)$$

The rotational inertia, $\boldsymbol{I}$, can be calculated from the tangential acceleration, $\boldsymbol{a_T}$, the hanging mass, $\boldsymbol{m}$, and the radius of the step pulley, $\boldsymbol{r}$.

Name ____________________ Class _____________ Date _________

Pre-Lab PART I: Computer Setup

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



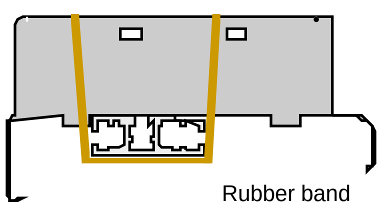
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P24 Prelab Linear Angular.DS	X28 Inertia	X28_CLAM.SWS

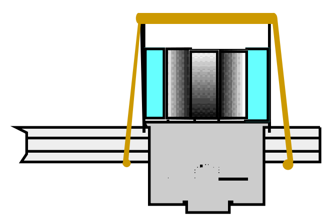
- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Velocity versus Time and a Digits display of Velocity.
- Note: The spoke arc length for the Photogate/Pulley System is set at 0.015 m. If you are using a different pulley, change the spoke arc length in the sensor window by double clicking on the Smart Pulley icon in the Experiment setup window.

Pre-Lab PART II: Sensor Calibration and Equipment Setup

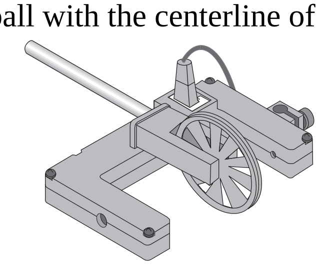
- You do not need to calibrate the Photogate/Pulley System.

1. Put the Rotating Platform on a horizontal surface near the edge of the surface.
2. Use a large rubber band to attach the Projectile Catcher to one end of the Rotating Platform.

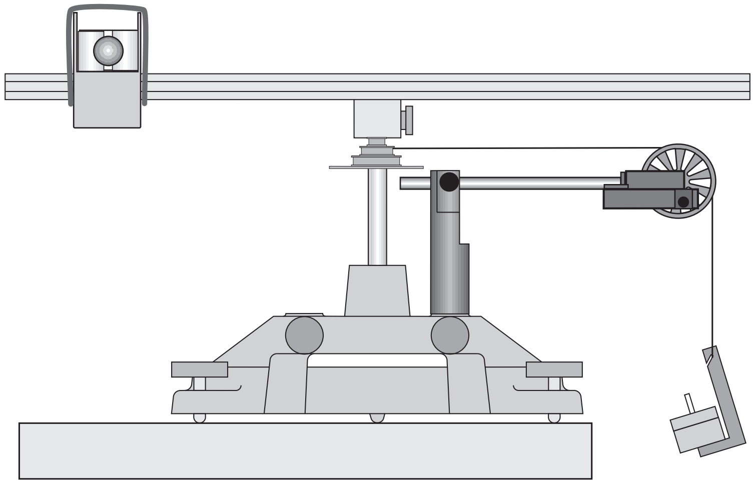




3. Use the leveling feet to level the platform.
4. Place the 1-inch (2.5-cm) steel ball into the catcher. Align the ball with the centerline of the platform.
5. Put the support post in the base of the Rotating Platform.
6. Use the Pulley Mounting Rod to attach the Pulley to the tab on the Photogate.
7. Mount the rod of the Photogate/Pulley System in the hole of the support post.

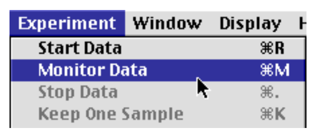


8. Use a piece of string that is about 20 centimeters longer than the distance from the top of the Photogate/Pulley System to the floor. Tie one end of the string through a hole in the step pulley that is on the Rotating Platform shaft. Put the string in the groove on the pulley.
9. Attach a mass hanger to the other end of the string.



Pre-Lab PART IIIA: Data Recording

1. To compensate for friction, find out how much mass must be put on the end of the string to overcome kinetic friction and allow the system to rotate at a constant speed. This friction mass will be subtracted from the total mass used to accelerate the system.
2. Wind the string around the platform's step pulley by rotating the platform until the mass hanger is raised almost to the pulley. Hold the platform in place.
3. Click the Velocity Digits display to make it active. Move it so you can see the display.
4. Release the platform so it can begin rotating. Start monitoring the speed. Watch the speed in the Digits display.



- In *DataStudio*, select 'Monitor Data' in the Experiment menu.
- In *ScienceWorkshop*, click the 'MON' button.

5. Add or subtract mass from the hanger until the speed displayed in the Digits display is nearly constant.

- NOTE: You can use individual paper clips to change the mass by small amounts.
- When the hanger reaches the floor, wind the string around the step pulley by rotating the platform until the mass hanger is almost to the Photogate/Pulley System, and then release the platform again. Continue adjusting the mass on the hanger until the platform rotates with a nearly constant speed.

6. End data recording.
7. Carefully measure and record the total mass on the end of the string in the Data Table in the Lab Report section.

Name ____________________ Class _____________ Date _________

Pre-Lab PART IIIB: Data Recording

1. Put a total of 50 g (0.050 kg) on the end of the string (don't forget to account for the mass hanger itself). Wind the string around the platform's step pulley by rotating the platform until the mass hanger is raised almost to the Photogate/Pulley System. Hold the platform.
2. Begin recording data and release the platform. End data recording just before the falling mass reaches the floor.
- "Run #1" will appear in the Data list window.
3. Use calipers to measure the diameter of the step pulley on the rotating platform. Calculate and record the radius of the step pulley in the Data Table in the Lab Report section.

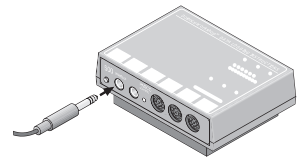
Pre-Lab Analyzing the Data

1. Click the Graph display to make it active. Find the slope of the Velocity vs. Time plot.
- In *DataStudio*, click the 'Fit' menu button (). Select 'Linear'. Use the cursor to click-and-draw a rectangle around the region of smoothest data in the Graph.
- 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 **"Curve Fit, Linear Fit"** from the Statistics Menu button ().
2. Record the value of the tangential acceleration in the Data Table in the Lab Report section.
3. Calculate the rotational inertia of the rotating platform system. Record the value in the Data Table in the Lab Report section.

For You To Do

Use the Projectile Launcher to shoot the ball into the Projectile Catcher mounted on the Rotating Platform. Use the Photogate/Pulley System to measure the motion of the Rotating Platform after the ball is captured. Use *DataStudio* or *ScienceWorkshop* to obtain the angular velocity of the system. From the data, calculate the average initial linear velocity of the ball.

PART I: Computer Setup



1. Leave the Photogate's phone plug connected to Digital Channel 1 on the interface.
2. Open the document titled as shown:

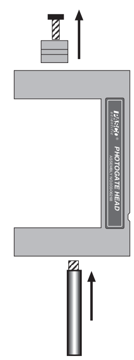
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P24 Linear Angular.DS	P28 Cons Linear & Ang Mom	P28_CLAM.SWS

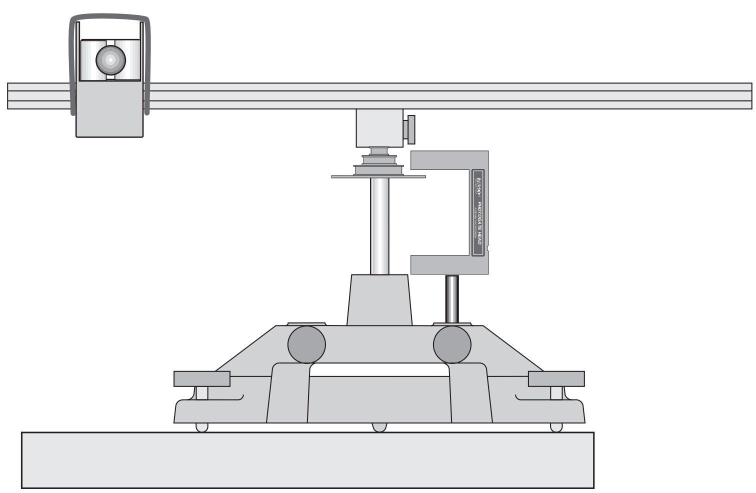
- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Table display of angular velocity.

PART II: Sensor Calibration and Equipment Setup

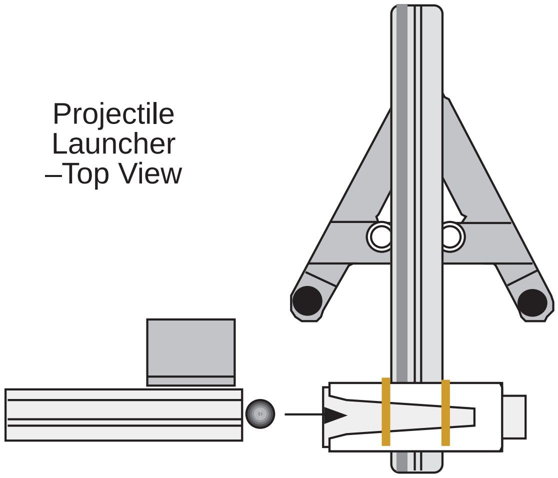
- You do not need to calibrate the Photogate/Pulley System.

1. Measure the distance from the axis of the Rotating Platform to the center of the ball in the Catcher. Record the distance as the radius, R, in the Data section.
2. Remove the ball from the Projectile Catcher. Measure the mass of the ball, m_b, and record the value in the Data section.
3. Remove the Photogate/Pulley System from the Rotating Platform's support post and also remove the support post. Remove the pulley so you can use the Photogate. Remove the swivel clamp from the side of the Photogate.
4. Attach the Photogate to the Rotating Platform's short threaded rod. Mount the Photogate to the base of the Rotating Platform.
5. Adjust the position of the threaded rod so the Photogate is aligned with the holes on the bottom lip of the Rotating Platform's step pulley.





6. Clamp the Projectile Launcher in position so it can fire the ball into the catcher that is mounted on the Rotating Platform.



7. Move the platform so the edge of the Catcher is against the muzzle of the Launcher and the platform is perpendicular to the line-of-flight of the Launcher.
8. Adjust the base of the Rotating Platform so that the Photogate beam is unblocked (the red light-emitting diode is OFF).
9. Use a spirit level to check the rotating platform. Re-level the platform, if necessary.

PART IIIA: Data Recording – Catch the Ball

1. Place the ball in the Projectile Launcher and cock the launcher to its long-range position.
2. Place the Rotating Platform so the end of the catcher is next to the muzzle of the Launcher.
3. Begin data recording. Pull upward on the string of the launcher to fire the ball into the catcher.
4. Stop data recording just before the rotating platform swings around to the launcher. Stop the rotating platform before it reaches the launcher.

- Do not let the Rotating Platform and Catcher collide with the launcher.

5. Repeat the data recording process a total of five times.

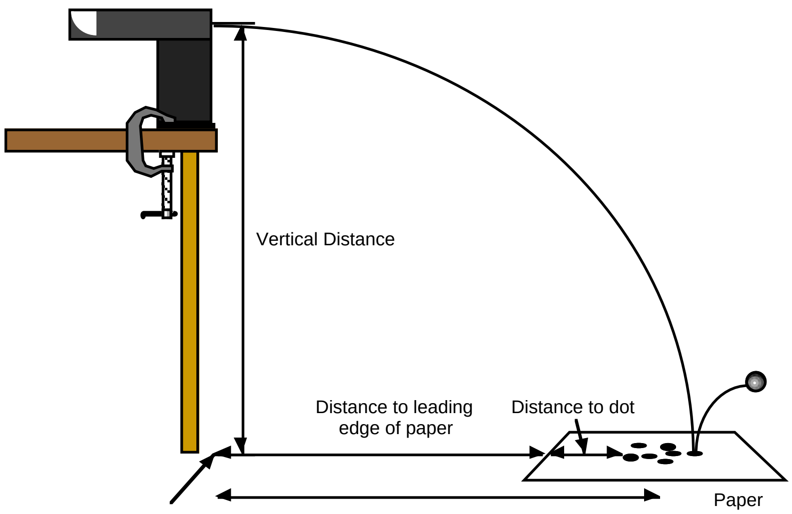
- Be careful when removing the ball from the catcher. Do not change the position of the catcher on the platform.

PART IIIB: Data Recording – Measure Initial Speed of the Projectile

1. Move the Rotating Platform out of the way of the Projectile Launcher. Aim the Launcher away from the table. Clear an area at least three meters from the table.
2. Put the ball into the Projectile Launcher and cock the Launcher to the long-range position. Fire one shot to locate where the ball hits the floor.
3. Tape a piece of white paper at the spot where the ball hit the floor. Tape a piece of carbon paper (carbon-side DOWN) on top of the white paper.
4. Fire five shots.
5. Measure the vertical distance from the bottom of the ball as it leaves the Launcher to the floor.

- The position of the ball when it is in the barrel of the Launcher is marked on the label of the launcher. You can use the outline of the ball for your measurement.

6. Use a plumb bob to find the point on the floor that is directly beneath the end of the barrel of the launcher.
7. Measure from the point on the floor to the leading edge of the white paper.
8. Measure from the leading edge of the white paper to each of the five dots and record these distances in the Data Table in the Lab Report section.



Analyzing the Data

1. Click the Table display to make it active.
2. Select 'Run #1'.

- In *DataStudio*, select Run #1 from the Data Menu (Data) in the Table display.
- In *ScienceWorkshop*, select Run #1 from the Data Menu (DATA).

3. The Table displays the angular speed of the rotating platform after it captured the ball. Record the first angular velocity value for the run in the Data Table.
4. Repeat the procedure to obtain angular velocity values for the other four runs of data.
5. Calculate the linear speed for each run of data, based on the mass of the ball, the angular momentum of the rotating system, and the radius, R, of the rotating system. Record the values in the Data Table.
6. From the data gathered in Part IIIB, find the average of the horizontal distances and record the value in the Data Table. Add the average value to the horizontal distance to the edge of the paper. Use the total as the horizontal distance, x.
7. Calculate the time of flight $t = \sqrt{\frac{2y}{g}}$ and the initial velocity of the ball $v_0 = \frac{x}{t}$.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - P24: Conservation of Linear and Angular Momentum

What Do You Think?

What are differences between linear and rotational motion? How is momentum calculated for linear and rotational motion?

Pre-Lab Data Table

Item	Value
Frictional mass	
Mass, m (0.050 kg - frictional mass)	
Radius of step pulley	
Tangential acceleration	
Rotational inertia of system	

Data Tables

Item	Value
Radius (R)	
Mass of ball (m_b)	

Run	Angular speed (rad/sec)	Linear speed, v_0, calculated (m/s)
1		
2		
3		
4		
5		
Avg.		

Item	Value
Vertical Distance	
Time of Flight	

Trial	Horizontal Distance (m)
1	
2	
3	
4	
5	
Average	

Item	Value
Horizontal Distance to edge of paper	
Total Horizontal Distance	
Linear speed	

Questions

1. What is the percent difference between the value of the measured linear speed and the average value of the calculated linear speed of the ball?

2. From the data, determine the kinetic energy of the ball as it left the launcher and the rotational kinetic energy of the ball, catcher, and disk system.

3. Based on this information, was kinetic energy conserved throughout the motion of the ball? Justify your answer.

Name ____________________ Class ______________ Date _________

Activity P25: Transforming Gravitational Potential Energy to Kinetic Energy (Rotary Motion Sensor)

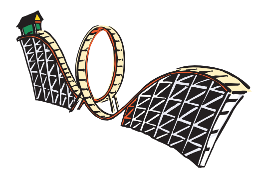
Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Energy	P25 GPE to KE.DS	(See end of activity)	(See end of activity)

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Rotary Motion Sensor (CI-6538)	1	**Mass and Hanger Set (ME-9348)**	1
Balance (SE-8723)	1	**Rotational Accessory (CI-6691)**	1
Base and Support Rod (ME-9355)	1	**Thread (inc. w/ CI-6691)**	1 m

Note

For this activity you need to know the rotational inertia of the disk that is part of the Rotational Accessory. Refer to activity "P22: Rotational Inertia" for information about how to measure the rotational inertia.

What Do You Think?



In this activity, a falling object applies a constant net torque to a rotating disk. As the object falls, its gravitational potential energy decreases and its translational kinetic energy increases. At the same time, the rotational kinetic energy of the disk increases. How does the decrease in gravitational potential energy compare to the increase in translational and rotational kinetic energy?

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

Background

The gravitational potential energy of an object depends on its weight and its vertical distance, h, relative to a reference point (usually the Earth's surface). The gravitational potential energy is:

$$P.E._{grav} = mgh$$

where m is the mass of the object and g is the acceleration due to gravity. The kinetic energy of a rotating object depends on its rotational inertia, I, and its angular speed, ω. The rotational kinetic energy is:

$$K.E._{rotational} = \tfrac{1}{2} I\omega^2.$$

As the object falls, it has translational kinetic energy:

$$K.E. = \tfrac{1}{2} mv^2$$

where m is the mass of the object, and v is its speed.

SAFETY REMINDERS

- Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

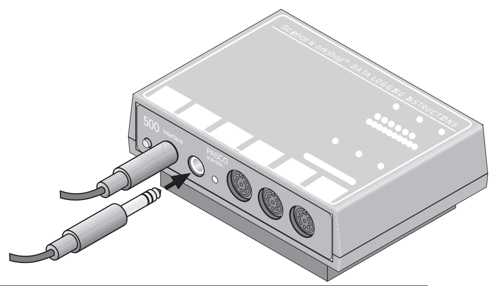
For You To Do

Attach a hanging mass to the step pulley on a Rotary Motion Sensor. Let the hanging mass drop so it causes a disk to rotate. Use the Rotary Motion Sensor to measure the motion of the hanging mass and the motion of the rotating disk. Use *DataStudio* or *ScienceWorkshop* to record and display the position and velocity of the hanging mass and the angular velocity of the rotating disk. Calculate the rotational kinetic energy of the rotating disk, the translational kinetic energy of the hanging mass, and the change in gravitational potential energy of the hanging mass.

The angular speed, ω, of the rotating disk is related to the linear speed, $\boldsymbol{v}$, of the falling object:

$\omega = \frac{\boldsymbol{v}}{\boldsymbol{r}}$ where $\boldsymbol{r}$ is the radius of the step pulley on the Rotary Motion Sensor.

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's stereo phone plugs into Digital Channels 1 and 2 on the interface.
3. Open the file titled as shown:

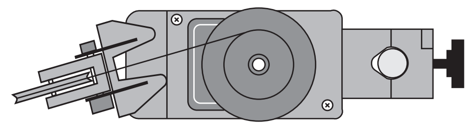
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P25 GPE to KE.DS	(See end of activity)	(See end of activity)

- The *DataStudio* file has a Workbook display, a Table display, and a Graph display. Read the instructions in the workbook.
- Data recording is set at 20 Hz. The Rotary Motion Sensor is set for 360 divisions per rotation and the 'Linear Calibration' is set for the 'Medium Pulley (Groove)'.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.

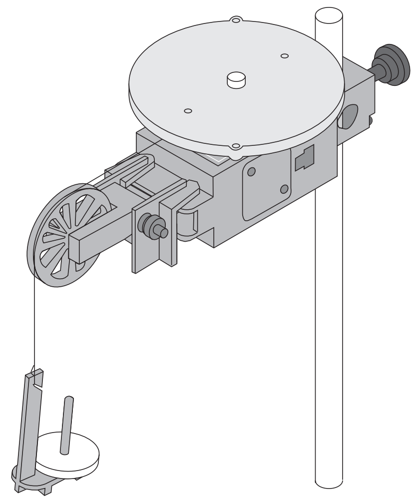
Name ____________________ Class _____________ Date _________

PART II: Sensor Calibration and Equipment Setup

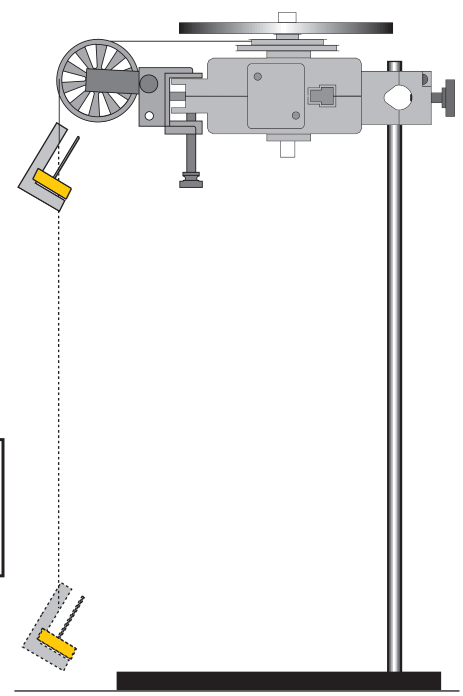
- You do not need to calibrate the sensor.



1. Mount the Rotary Motion Sensor on a support rod so the step pulley is on top.
2. Mount the clamp-on Super Pulley on the end of the Rotary Motion Sensor.
3. Use a piece of thread about 10 cm longer than the distance from the Super Pulley to the ground. Tie one end of the thread to the edge of the *medium* groove on the step pulley on the Rotary Motion Sensor. Drape the thread over the Super Pulley.
4. Attach the other end of the thread to a mass hanger. Adjust the angle of the Super Pulley so the thread is tangent to the step pulley and in the middle of the groove on the Super Pulley.
5. Remove the thumbscrew from the step pulley on top of the Rotary Motion Sensor. Place the disk on the pulley and attach the disk with the thumbscrew.



PART IIIA: Data Recording – Hanging Mass = 0.010 kg



1. Adjust the position of the mass hanger on the thread. Attach the hanger so it is high enough on the thread that the mass hanger will not hit the floor at its lowest position.
2. Add 5 g (0.005 kg) to the mass hanger so the total mass is about 10 g (0.010 kg).
3. Rotate the disk to wind the thread around the step pulley until the mass hanger is almost up to the Super Pulley. Hold the disk at this position.
4. Start recording data. (Hint: Click 'Start' in *DataStudio* or 'REC' in *ScienceWorkshop*.)

- Make sure that data recording has started. In *DataStudio*, the clock display will begin to change. In *ScienceWorkshop*, the 'data indicator' under 'REC' will begin to flash.

- After data recording starts, release the disk and let the mass fall while the Rotary Motion Sensor measures the motion.

5. Stop recording data *just before* the mass reaches its lower position. Stop the disk.

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

6. Remove the mass hanger and measure its total mass. Record the mass in the Lab Report section.

Note: If the position, velocity, and angular velocity are negative, switch the position of the plugs in the interface.

PART IIIB: Data Recording – Different Hanging Masses

1. Repeat the data recording process but change the hanging mass to 15 g (0.015 kg) and then 20 g (0.020 kg).
2. Measure the total mass of the mass hanger after each run and record the mass in the Lab Report section.

Analyzing the Data

1. Use the Table display to determine the following:

q change in position of the hanging mass (Δh)

q final linear speed of the hanging mass (v)

q final angular speed of the rotating disk (ω)

- Scroll to the bottom of the Table. The column of 'Position' data will have one more value than the columns of 'Velocity' and 'Angular Velocity'.

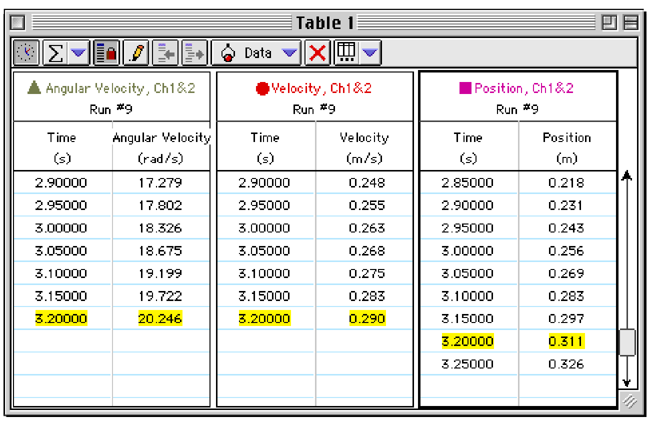
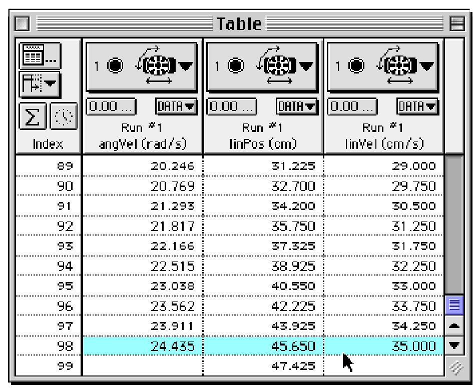


Table 1

Angular Velocity, Ch1&2 Run #9 Time (s)	Angular Velocity (rad/s)	Velocity, Ch1&2 Run #9 Time (s)	Velocity (m/s)	Position, Ch1&2 Run #9 Time (s)	Position (m)
2.90000	17.279	2.90000	0.248	2.85000	0.218
2.95000	17.802	2.95000	0.255	2.90000	0.231
3.00000	18.326	3.00000	0.263	2.95000	0.243
3.05000	18.675	3.05000	0.268	3.00000	0.256
3.10000	19.199	3.10000	0.275	3.05000	0.269
3.15000	19.722	3.15000	0.283	3.10000	0.283
3.20000	20.246	3.20000	0.290	3.15000	0.297
				3.20000	0.311
				3.25000	0.326



Table

Index	Run #1 angVel (rad/s)	Run #1 linPos (cm)	Run #1 linVel (cm/s)
89	20.246	31.225	29.000
90	20.769	32.700	29.750
91	21.293	34.200	30.500
92	21.817	35.750	31.250
93	22.166	37.325	31.750
94	22.515	38.925	32.250
95	23.038	40.550	33.000
96	23.562	42.225	33.750
97	23.911	43.925	34.250
98	24.435	45.650	35.000
99		47.425	

2. Record the final angular speed of the rotating disk (last value for angular velocity), the final linear speed of the hanging mass (last value for velocity), and the change in position of the hanging mass (second to last value for position).
3. Repeat the process to find the final angular speed, the final linear speed, and the change in position of the hanging mass for the other hanging masses.
4. Use your data to calculate the rotational kinetic energy, the translational kinetic energy, and the change in gravitational potential energy for each run of data.
5. Compare the total kinetic energy (rotational plus translational) to the change in gravitational potential energy. Calculate the percent different between the KE and the GPE.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report – Activity P25: Transforming Gravitational Potential Energy to Kinetic Energy

What Do You Think?

In this activity, a falling object applies a constant net torque to a rotating disk. As the object falls, its gravitational potential energy decreases and its translational kinetic energy increases. At the same time, the rotational kinetic energy of the disk increases. How does the decrease in gravitational potential energy compare to the increase in translational and rotational kinetic energy?

Data

Run	mass (kg)	angular speed (rad/s)	linear speed (m/s)	change in position (m)
1				
2				
3				

Rotational inertia, ***I***, of the disk (from activity P22) 1.48×10^{-4} kg m^2

Run	$K.E._{rotational} = \frac{1}{2} I\omega^2$	$K.E. = \frac{1}{2} mv^2$	Total KE	$P.E._{grav} = mgh$	% difference
1					
2					
3					

Questions

1. Is the rotational kinetic energy equal to the gravitational potential energy of the falling object?

2. How does the total kinetic energy compare to the gravitational potential energy of the falling object?

Name ____________________ Class _____________ Date _________

Appendix: Modify a *ScienceWorkshop* File

Modify an existing *ScienceWorkshop* file to add the Rotary Motion Sensor.

Open the *ScienceWorkshop* File

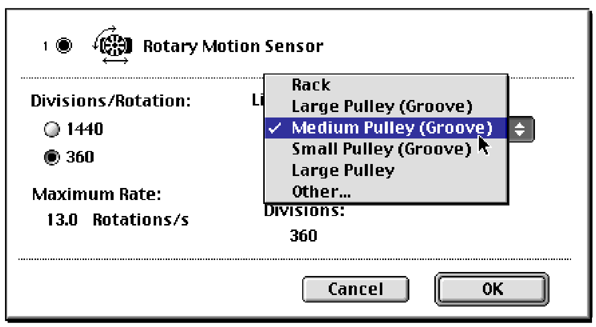
Open the file titled as shown:

ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P29 Grav PE to Total KE	P29_GRAV.SWS

- The *ScienceWorkshop* file has a Graph display and a Table display of Velocity versus Time (using data from a Smart Pulley).
- You need to replace the Smart Pulley with the Rotary Motion Sensor in the Experiment Setup window and set up the Rotary Motion Sensor parameters.
- Finally, close the existing displays and create a new Graph display and a new Table display.

Set Up the Rotary Motion Sensor

In the Experiment Setup window, click and drag the digital sensor plug to Channel 1. Select 'Rotary Motion Sensor' from the list of sensors. Click 'OK'. **Result**: The Rotary Motion Sensor setup window opens.



Select 'Medium Pulley (Groove)' from the 'Linear Calibration' menu. Click 'OK' to return to the Experiment Setup window.

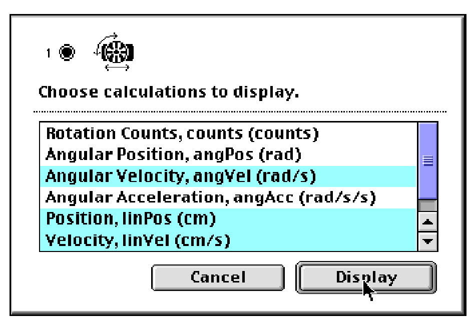
Set the Sampling Options

Click the 'Sampling Options' button in the Experiment Setup window or select 'Sampling Options' from the Experiment menu to open the Sampling Options window. **Result**: The Sampling Options window opens.

Under 'Periodic Samples' click the right arrow to set the sample rate at '20 Hz' (20 measurements per second). Click 'OK' to return to the Experiment Setup window.

Create a New Graph Display

Close the existing Graph display. In the Experiment Setup window, click and drag the Graph display icon to the Rotary Motion Sensor icon. **Result**: The 'Choose Calculations…' window opens.

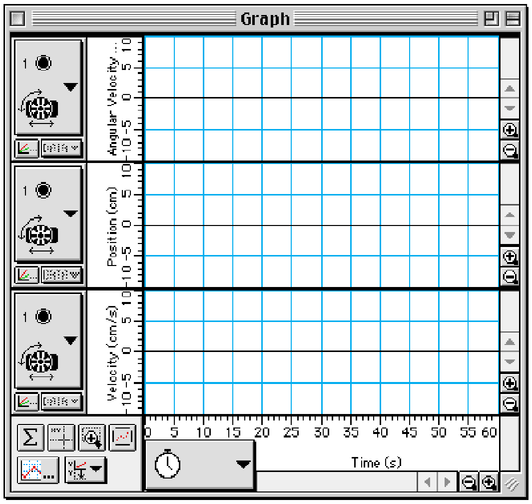


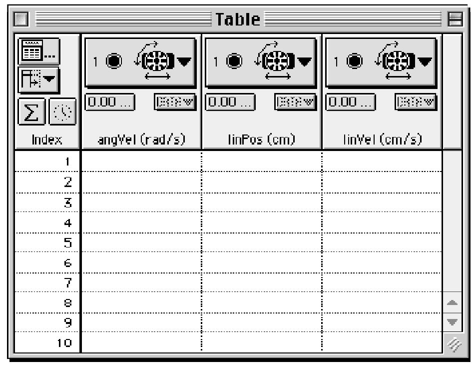
Select 'Angular Velocity', 'Position', and 'Velocity' from the list. Click 'OK' to return to the Experiment Setup window. **Result**: The new Graph display shows a plot for each of the three measurements.

Create a New Table Display

Close the existing Table display. In the Experiment Setup window, click and drag the Table display icon to the Rotary Motion Sensor icon. Result: The ‘Choose Calculations…’ window opens.

Select ‘Angular Velocity’, ‘Position’, and ‘Velocity’ from the list. Click ‘OK’ to return to the Experiment Setup window. **Result**: The new Table display shows a plot for each of the three measurements.





Name ____________________ Class _____________ Date _________

Activity P26: Centripetal Force on a Pendulum (Force Sensor, Photogate)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Centripetal force	P26 Centripetal Force.DS	P30 Centripetal Force	P30_CENT.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Economy Force Sensor (CI-6746)	1	**Clamp, right angle (SE-9444)**	2
Photogate (ME-9204B)	1	**Mass and Hanger Set (ME-8967)**	1
Balance (SE-8723)	1	Pendulum bob	1
Base and Support Rod (ME-9355)	1	**String (SE-8050)**	1 m
Calipers (SF-8711)	1	**Support Rod (ME-8736)**	1

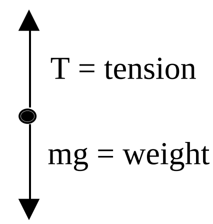
What Do You Think?

What are the factors that affect the centripetal force on a pendulum bob as the pendulum swings back and forth? Does the centripetal force depend on how fast the pendulum bob is swinging?

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

Background

A pendulum bob follows a circular path. Therefore, it is acted on by a centripetal ("center-seeking") force. In the case of the pendulum, the tension in the string causes the bob to follow the circular path. At the bottom of the pendulum's swing the net force on the bob is the combination of the tension in the string and the force due to gravity.



From Newton's Second Law, $\Sigma F = T - mg = ma = F_c$

where T is the tension in the string, m is the mass of the pendulum bob, g is the acceleration due to gravity, and F_c is the centripetal force.

The Force Sensor will be zeroed when the pendulum is at rest in its equilibrium position (when $T = mg$). Thus the force measured by the Force Sensor when the pendulum passes through the lowest point of the swing is equal to the centripetal force F_c.

The centripetal force can also be found using the speed, v, of the bob as it passes through the lowest point of the swing using:

$$F_c = m\frac{v^2}{r}$$

where r is the radius of the circular path which, in this case, is equal to the length of the pendulum.

SAFETY REMINDER

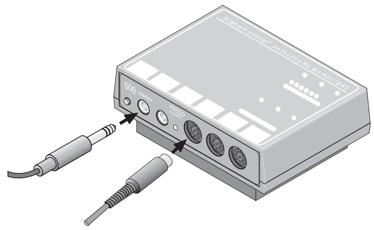
- Follow the directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the Force Sensor to measure the centripetal force on a pendulum bob at the lowest point of its swing. Use the Photogate to measure the time that the pendulum bob blocks the Photogate beam. Enter the value for the diameter of the pendulum bob. For the bottom of the pendulum swing, *DataStudio* or *ScienceWorkshop* calculates and displays the speed of the pendulum bob and the centripetal force on the pendulum.

PART I: Computer Setup



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

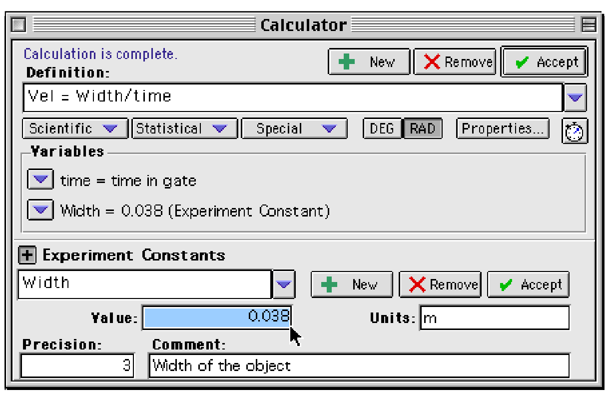
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P26 Centripetal Force.DS	P30 Centripetal Force	P30_CENT.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Force and Velocity vs. Time.
- Data recording is set at 100 Hz for the Force Sensor.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Photogate.
- To calibrate the Force Sensor, refer to the description in the Force Sensor Manual.

1. Measure the value of the diameter of the pendulum bob. Record the diameter in the Data Table in the Lab Report section.
2. Enter the diameter into the software.



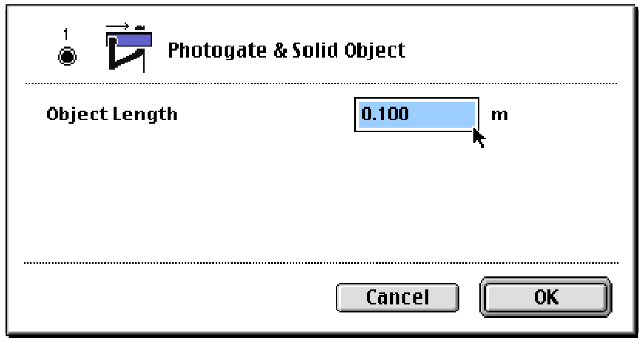
- In *DataStudio*, double click on the Vel calculation in the Summary Window. The Calculator window will open. The window shows the calculation for velocity.

  The pendulum width is stored as an 'Experiment Constant'. If the diameter for the pendulum is different than the value listed, highlight the width value in the 'Value' window and type in diameter of the pendulum.

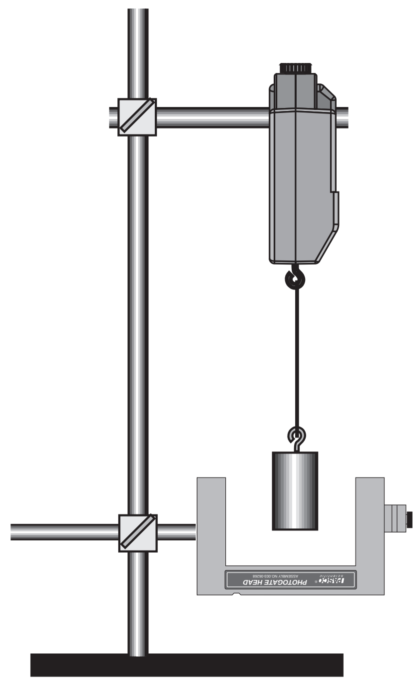
  Click the 'Accept' button to save your change.

  Close the Experiment Calculator window.

- In the *ScienceWorkshop* Experiment Setup window, double click on the Photogate & Solid Object icon. If the diameter for the pendulum is different than the value listed, highlight the 'Object Length' value and type in diameter of the pendulum. Click OK to accept the change.



3. Mount the Force Sensor on a horizontal rod with the hook end down.
4. Measure the mass of the pendulum bob. Record the mass in the Data Table in the Lab Report section.
5. To make the pendulum, use a piece of string that is about one meter long. Tie one end of the string to the hook on the Force Sensor and tie the other end to the pendulum bob.
6. Arrange the Photogate so the pendulum bob blocks the Photogate's beam when the bob is at rest. The center of mass of the pendulum bob should be approximately at the same height as the Photogate beam.
7. Measure the length of the pendulum from the bottom of the Force Sensor's hook to the middle of the pendulum bob. Record the length of the pendulum in the Data Table.



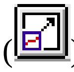
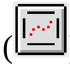
- Practice swinging the pendulum bob. Pull the pendulum bob to the side about 15 to 20 centimeters. Gently release the bob so it swings through the Photogate as smoothly as possible. The middle of the pendulum should break the photogate beam. Adjust the position of the Photogate if necessary.
- Do not let the pendulum bob hit the Photogate.

PART III: Data Recording

1. When the pendulum bob is at rest, zero the Force Sensor by pressing the tare button.
2. Set the pendulum in motion. Let the pendulum swing back-and-forth several times to allow any oscillations to damp out.
3. Begin recording data.
4. Record data for about 20 seconds. End data recording.

Analyzing the Data

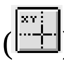
1. Click on the Graph Display to make it active. Rescale the Graph axes to fit the data.

- In *DataStudio*, click on the 'Scale to Fit' button ().
- In *ScienceWorkshop*, click on the 'Autoscale' button ().

2. Find the maximum centripetal force and corresponding velocity value.

In *DataStudio*, click the Force vs. Time plot to make it active. Click the 'Smart Tool' button ().

- Move the Smart Tool to the first trough in the plot of Force versus Time and read the value of force. Record the absolute value in the Data Table in the Lab Report section.
- Click on the plot of Velocity vs. Time and click on the Smart Tool button. A second Smart Tool will appear. Place the tool at the velocity point that corresponds in time to the trough you measured in the plot of centripetal force. Record the value of speed in the Data Table.

In *ScienceWorkshop*, click the 'Smart Cursor' ().

- Move the Smart Cursor to the first trough in the plot of force versus time and read the value of force. Record the absolute value in the Data Table in the Lab Report section.
- Press and hold the Shift key on the keyboard. The horizontal position of the Smart Cursor will freeze. Move the Smart Cursor vertically into the plot of velocity and place the cursor at the velocity point that corresponds to the trough you measured in the plot of centripetal force. Record the value of speed in the Data Table.

3. Repeat the data analysis process for four more troughs on the plot of centripetal force. Record the maximum centripetal force and the corresponding speed in the Data Table in the Lab Report section.
4. For each value of speed you measured, calculate the centripetal force using the mass, speed, and length of the pendulum. Record the calculated value of centripetal force in the Data Table.
5. Calculate the percent difference between the measured centripetal force and the calculated centripetal force for each set of points. Record the percent differences in the Data Table.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P26: Centripetal Force on a Pendulum

What Do You Think?

What are the factors that affect the centripetal force on a pendulum bob as the pendulum swings back and forth? Does the centripetal force depend on how fast the pendulum bob is swinging?

Data Tables

Item	Value
Diameter	
Mass	
Length	

Points	F_c, measured (N)	v (m/s)	F_c, calculated (N)	% difference
1				
2				
3				
4				
5				

Questions

1. How do your measured values of centripetal force compare to the calculated values of centripetal force?

2. What are possible reasons for the differences between the measured and calculated values of centripetal force?

Optional

- Try a different mass value for the pendulum bob or a different length for the pendulum or change the speed of the pendulum and repeat the data recording process.

Optional Data Tables

Item	Value
Diameter	
Mass	
Length	

Points	F_C, measured (N)	v (m/s)	F_C, calculated (N)	% difference
1				
2				
3				
4				
5				

Questions

1. How do your measured values of centripetal force compare to the calculated values of centripetal force?

2. How do the centripetal force values in the optional activity compare with the values from the original activity?

Name ____________________ Class _____________ Date _________

Activity P27: Speed of Sound in Air
(Sound Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Speed of sound	P27 Speed of Sound 1.DS	(See end of activity)	(See end of activity)

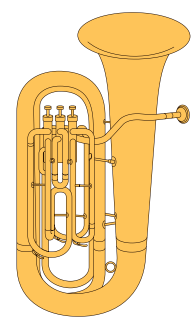
Equipment Needed	**Qty**	**Other**	**Qty**
Sound Sensor (CI-6506B)	1	Tape, duct	1 roll
Base and Support Rod (ME-9355)	1	Tube, cardboard, 15 cm diameter	1
Clamp, three-finger (SE-9445)	1		
Tape Measure (SE-8712)	1		

What Do You Think?

How can you use a Sound Sensor to measure the speed of sound in air?

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

Background



The speed of sound is different in different materials. The speed depends on the elastic modulus and the density of the material. For example, the elastic modulus of helium is about the same as the elastic modulus of air, but the density of helium is much less. Therefore, the speed of sound in helium is about three times faster than the speed in air.

In gases, the speed of sound depends on the temperature. In air, the speed increases approximately 0.60 m/s for each Celsius degree increase in temperature.

Theoretically, you can calculate the speed of sound from the distance the sound travels and the time it takes. In practice the calculation is often based on the interval of time between when a sound is produced and its echo is detected. The speed of sound is the round trip distance divided by the round trip time.

SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Snap your fingers at the open end of a tube that is closed at the other end. Use a Sound Sensor to detect the snapping sound and its echo.

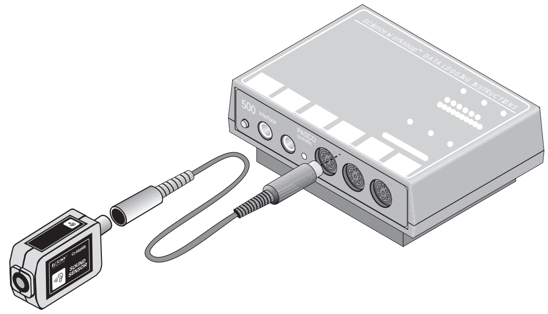
Use *DataStudio* or *ScienceWorkshop* to measure the time between the sound and its echo. Measure the length of the tube. Use the distance and the round trip time of the sound to calculate the speed of sound in air.

PART I: Computer Setup

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

2. Connect one end of the interface cable to the Sound Sensor and the other end into Analog Channel A on the interface.

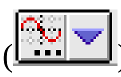
3. Open the file titled as shown:

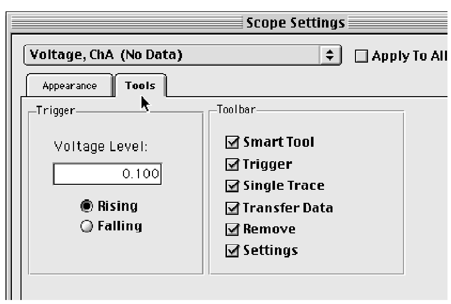


DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P27 Speed of Sound 1.DS	(See end of activity)	(See end of activity)

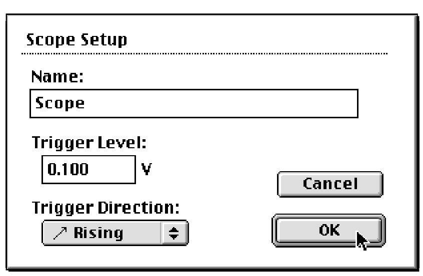
- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- Data sampling is set at 10000 measurements per second (10000 Hz).
- See the pages at the end of this activity for information about creating a *ScienceWorkshop* file.

4. Set the triggering in the Scope display to start on a ‘rising’ voltage of 0.100 volts.

- Hint: In *DataStudio*, click the ‘Scope Settings’ button () in the Scope display toolbar. **Result**: The Scope Settings window opens. Click the ‘Tools’ tab and set the trigger level. Click ‘OK’ to return to the Scope display.



- In *ScienceWorkshop*, double-click the Scope display. **Result**: The Scope Setup window opens. Set the trigger level. Click ‘OK’ to return to the Scope display.



Name ____________________ Class _____________ Date _________

PART II: Sensor Calibration and Equipment Setup

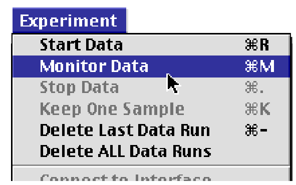
- **You do not need to calibrate the sensor.**

1. Close one end of the tube with duct tape.
2. Use a support rod and clamp to mount the Sound Sensor in the middle of the open end of the tube.

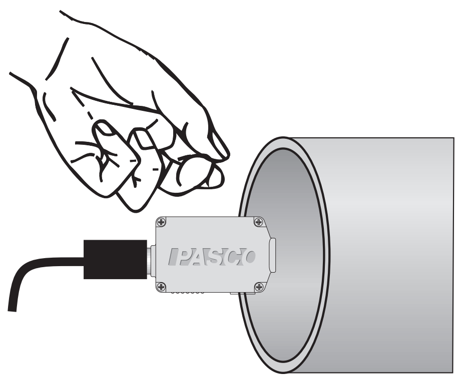
3. Measure the length of the tube and record the length in the Data Table.

PART III: Data Recording

1. Start monitoring data. (Hint: In *DataStudio*, select 'Monitor Data' from the Experiment menu. In *ScienceWorkshop*, click 'MON'.)



2. Snap your fingers at the open end of the tube. Watch the results on the Scope display.

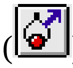


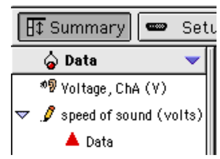
- Hint: If the first trace of data does not show the snapping sound and its echo, adjust the sweep speed in the Scope display.

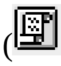
3. Stop monitoring data. (Hint: Click 'Stop'.)

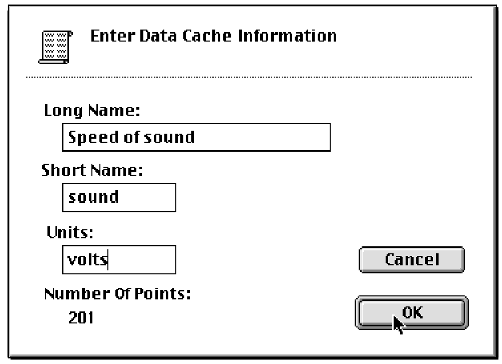
Analyzing the Data

1. Transfer the trace of data from the Scope display.

- In *DataStudio*, click the ‘Transfer Data’ button () in the Scope toolbar. **Result**: The data run appears under ‘Data’ in the Summary list.



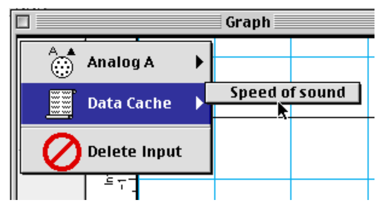
- In *ScienceWorkshop*, click the ‘Data Snapshot’ button () in the Scope display. **Result**: The ‘Enter Data Cache Information’ window opens. Enter a ‘Long Name’ and a ‘Short Name’. Enter ‘volts’ as the Units. **Result**: A new data run appears in the Data list. Click ‘OK’ to return to the Scope display.



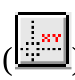
2. View the data in the Graph display.

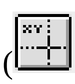
- In the *DataStudio* Graph display, select the run of data from the ‘Data menu’ (). **Result**: The Graph display shows the sound and its echo.

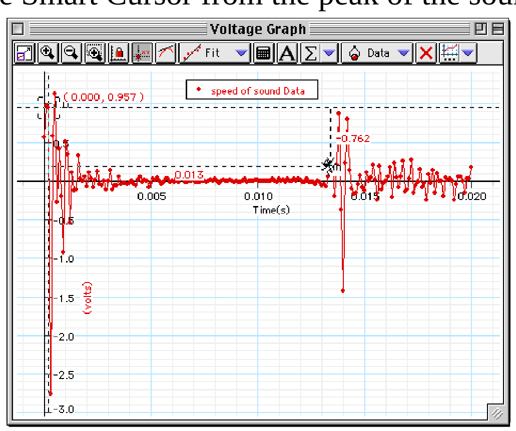
- In *ScienceWorkshop*, select ‘New Graph’ from the Display menu. **Result**: A Graph display opens. Select ‘Data Cache, Speed of sound’ from the ‘Y-Axis Input menu’. **Result**: The Graph display shows the sound and its echo.

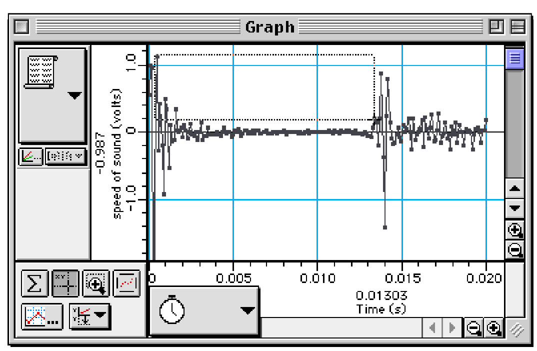


3. Use the Graph displays built-in analysis tools to find the time between the first peak of the sound and the first peak of its echo. Calculate the speed of sound.

- In *DataStudio*, use the ‘delta function’ of the Smart Tool (). Click and drag the corner of the Smart Tool from the first peak of the sound to the first peak of the echo.

- In *ScienceWorkshop*, use the ‘delta function’ of the Smart Cursor (). Click and drag the Smart Cursor from the peak of the sound to the peak of the echo.





Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P27: Speed of Sound in Air

What Do You Think?

How can you use a Sound Sensor to measure the speed of sound in air?

Data Table

Length of Tube (m)	Time (s)	Speed of Sound (m/s)

(Remember that the time from the first peak of the sound to the first peak of the echo is the 'round-trip' time for the sound to go down-and-back in the tube.)

Question

1. How does your experimental value for the speed of sound compare to the accepted value of 343 m/s for the speed of sound in air at a temperature of 20˚ C?

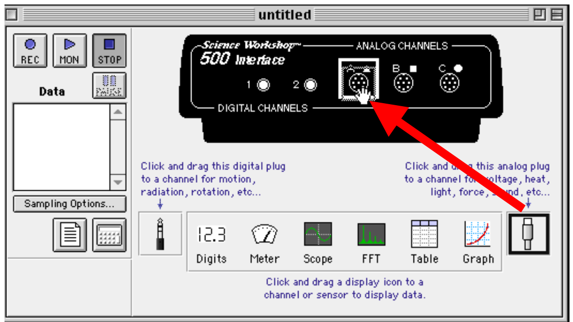
Name ____________________ Class _____________ Date _________

Appendix: Set Up *ScienceWorkshop*

Create a *ScienceWorkshop* file to measure the speed of sound in air.

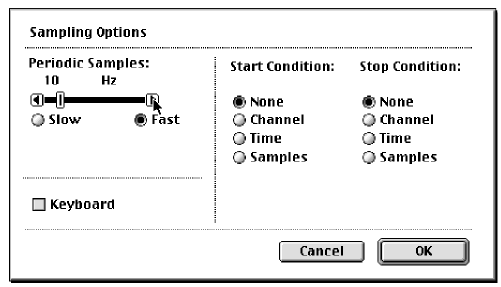
Set Up the Sensor

In the Experiment Setup window, click and drag the analog sensor plug to Channel A. Select 'Sound Sensor' from the list of sensors. Click 'OK' to return to the Experiment Setup window.



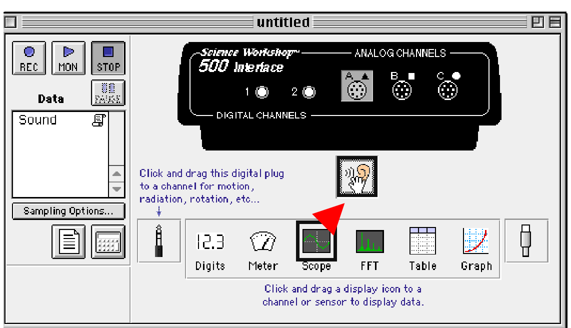
Set the Sampling Options

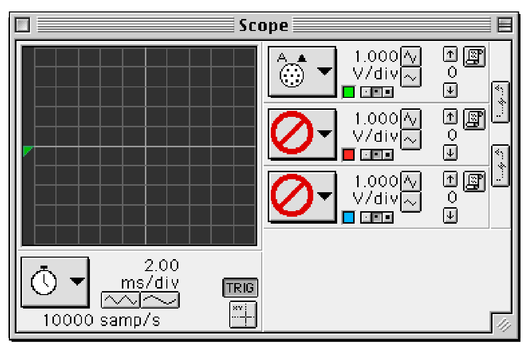
Click the 'Sampling Options' button in the Experiment Setup window or select 'Sampling Options' from the Experiment menu to open the Sampling Options window. Under 'Periodic Samples' click the right arrow repeatedly to set the sample rate at '10000 Hz'. Click 'OK' to return to the Experiment Setup window.



Set Up the Display

In the Experiment Setup window, click and drag the Scope display icon to the Sound Sensor icon. Result: The Scope display opens.





Name ____________________ Class ______________ Date _________

Activity P28: Interference of Sound Waves - Beats (Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Waves	P28 Beats.DS	P33 Interference-Beats	P33_BEAT.SWS

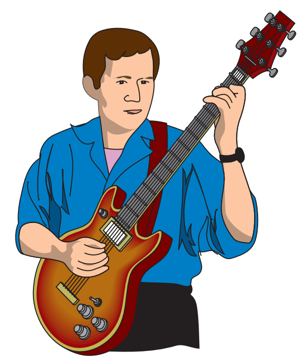
Equipment Needed	**Qty**
Voltage Sensor (CI-6503)	1
Dual Function Generator (WA-9301A)	1
Speaker (WA-9303)	1

What Do You Think?

In a typical classroom of science students, one or two people may play a guitar. They could describe to you the phenomenon they are trying to eliminate in the process of tuning. Ask a guitar player to describe what they are listening to as they tune a guitar. Write a brief description of what you hear when two slightly out-of-tune guitar strings are played at the same time.

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

This activity examines the relationship between the beat frequency and the frequencies of the two interfering sound waves and shows beats on a Scope display.



Background

When two sound waves of slightly different frequency are produced simultaneously, they interfere with each other and the resulting sound that you hear is the superposition of the two waves. The combined sound seems to be one frequency, but the intensity varies. This loudness variation is called beats.

The beat frequency (number of beats per second) should equal the difference between the frequencies of the waves that interfere:

$$f_{beat} = |f_2 - f_1|$$

SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

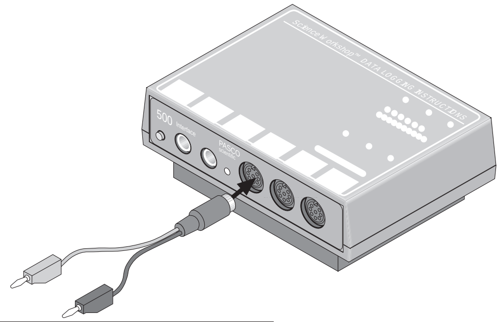
For You To Do

In this activity, use a special dual function generator to produce two sound waves of slightly different frequencies. Use the Voltage Sensor to measure the combined waveform. Use *DataStudio* or *ScienceWorkshop* to display and analyze the waveform.

Use one of the built-in analysis tools of the software to determine the beat frequency. Then use the Frequency Spectrum (FFT) display to observe the dominant frequencies of each individual wave. Then compare the beat frequency to the difference in frequency of the two interfering waves.

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 A on the interface.
3. Open the document titled as shown:



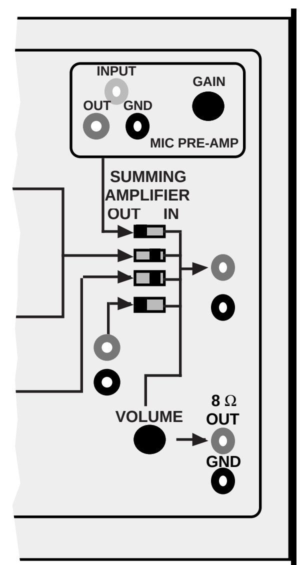
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P28 Beats.DS	P33 Interference-Beats	P33_BEAT.SWS

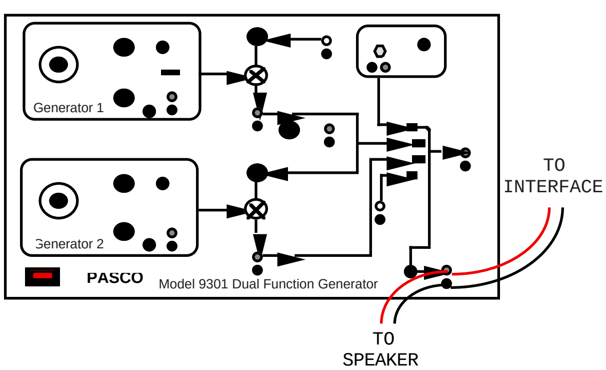
- The document opens with a Scope display and a Frequency Spectrum (FFT) display.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensor.

1. Plug in power cord of the Dual Function Generator. Set the SUMMING AMPLIFIER found on the right hand edge of the Dual Function Generator so that the output from both Generatc and Generator 2 will go into the VOLUME control at the lowe right corner of the generator. (Put the middle 2 switches to the position.)
2. Plug the Voltage Sensor banana plugs into the output jacks on lower right of the Generator marked 8 Ω OUT and GND.
3. Connect the speaker plug into the top of the Voltage Sensor banana plugs.

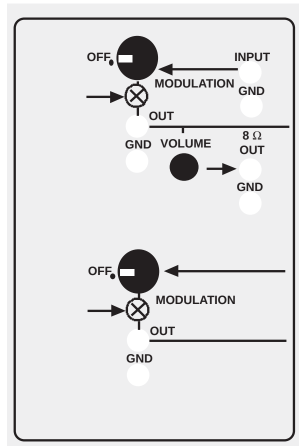




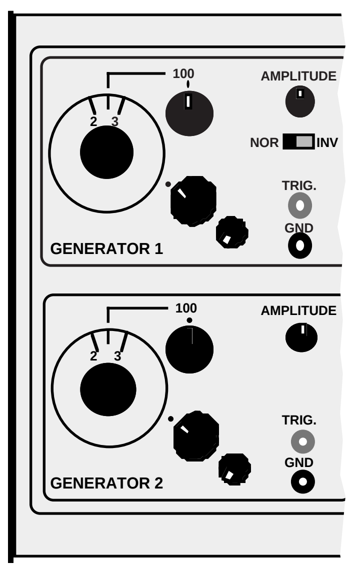
Name ____________________ Class ______________ Date _________

PART II: Equipment Setup - Continued

4. Turn the MODULATION control on each of the Generators to OFF.



5. Set GENERATOR 1 to a sine wave. Put the frequency range select control at 100. Put the AMPLITUDE control at the halfway point. Set the frequency at about 250 Hz.
6. Set GENERATOR 2 to a sine wave. Put the frequency range select control at 100. Put the AMPLITUDE control at the halfway point. Set the frequency at about 230 Hz.
7. Turn on the Dual Function Generator. Adjust the VOLUME control at the lower right corner of the generator.

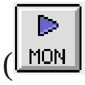


- Note: You should be able to hear the output from both GENERATOR 1 and GENERATOR 2 of the Dual Function Generator from the speaker.

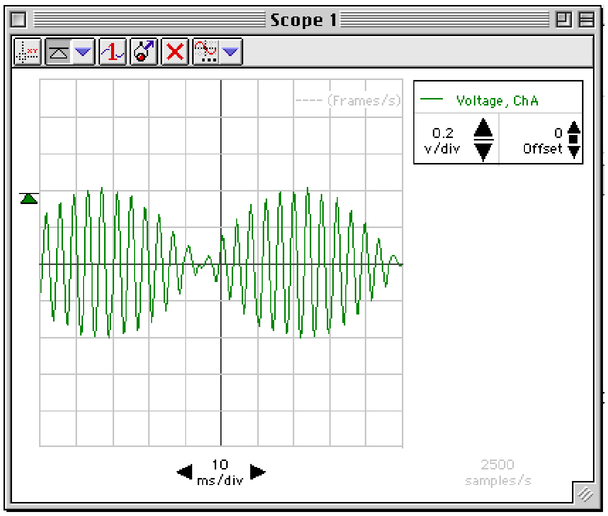
PART III: Data Recording

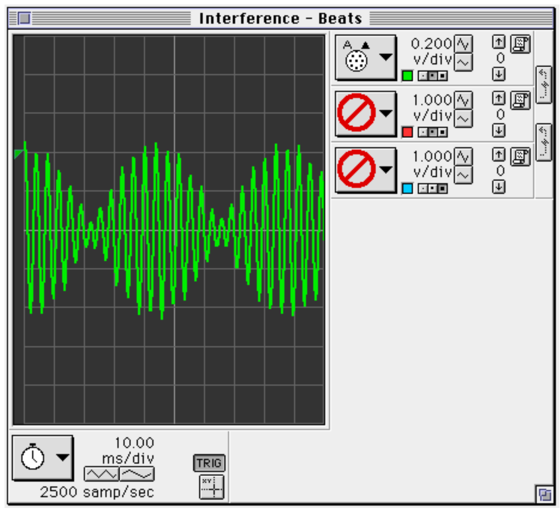
1. Start monitoring data.

- Hint: In *DataStudio*, click the Start button ().

- Hint: In *ScienceWorkshop*, click the MON button ().

- The Scope should display a waveform somewhat like the examples shown here.





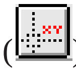
- Notice that the sweep speed is set to 10.00 ms/div, and that the sensitivity is set to 0.200 v/div. Notice also that the trigger level is set to match the maximum amplitude of the waveform.

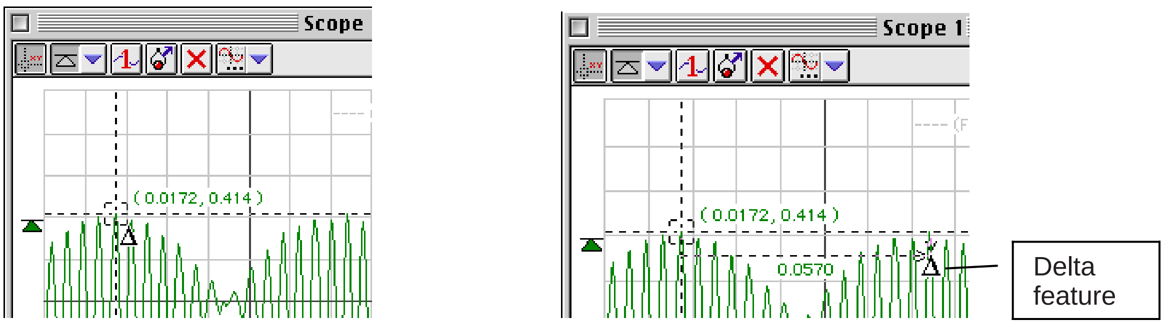
2. Adjust the Scope controls as necessary in order to display your waveform.
3. Click the STOP button to stop monitoring data.

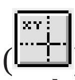
Name ____________________ Class _____________ Date _________

Analyzing the Data

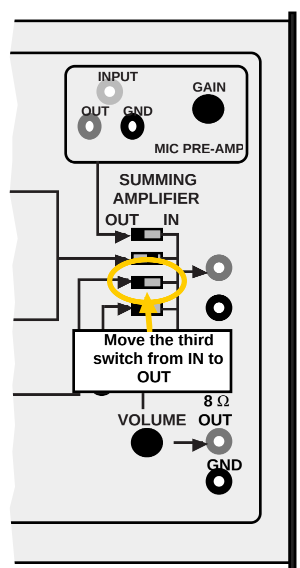
1. Use the Scope display's built-in analysis tool to find the time (or period) from one maximum amplitude to the next. Record the time in the Lab Report section.

- Hint: In *DataStudio*, click the Smart Tool button (). Move the Smart Tool to the first point of maximum amplitude on the Scope display. Use the "delta" feature of the Smart Tool to find the time to the next maximum amplitude. To use the "delta" feature, move the cursor toward a corner of the Smart Tool until the cursor changes to a "Δ" shape. Move the "Δ" shaped cursor to the next maximum. Record the time.



- Hint: In *ScienceWorkshop*, click the Smart Cursor button () and move the cursor to the first point of maximum amplitude on the Scope display. Use the "delta" feature of the Smart Cursor to find the time to the next maximum amplitude. To use the "delta" feature, hold down the mouse button as you move the cursor. Record the time.

- The next task is to find the frequency of each individual tone:



2. Turn off the signal from **GENERATOR 2** on the Dual Function Generator by moving the third switch in the **SUMMING AMPLIFIER** from **IN** to **OUT**. The remaining tone is coming from **GENERATOR 1** alone.

3. Set up the FFT display.

- Hint: In *DataStudio*, click the Window menu and select FFT1 from the list.

- Hint: In *ScienceWorkshop*, click the Display menu and select Frequency Spectrum from the end of the menu.

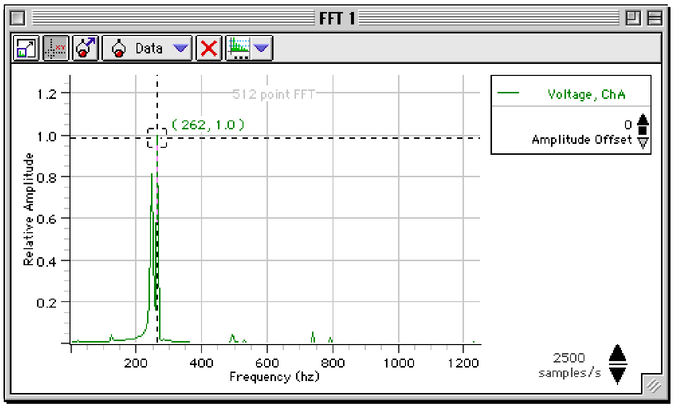
4. Start monitoring data from GENERATOR 1.

5. Hint: Click the Start button in *DataStudio* or click the MON button in *ScienceWorkshop*.

- The FFT (Frequency Spectrum) display will show the fundamental frequency of the signal from GENERATOR 1.

6. Use the FFT display's analysis tools to find the principal frequency of the signal from GENERATOR 1.

- Hint: In *DataStudio*, click the Smart Tool button. In *ScienceWorkshop*, click the Smart Cursor button. Move the cursor to the position of the maximum peak in the frequency spectrum.



7. Record the frequency that is displayed.

- Hint: In *DataStudio*, the frequency is the first number in the ordered pair next to the Smart Tool. In *ScienceWorkshop*, the frequency is shown in the area just below the horizontal axis.

8. Click the STOP button to stop monitoring data.
9. Turn <u>off</u> the signal from **GENERATOR 1** on the Dual Function Generator by moving the <u>second</u> switch in the **SUMMING AMPLIFIER** from **IN** to **OUT**. Turn <u>on</u> the signal from **GENERATOR 2** by moving the <u>third</u> switch from **OUT** to **IN**.

- The new tone is coming from GENERATOR 2 alone.

10. Start monitoring the data from GENERATOR 2.

- Hint: Click the Start button in *DataStudio* or the MON button in *ScienceWorkshop*.
- The Frequency Spectrum (FFT) display will show the fundamental frequency of the signal from GENERATOR 2.

11. Use the FFT display's analysis tools to find the principal frequency of the signal from GENERATOR 2.

- Remember in *DataStudio*, click the Smart Tool button. In *ScienceWorkshop*, click the Smart Cursor button. Move the cursor to the position of the maximum peak in the frequency spectrum.

12. Record the frequency that is displayed.

- Remember that in *DataStudio*, the frequency is the first number in the ordered pair next to the Smart Tool. In *ScienceWorkshop*, the frequency is shown in the area just below the horizontal axis.

13. Click the STOP button to stop monitoring data.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P28: Interference of Sound Waves - Beats

What Do You Think?

In a typical classroom of science students, one or two people may play a guitar. They could describe to you the phenomenon they are trying to eliminate in the process of tuning. Ask a guitar player to describe what they are listening to as they tune a guitar. Write a brief description of what you hear when two slightly out-of-tune guitar strings are played at the same time.

Analyzing the Data

Data Table

Time (ms)	Frequency (Hz)

Individual Frequencies for Dual Function Generator

GENERATOR 1	
GENERATOR 2	

1. Calculate the beat frequency: $\upsilon_{beat} = \frac{1}{time}$

2. Find the difference between the two individual frequencies and compare this to the beat frequency.

Beat Frequency (experimental) = Hz

Beat Frequency (theory) = |Frequency$_2$ - Frequency$_1$| = Hz

Percent difference between experimental and theoretical values =

Question

1. What are some factors that could account for the percent difference between experimental and theoretical values?

Name ____________________ Class ______________ Date _________

Activity P29: Electrostatic Charge (Charge Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Electrostatics	P29 Charge.ds	(See end of activity)	(See end of activity)

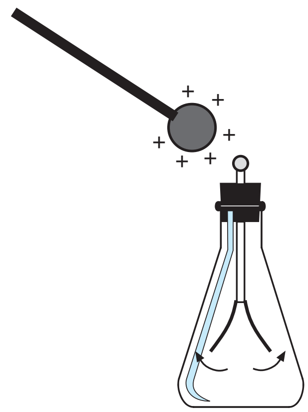
Equipment Needed	Qty	Equipment Needed	Qty
Charge Sensor (CI-6555)	1	**Faraday Ice Pail (ES-9042A)**	1
Charge Producers (ES-9057A)	1 set		

What Do You Think?

The purpose of this activity is to investigate the nature of charging an object by contact as compared to charging by induction. How does the charging of an object by contact compare to the charging of an object by induction?

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

Background



Electrostatics is the study of electrical charges and their characteristics. To experimentally investigate electrostatics, some charge-detecting or measuring device is needed. The most common instrument for this purpose is the electroscope, a device with two thin gold leaves vertically suspended from a common point. When a charged object is brought near the electroscope, the gold leaves separate, roughly indicating the magnitude of the charge.

Although there are many different versions of the electroscope, all such instruments depend upon the repulsion of like charges to produce an output or reading. Unfortunately, such devices are relatively insensitive (large amounts of charge are needed to make the gold leaves separate), and the device does not have a quantitative reading.

The Charge Sensor is somewhat like an 'electronic electroscope'. In addition to providing a quantitative measurement, the Charge Sensor is more sensitive and indicates polarity directly.

SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

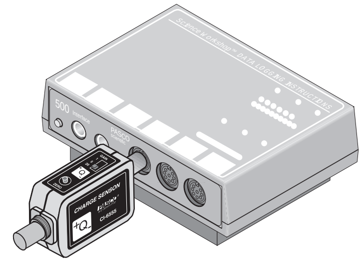
For You To Do

Use a Charge Sensor to determine the polarity of the Charge Producers. Then measure the amount of charge transferred to a 'Faraday Ice Pail' by contact with each kind of Charge Producer. Finally, use the Charge Sensor to measure the charge on the 'Faraday Ice Pail' that is caused by induction. Use *DataStudio* or *ScienceWorkshop* to record and display the data.

Compare charging by contact to charging by induction.

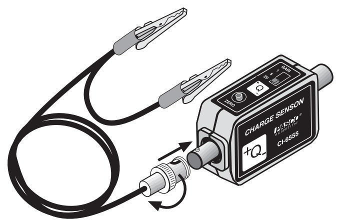
PART I: Computer Setup

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



2. Connect the Charge Sensor directly into Analog Channel A on the interface.

3. 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.



4. Open the file titled as shown:

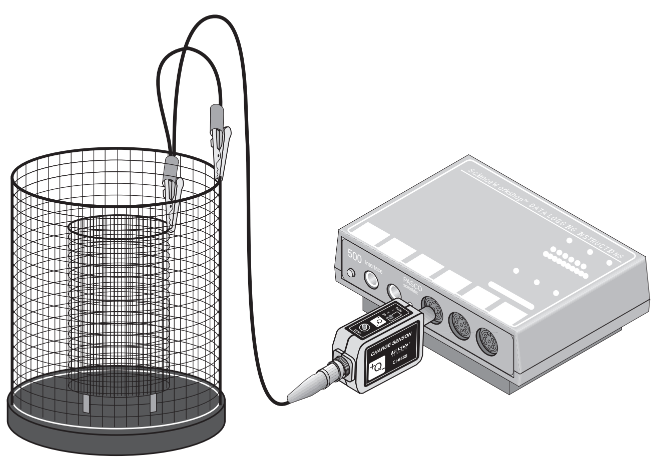
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P29 Charge.ds	(See end of activity)	(See end of activity)

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook. The file has a Graph display and a Meter display.
- Data recording is set at 10 samples per second (10 Hz).
- See the pages at the end of this activity for information about creating a *ScienceWorkshop* file.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the sensor for this activity.

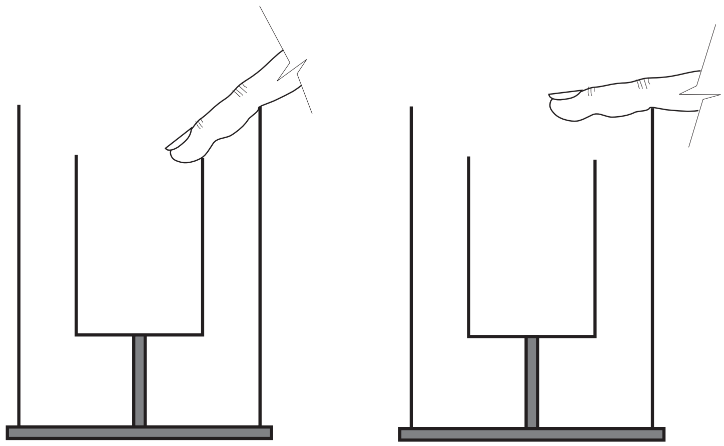
1. Connect the alligator clips of the sensor's cable assembly to the inner and outer baskets of the Faraday Ice Pail.



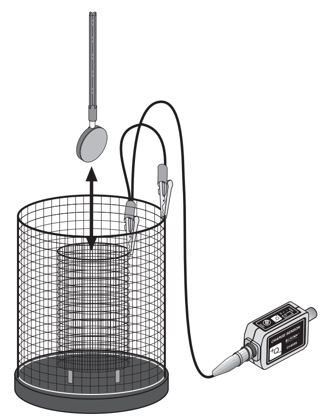
Name ____________________ Class ______________ Date _________

Preparing to Record Data

Before starting any experiment using the ‘Faraday Ice Pail’, the pail must be momentarily grounded. To ground the pail, touch the inner pail and the shield at the same time with the finger of one hand.



PART IIIA: Data Recording – Determine the Polarity of the Charge Producers



1. Ground the ‘Ice Pail’ and press the ‘ZERO’ button on the Charge Sensor to discharge the sensor.
2. Start recording data. (Hint: Click ‘Start’ in *DataStudio* or ‘REC’ in *ScienceWorkshop*.)
3. Briskly rub the blue and white surfaces of the Charge Producers together several times.

- Without touching the ‘Ice Pail’, lower the white Charge Producer into the ‘Ice Pail’. Watch the Meter and Graph displays.
- Remove the white Charge Producer and then lower the blue Charge Producer into the ‘Ice Pail’. Watch the results.

4. After a few moments, stop recording data.

PART IIIB: Data Recording – Charge on the White Charge Producer

1. Ground the ‘Ice Pail’ and press the ‘ZERO’ button on the Charge Sensor to discharge the sensor.
2. Start recording data.
3. Briskly rub the blue and white surfaces of the Charge Producers together several times.

- Lower the white Charge Producer into the ‘Ice Pail’. Rub the surface of the white Charge Producer against the inner pail and then remove the Charge Producer. Watch the Meter and Graph displays.

4. After a few moments, stop recording data.

PART IIIC: Data Recording – Charge on the Blue Charge Producer

1. Ground the 'Ice Pail' and press the 'ZERO' button on the Charge Sensor to discharge the sensor.
2. Start recording data.
3. Briskly rub the blue and white surfaces of the Charge Producers together several times.

- Lower the blue Charge Producer into the 'Ice Pail'. Rub the surface of the blue Charge Producer against the inner pail and then remove the Charge Producer. Watch the Meter and Graph displays.

4. After a few moments, stop recording data.

PART IIID: Data Recording – Charge by Induction

1. Ground the 'Ice Pail' and press the 'ZERO' button on the Charge Sensor to discharge the sensor.
2. Start recording data.
3. Briskly rub the blue and white surfaces of the Charge Producers together several times.

- <u>Without touching the 'Ice Pail' with the Charge Producer</u>, lower the white Charge Producer into the 'Ice Pail'.
- While the Charge Producer is still inside the inner pail, use the finger of one hand to momentarily ground the 'Ice Pail'. Watch the results.
- After you ground the 'Ice Pail', remove your hand and then remove the Charge Producer.

4. After a few moments, stop recording data.
5. Ground the 'Ice Pail' and zero the sensor and repeat the procedure using the blue Charge Producer.

Analyzing the Data

Use your observations and the Graph of your data to answer the questions in the Lab Report.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P29: Electrostatic Charge

What Do You Think?

The purpose of this activity is to investigate the nature of charging an object by contact as compared to charging by induction. How does the charging of an object by contact compare to the charging of an object by induction?

Questions

1. What polarity is the white Charge Producer? What polarity is the blue Charge Producer?

2. What happens to the charge on the 'Ice Pail' when you rub the inner pail with the white Charge Producer and then remove the Charge Producer?

3. What happens to the charge on the 'Ice Pail' when you rub the inner pail with the blue Charge Producer and then remove the Charge Producer?

4. What happens to the charge on the 'Ice Pail' when the white Charge Producer is lowered into the inner pail without touching the inner pail?

5. What happens to the charge on the 'Ice Pail' when the 'Ice Pail' is momentarily grounded while the Charge Producer is still inside the inner pail?

6. What happens to the charge on the 'Ice Pail' after the Charge Producer is removed from the inner pail?

7. How does the result of charging by contact differ from the result of charging by induction?

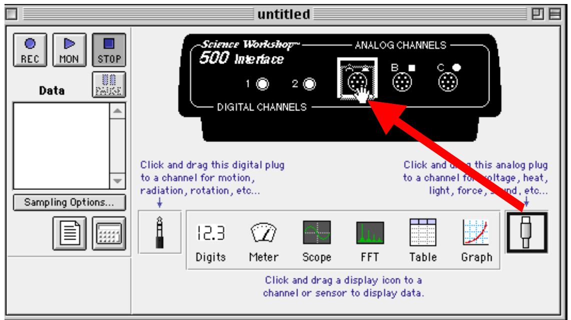
Name ____________________ Class _____________ Date _________

Appendix: Modify a *ScienceWorkshop* File

Create a *ScienceWorkshop* file to measure the charge on a 'Faraday Ice Pail'.

Set Up the Charge Sensor

In the Experiment Setup window, click and drag the analog sensor plug to Channel A. Select 'Charge Sensor' from the list of sensors. Click 'OK' to return to the Experiment Setup window. **Result**: The Charge Sensor icon appears below Channel A on the interface.



Set Up the Display

In the Experiment Setup window, click and drag the Meter display icon to the Charge Sensor icon. **Result**: The Meter display shows 'Voltage'.

Repeat the process. Drag the Graph display icon to the Charge Sensor icon.

Arrange the Experiment Setup window and the displays so you can see the Meter and Graph displays.

Name ____________________ Class _____________ Date _________

Activity P30: Induction – Magnet through a Coil (Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Electromagnetism	P30 Induction.DS	P41 Induction - Magnet	P41_INDU.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Voltage Sensor (CI-6503)	1	Bar Magnet, alnico (EM-8620)	2
AC/DC Electronics Lab (EM-8656)	1		

What Do You Think?

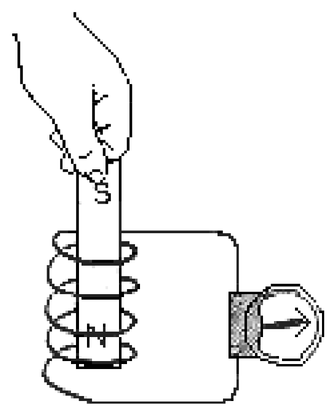
When electricity is passed through a conducting wire a magnetic field can be detected near the wire. Micheal Faraday was one of the first scientists to reverse the process. The essence of his work is decribed in the following statement:

> You can send electricity through a conducting wire to make a magnetic field. Is the reverse possible? Can you use a magnet and a conducting wire to make electricity?

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

The purpose of this activity is to measure the Electromotive Force (EMF) induced in a coil by a magnet dropping through the center of a coil.

Background



When a magnet is passed through a coil there is a changing magnetic flux through the coil which induces an Electromotive Force (EMF) in the coil. According to Faraday's Law of Induction:

$$\mathcal{E} = -N\frac{\Delta\phi}{\Delta t}$$

where $\mathcal{E}$ is the induced EMF, N is the number of turns of wire in the coil, and $\frac{\Delta\phi}{\Delta t}$ is the rate of change of the flux through the coil.

In this activity, a plot of the EMF versus time is made and the area under the curve is found by integration. This area represents the flux since:

$$\mathcal{E}\Delta t = -N\Delta\phi$$

SAFETY REMINDERS

- Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the Voltage Sensor to measure the voltage (EMF) induced in a coil as a bar magnet moves through the coil. Use *DataStudio* or *ScienceWorkshop* to record, display, and analyze the data.

PART I: Computer Setup

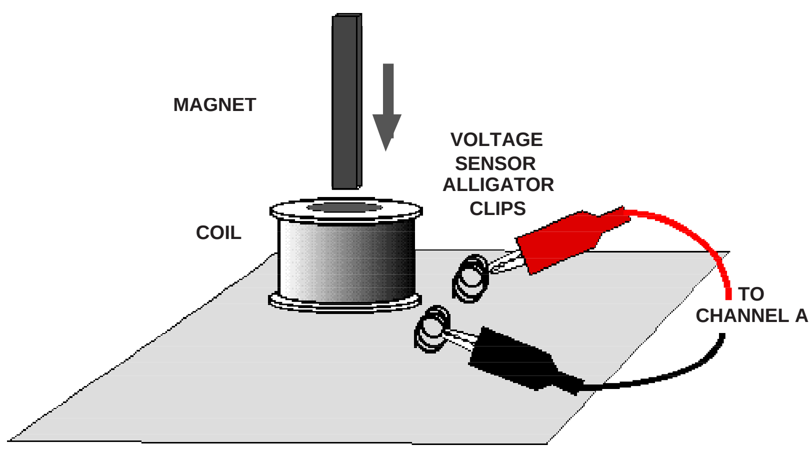
1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Voltage Sensor DIN plug into Analog Channel A.
3. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P30 Induction.DS	P41 Induction - Magnet	P41_INDU.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document opens with a Graph display of Voltage vs. Time and a Meter display of Voltage.
- Data recording is set at 200 Hz. The Start Condition is set to begin when voltage is at 0.05 volts. The Stop Condition is set when Time = 0.4 seconds.
- Note: In *DataStudio*, the data recorded for 0.3 seconds prior to the Start Condition are kept as well.

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensor.



1. Put alligator clips on the ends of the Voltage Sensor leads.
2. Attach a Voltage Sensor lead to one component spring next to the inductor coil on the circuit board. Attach the other lead to the other component spring next to the coil.
3. Arrange the circuit board so the corner with the coil is beyond the edge of the table, and a magnet dropped through the coil can fall freely.

• The bar magnet will be dropped through the coil. Make sure that the magnet does not strike the floor, or it may break.

Name ____________________ Class _____________ Date _________

Part III: Data Recording

1. Hold the magnet so that the south end is about 2 cm above the coil.

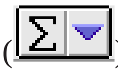
- Note: If you are using the PASCO Model EM-8620 Alnico Bar Magnet the North end is indicated by the narrow groove near one end. For the first run, hold the magnet with groove end 'up'.

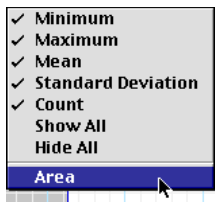
2. Start recording data. Let the magnet drop through the coil.

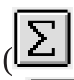
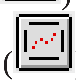
- Data recording will begin when the magnet falls through the coil and the voltage from the coil reaches 0.05 V. Data recording will end automatically after 0.5 seconds.

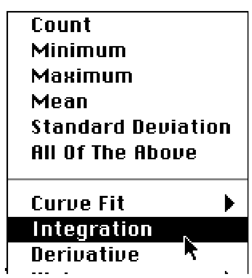
Analyzing the Data

1. Set up your Graph to show the area under the curve of voltage versus time.

- Hint: In *DataStudio*, click the Statistics menu button () and select 'Area'.

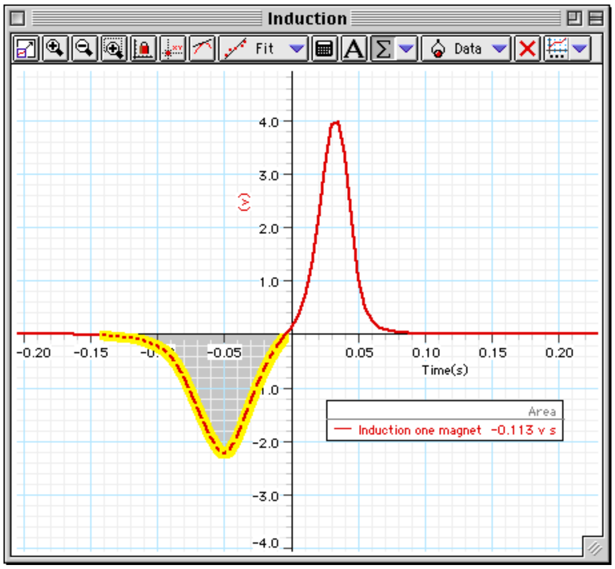


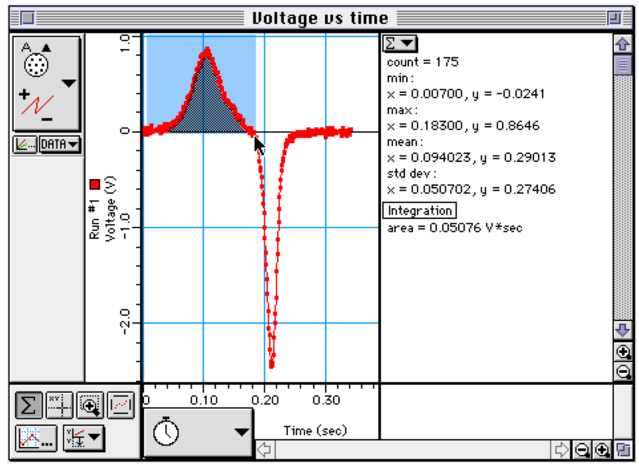
- Hint: In *ScienceWorkshop*, click the Statistics button () to open the Statistics area on the right side of the graph. Click the Autoscale button () to rescale the graph to fit the data. In the Statistics area, click the Statistics Menu button (). Select 'Integration' from the menu.



2. In the Graph display, use the cursor to select a rectangle around the first peak of the voltage plot.

3. In *DataStudio*, the value for ‘Area’ appears in the legend in the Graph. In *ScienceWorkshop*, the ‘area’ under the curve for the first peak appears in the statistics area under ‘Integration’ on the right side of the Graph.





4. Record the value of Integration for the first peak.

Integration (first peak) = __________ V*sec

5. Repeat the process to find the area under the second peak. Record the value.

Integration (second peak) = __________ V*sec

Record your results in the Lab Report section.

Optional

Repeat the data recording and data analysis procedures for the following optional setups:

- Tape two bar magnets together so both south ends are together.
- Re-arrange the two bar magnets so that the south end of one is with the north end of the other.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P30: Induction – Magnet through a Coil

What Do You Think?

When electricity is passed through a conducting wire a magnetic field can be detected near the wire. Micheal Faraday was one of the first scientists to reverse the process. The essence of his work is decribed in the following statement:

> You can send electricity through a conducting wire to make a magnetic field. Is the reverse possible? Can you use a magnet and a conducting wire to make electricity?

Data

Integration (first peak) = V*sec

Integration (second peak) = V*sec

Questions

1. Is the incoming flux equal to the outgoing flux?

2. Why is the outgoing peak higher than the incoming peak?

3. Why are the peaks opposite in direction?

Name ____________________ Class ______________ Date _________

Activity P31: Magnetic Field of a Permanent Magnet (Magnetic Field Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Magnetism	P31 Permanent Magnet.DS	P51 Permanent Magnet	P51_PERM.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Magnetic Field Sensor (CI-6520A)	1	Meter stick, non-metal	1
Magnet*, disk, Neodymium, 1/2 or 3/4”(EM-8648)	1		

***Warning: Keep magnets away from the computers and computer disks.**

What Do You Think?

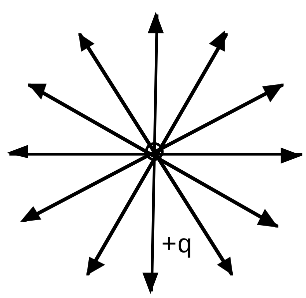
How does the strength of the magnetic field of a permanent disk magnet change with distance?

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

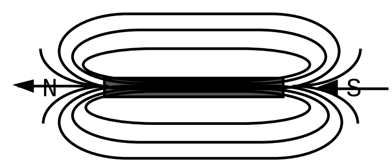
Background

The strength of a magnetic field varies with distance from the magnet. The strength of the magnetic field could vary inversely as the square of distance, as with the strength of a gravitational field or an electrical field. The strength of the magnetic field could vary in a different way relative to distance.

The gravitational field or electric field of a point mass or charge is radial, while the magnetic field of a magnet consists of complete loops that surround and go through the magnet.



ELECTRIC FIELD LINES



MAGNETIC FIELD LINES

SAFETY REMINDER

- Follow the directions for using the equipment.
- Keep magnets away from the computers and computer disks.

THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

Use the Magnetic Field Sensor to measure the magnetic field strength of a small neodymium magnet as the distance between the sensor and the magnet changes. Use *DataStudio* or *ScienceWorkshop* to record and display the magnetic field strength and the entered distance. Determine the relationship between the measured strength of the magnetic field and the distance from the magnet.

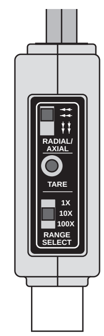
PART I: Computer Setup

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

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P31 Permanent Magnet.DS	P51 Permanent Magnet	P51_PERM.SWS

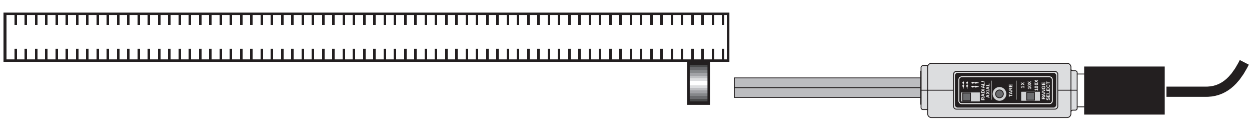
- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Digits display of Magnetic Field Strength and a Graph display of Magnetic Field Strength vs. Distance.
- Data recording is set for 10 Hz. Keyboard Sampling allows the user to enter the distance in meters.

PART II: Sensor Calibration and Equipment Setup



- You do not need to calibrate the Magnetic Field Sensor.

1. Place the meter stick on a flat surface away from the computer.
2. Place the Magnetic Field Sensor so the end of the rod is even with the zero end of the meter stick.
3. Select AXIAL by pressing the Field Selector Switch on the top of the sensor box.
4. Move the magnet away from the sensor. Zero the Magnetic Field Sensor by pressing the TARE button on the top of the sensor box.



5. Keeping the magnet away from the computer, place the magnet next to the 0.005 m (5-cm) mark on the meter stick.

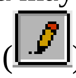
Name ____________________ Class _____________ Date _________

PART III: Data Recording

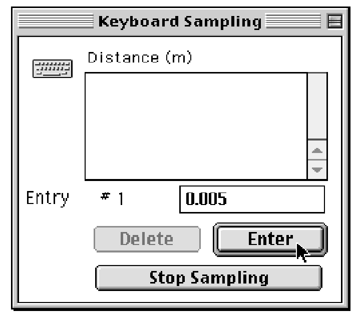
1. Begin data recording.

In *DataStudio*, arrange the Table display so you can see it clearly. Click the Start button. The button turns into a 'Keep' and 'Stop' button (

). The magnetic field strength appears in the first cell in the Table display. Check to make sure that the strength is a large positive number. If it is not, flip the magnet to point the opposite pole towards the sensor. Click the 'Keep' button to record the magnetic field strength.

Note: If the default distance value does not correlate with the distance you measured for a given magnetic field strength, you may edit the distance. Select the 'Edit Data' tool from the tool bar on the Table Display ().

Click on the distance and type in the correct value.



In *ScienceWorkshop*, move the Digits display so you can see it clearly. Click the 'REC' button to start recording data. **Result**: The Keyboard Sampling window will open. When the magnetic field strength stabilizes, type '0.005' as the distance value and click 'Enter' to record the magnetic field strength and the distance values.

2. Move the magnet 0.005 m further away so that it is 0.010 m from the end of the sensor.

3. Enter 0.010 m for the distance. Record the data by clicking on 'Keep' in *DataStudio* or 'Enter' in *ScienceWorkshop*.

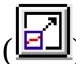
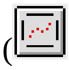
4. Repeat the process of moving the magnet by 0.005 m increments, and recording the values until the magnetic field strength reaches about 10 Gauss, or does not change as the distance increases.

5. End data recording.

- In *DataStudio*, stop data recording by clicking on the 'Stop' button.
- In *ScienceWorkshop*, stop data recording by clicking the Stop Sampling button in the Keyboard Sampling window.

Analyzing the Data

1. Click to make the Graph display active.
2. Rescale the Graph axes to show the data and apply a fit to the data.

- In *DataStudio*, click the 'Scale to fit' button () to rescale the Graph axes. Next, click the 'Fit' menu button () and select 'Inverse Square'. If the Mean Square Error is large, click and hold down on the mouse button while dragging the mouse to select a region of data. When the mouse button is released, the data points will be highlighted. Only highlighted data points will be used for the fit.
- In *ScienceWorkshop*, click the 'Statistics' button to open the Statistics area on the right side of the Graph. Click the 'Autoscale' button () to rescale the Graph axes to show the data. In the Statistics area, click the Statistics Menu button (). Select 'Curve Fit, Power Fit' from the Statistics Menu. A message stating that there is no valid solution may appear. If it does, click on the number next to **a4** and type **- 2**. If the same message appears, or the value of chi^2 is very large, select a section of data that appears to be the most smooth. To select a region, click and hold down on the mouse button while dragging the mouse. Release the mouse button. The selected region will be highlighted. Only highlighted data points will be used for the fit.

3. Record the equation of fit in the Data Table in the Lab Report section.

Record your results in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P51: Magnetic Field of a Permanent Magnet

What Do You Think?

How does the strength of the magnetic field of a permanent (disk) magnet change with distance?

Data Table

Item	Equation
Equation of Fit	

Questions

1. Does the magnetic field strength increase or decrease as the distance from the magnet is increased?

2. Is the relationship between magnetic field strength and distance linear?

3. Based on the results of the curve fit in the statistics area, what is the relationship between the magnetic field strength and the distance from the magnet?

Optional

- Repeat the activity with a different type of magnet.

Optional Data Table

Item	Equation
Equation of Fit	

Optional Questions

1. Does the magnetic field strength increase or decrease as the distance from the magnet is increased?

2. How does the plot of Magnetic Field Strength vs. Distance for this magnet compare with the plot for the original magnet?

Name ____________________ Class ______________ Date _________

Activity P32: Variation of Light Intensity (Light Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Illuminance	P32 Vary Light.DS	P54 Light Bulb Intensity	P54_BULB.SWS

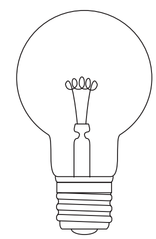
Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Light Sensor (CI-6504A)	1	Fluorescent light source (AC)	1
Flashlight (or other DC light source)	1	Incandescent light source (AC)	1

What Do You Think?

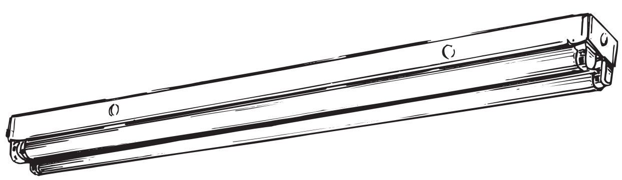
The purpose of this activity is to compare the variation in intensity of light from light sources. How does the light from a DC light source compare to light from an AC light source? How does the light from a fluorescent tube compare to the light from an incandescent bulb?

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

Background



Electric light bulbs are powered by a voltage of 60 Hz (or 50 Hz in some countries) sinusoidal wave. The maximum amplitude of the voltage, and thus a maximum brightness, occurs twice per cycle because an electric bulb is excited when the voltage increases, regardless of the polarity of the voltage. An electric bulb will have maximum intensity 120 times per second (or 100 times/second). It will also have minimum intensity 120 times per second (or 100 times/second).



Fluorescent lights blink on and off at a particular frequency. The light intensity from incandescent bulbs powered by AC fluctuates as well. The light intensity from an incandescent bulb powered by DC should not vary.

SAFETY REMINDERS

- Follow directions for using the equipment.

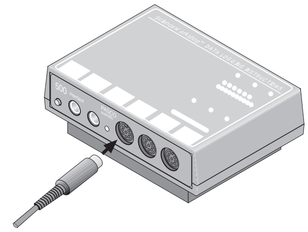
THINK SAFETY
ACT SAFELY
BE SAFE!

For You To Do

In this activity, use the Light Sensor to measure the intensity of light from light bulbs powered by AC or DC. There are three parts to the activity: Part A = Fluorescent bulb, AC; Part B = Incandescent bulb, AC; and Part C = Incandescent bulb, DC.

Use *DataStudio* or *ScienceWorkshop* to monitor and display the variations, if any, in the light intensity. Compare the light intensity of fluorescent and incandescent lights powered by AC, and an incandescent light powered by DC.

PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Light Sensor cable into Analog Channel A on the interface. Connect the Light Sensor to the cable.
3. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P32 Vary Light.DS	P54 Light Bulb Intensity	P54_BULB.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document opens with a Scope display of voltage from the Light Sensor in Channel A and a Frequency Spectrum (FFT) display for the same sensor. It also has a Digits display for the voltage from the Light Sensor.
- The data measurement is set at 5000 Hz (set by the Sweep Speed control in the Scope display). The Frequency Spectrum (FFT) is set to 256 data points.

PART II: Sensor Calibration & Equipment Setup

- You do not need to calibrate the Light Sensor. However, you may need to adjust the sensitivity of the sensor, depending on the brightness of the light source and how close the sensor is to the source.

Adjusting Light Sensor Sensitivity

- The Light Sensor has a GAIN switch on the top of the sensor box. The GAIN switch selects the amount of amplification for the signal that is sent to the interface. The settings are 1, 10, and 100. The setting of 10 amplifies the signal ten times and the setting of 100 amplifies the signal one hundred times.

Try the following to become more familiar with the Light Sensor:

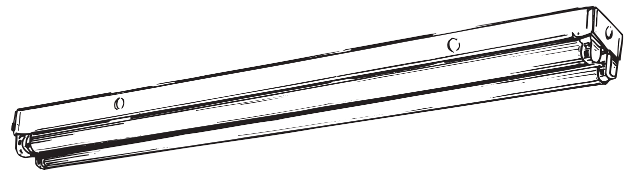
- Place the Light Sensor on a table so the port on the sensor is below an overhead light. Set the GAIN switch to 1.
- Start monitoring data. Move the Digits display of Input Volts so you can see it clearly.
- Switch the GAIN to 10 and observe the value of Input Volts in the Digits display. Then switch to 100 and observe the value of Input Volts.

NOTE: The maximum voltage from the sensor is 4.9 V for any GAIN setting.

- Cover the Light Sensor port and observe the value of Input Volts.
- Return the GAIN setting to 10. Pick up the sensor. Observe the value of Input Volts as you move the Light Sensor closer to the overhead light source. Observe what happens when you move the Light Sensor farther from the light source.
- Click STOP to stop monitoring data.

Name ____________________ Class _____________ Date _________

Equipment Setup



1. Place the Light Sensor within a few feet of a fluorescent bulb that is powered by AC.
2. Turn on the fluorescent bulb.

PART IIIA: Data Recording – Fluorescent Bulb, AC

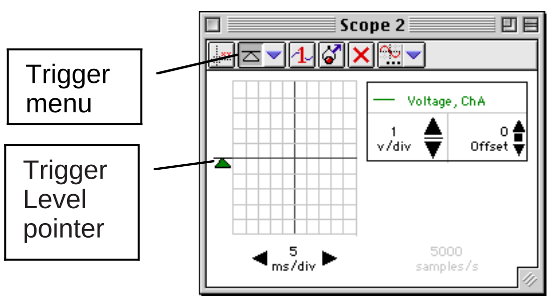
1. Start monitoring data. (Hint: In *DataStudio*, click the 'Start' button (). In *ScienceWorkshop*, click the 'MON' button.) Arrange the Scope display, the Digits display, and the Frequency Spectrum (FFT) so you can see them clearly.

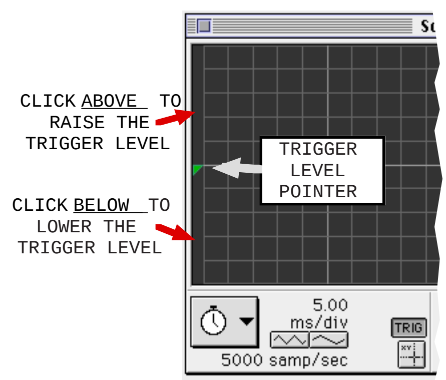
- NOTE: It is likely that you will see a value in the Digits display, and a spectrum in the Frequency Spectrum display, but <u>nothing</u> in the Scope display. This is because the trigger control in the Scope is on, and the trigger level may be set too low for the voltage produced by the Light Sensor.

2. Adjust the Scope display until you see the trace of voltage from the Light Sensor:

- First, adjust the trigger level.

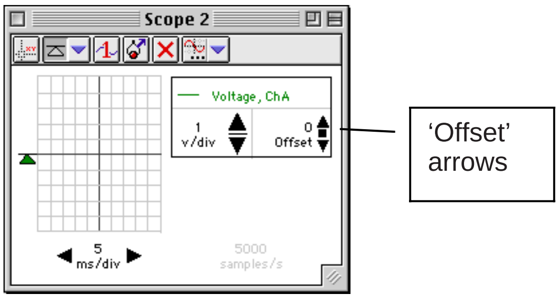
  In *DataStudio*, move the small triangle (the 'Trigger Level' pointer) on the left side of the display up or down to the desired voltage level. In *ScienceWorkshop*, click in the space along the left edge of the Scope display that is above the Trigger Level pointer. When you click above or below the Trigger Level Pointer, it "jumps" to the spot you clicked. The value in the Digits display will indicate the <u>approximate</u> trigger level you need.

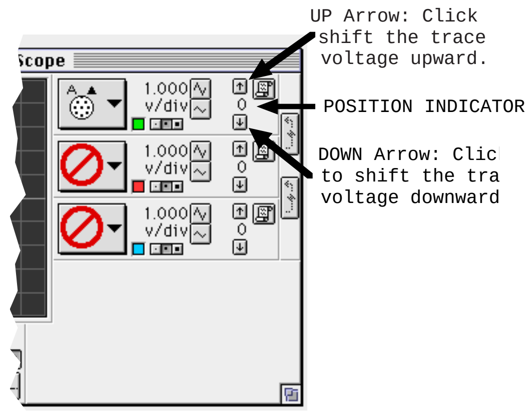




- Second, adjust the vertical position of the trace of voltage.

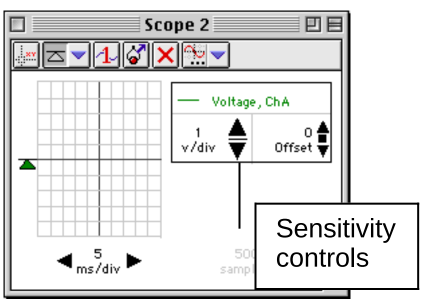
  In *DataStudio*, click the up or down arrows next to 'Offset'. In *ScienceWorkshp*, click the 'UP/DOWN Arrows' in the right side of the Scope display.

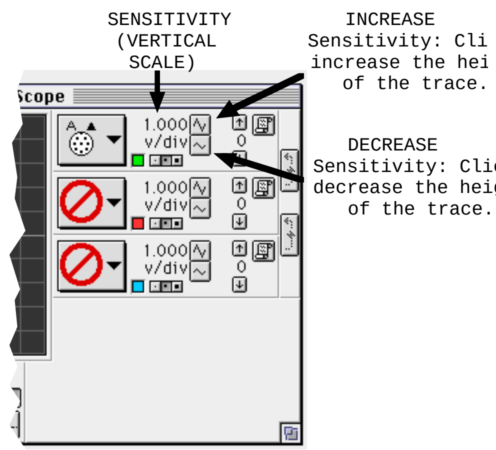


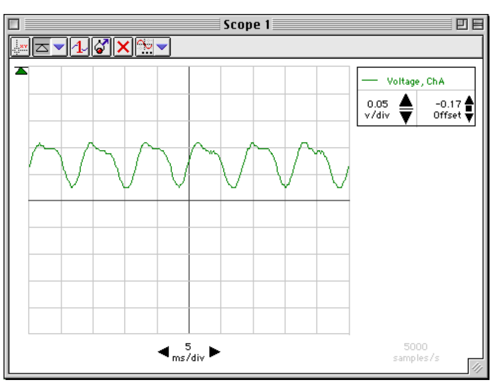


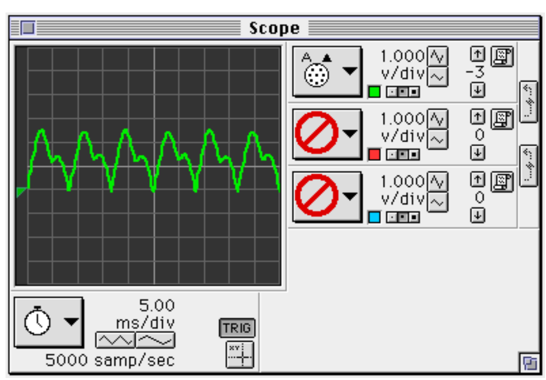
- Finally, adjust the Sensitivity (volts per division) if needed.

  In *DataStudio*, click the arrows to increase or decrease the sensitivity. In *ScienceWorkshop*, click the **Vertical Scale** buttons in the right side of the Scope display.





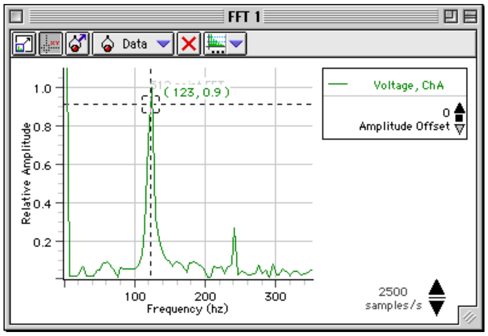


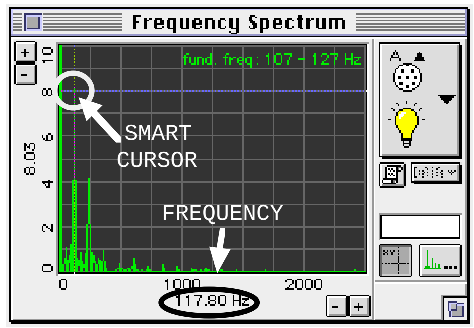


3. Use the Frequency Spectrum to measure the frequency of the signal from the Light Sensor. Record the value of the frequency in the Lab Report section.

- Make the FFT display (Frequency Spectrum) active. In *DataStudio*, click the 'Smart Tool' button. In *ScienceWorkshop*, click the 'Smart Cursor' button. Move the cursor/cross-hair to the top of the first peak in the display area. In *DataStudio*, the frequency is the first number in the ordered pair. In *ScienceWorkshop*, the frequency is shown below the horizontal axis.

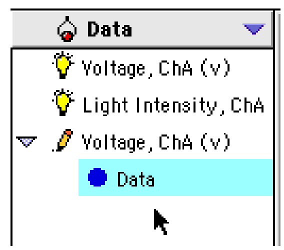
4. Click the STOP button to stop monitoring data.



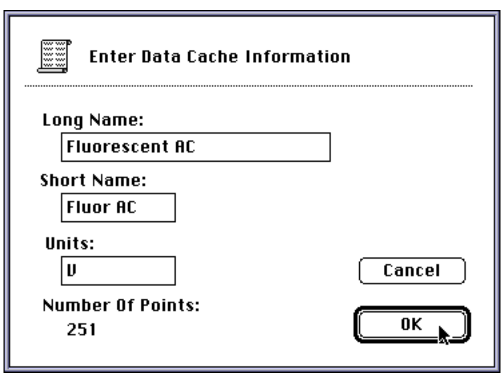


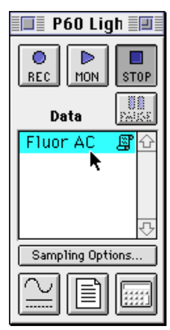
5. Save the trace that is displayed on the Scope. Click the Scope to make it active.

- In *DataStudio*, click the 'Transfer' button (). The data in the Scope is automatically added to the data list.



- In *ScienceWorkshop*, click the 'Data Snapshot' button () in the right side of the Scope display. The **Data Cache Information** window will open. Enter appropriate information for the **Long Name**, **Short Name**, and **Units**. Click **OK** to return to the Scope.





- The **Short Name** for the Data Cache will appear in the Data List in the Experiment Setup window. (NOTE: You can display and analyze the Data Cache in any display that can show recorded data such as the Graph, Table, or FFT.)

PART IIIB: Incandescent Light – AC

Repeat the activity using an incandescent light connected to an AC power supply.

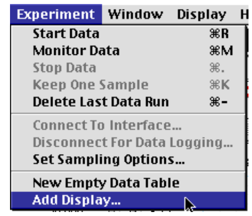
PART IIIC: Incandescent Light – DC

Repeat the activity using a battery operated flashlight.

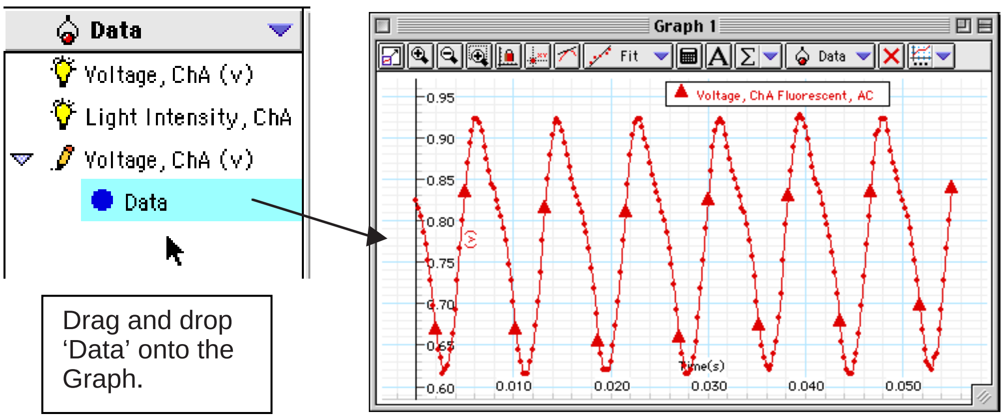
Analyzing the Data

1. Set up a Graph display to show data for the AC fluorescent light, AC incandescent light, and DC incandescent light.

- Hint: In *DataStudio*, do the following:

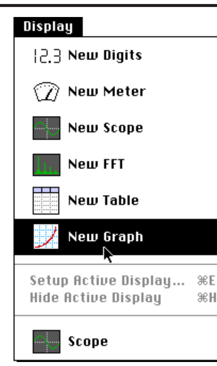


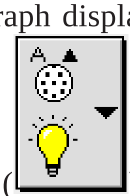
- Click 'Add Display…' from the Experiment menu.
- Select 'Graph' from the 'Please Choose…' window. Click 'OK'.
- Click and drag 'Data' from the Data list to the new Graph display.

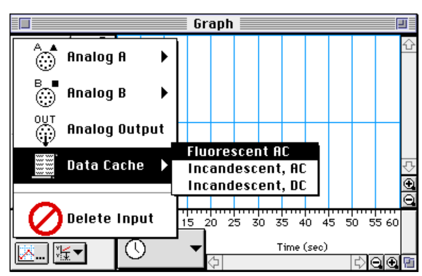


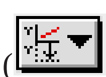
- The Graph automatically rescales to fit the data. Repeat the process for the other runs of data.

- Hint: In *ScienceWorkshop*, do the following:

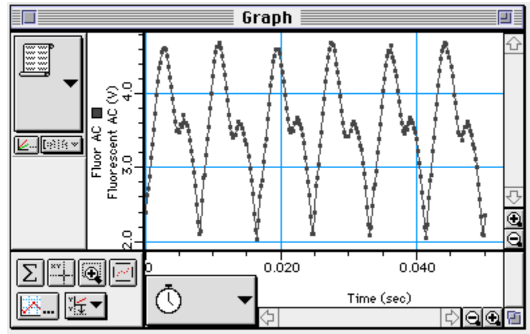


- Click the **Display Menu**. Select **New Graph** from the Display Menu.
- In the new Graph display, click the **Vertical Axis Input Menu** button (). Select **Data Cache, Fluorescent AC** from the Input Menu.

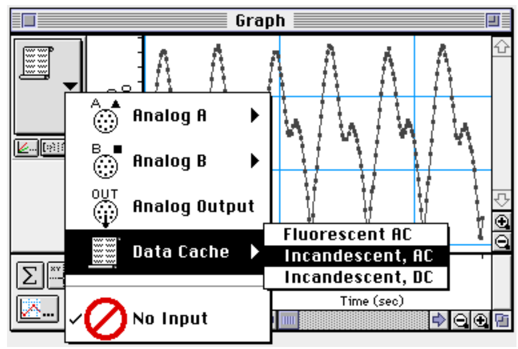


- The Graph will show the data seen in the Scope display for the fluorescent bulb powered by AC.
- Click the **Add Plot Menu** button () in the lower left corner of the Graph. Select **Data Cache, Incandescent AC** from the Add Plot Menu.

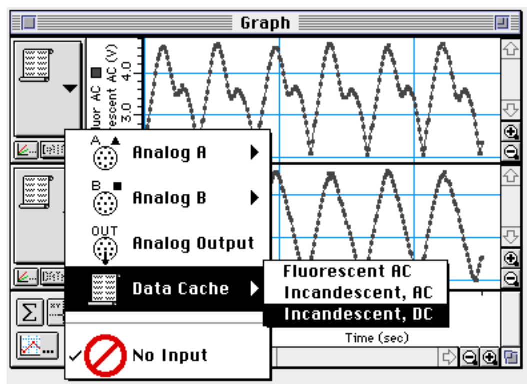
- A new plot will be added to the Graph. It will show the data seen in the Scope display for the incandescent bulb powered by AC.



- Click the **Add Plot Menu** button again. Select **Data Cache, Incandescent DC** from the Add Plot Menu.



- A third plot will be added to the Graph.



Name ______________________ Class _______________ Date _________

Lab Report - Activity P32: Variation of Light Intensity

What Do You Think?

The purpose of this activity is to compare the variation in intensity of light from light sources. How does the light from a DC light source compare to light from an AC light source? How does the light from a fluorescent tube compare to the light from an incandescent bulb?

Data Table

Light Source	Frequency
Fluorescent, AC	
Incandescent, AC	
Incandescent, DC	

Questions

1. How does the frequency of light intensity variation for the fluorescent AC bulb and the incandescent AC bulb compare to the accepted value for AC frequency?

2. How does the fluctuation of an incandescent bulb run on 60 Hz (or 50 Hz) AC differ from the fluorescent bulb?

3. How does the fluctuation of a light bulb run on 60 Hz (or 50 Hz) AC differ from the incandescent bulb powered by DC?

Name ____________________ Class _____________ Date _________

Activity P33: Light Intensity versus Position (Light Sensor, Rotary Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Inverse Square Law	P33 Light vs Position.DS	(See end of activity)	(See end of activity)

Equipment Needed	Qty	Equipment Needed	Qty
Light Sensor (CI-6504A)	1	Basic Optics System (OS-8515)	1
Rotary Motion Sensor (CI-6538)	1	Mass and Hanger Set (ME-9348)	1
Aperture Bracket (OS-8534)	1	String (SE-8050)	1 m
Base and Support Rod (ME-9355)	1		

What Do You Think?

Does the total light energy that passes through an imaginary spherical boundary change as distance from the point light source increases?

Does the light intensity on the surface of an imaginary spherical boundary change as the distance from the point light source increases?

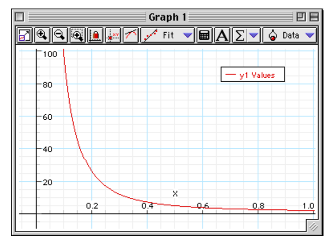
How does the change in light intensity with distance for a 'real' light source compare to the change in light intensity with distance for an ideal 'point' light source?

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

The purpose of this activity is to investigate the relationship between light intensity and the distance from a light source.

Background

The light from a point light source spreads out uniformly in all directions. The intensity at a given distance **r** from the light will be equal to the power output of the light divided by the surface area of the sphere through which the light has spread. Since the area of the sphere varies as the square of its radius, **r**, the intensity will vary as $1/r^2$.



SAFETY REMINDERS

- Follow directions for using the equipment.

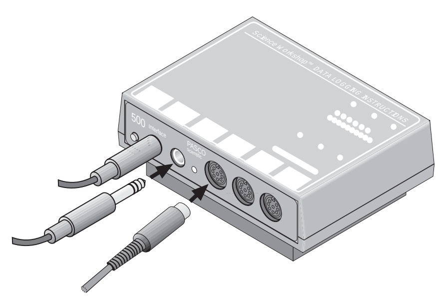
For You To Do

Use the Light Sensor to measure the light intensity as the sensor moves away from a stationary light source powered by DC. Use the Rotary Motion Sensor to measure the distance between the light source and the Light Sensor.

Use *DataStudio* or *ScienceWorkshop* to record and display the light intensity and the distance. Use a graph of light intensity versus position to determine the relationship between them.

PART I: Computer Setup

1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Light Sensor into Analog Channel A on the interface.

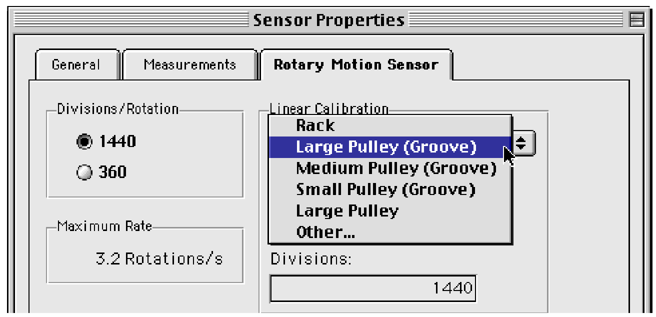


3. Connect the Rotary Motion Sensor stereo phone plugs to Digital Channels 1 and 2.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P33 Light vs Position.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 Graph display of light intensity versus position.
- Data recording is set at 20 Hz. The Rotary Motion Sensor is set for 1440 divisions per rotation.

5. In the Experiment Setup window, double-click the sensor icon to open the Sensor Properties window. Click the 'Rotary Motion Sensor' tab. Click the 'Linear Calibration' menu and select 'Large Pulley (Groove)'. Click 'OK' to return to the setup window.

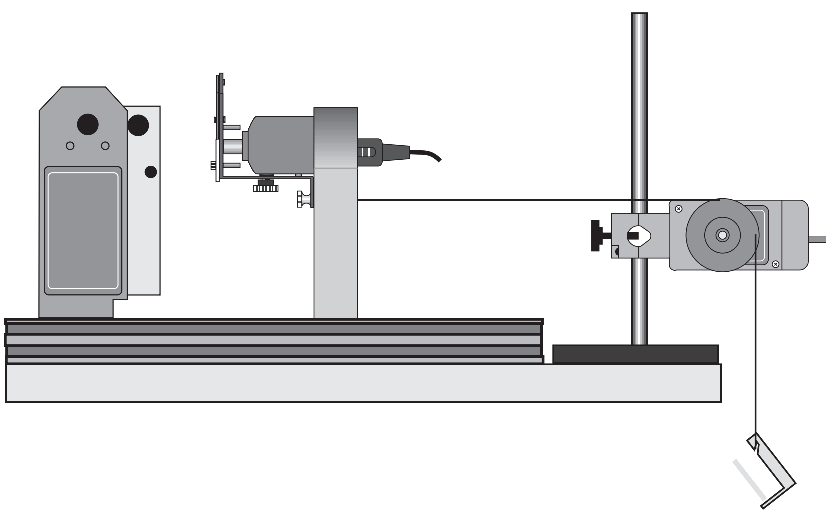


- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.

PART II: Equipment Setup and Sensor Calibration

Equipment Setup

1. Mount the Light Sensor on the Aperture Bracket and attach the Aperture Bracket to the Aperture Bracket Holder. Put the Aperture Bracket Holder onto the Optics Bench about 25 cm from one end.
2. Rotate the Aperture Disk so the open circular aperture is in line with the opening to the Light Sensor
3. Mount the Light Source on the Optics Bench so the 'point source' side of the source faces the Light Sensor.
4. Remove the 'O' ring from the pulley on the Rotary Motion Sensor. Mount the sensor on a support rod near the end of the Optics Bench.
5. Connect one end of a string to the Aperture Bracket Holder. Put the string over the pulley on the Rotary Motion Sensor. Attach a mass hanger at the other end of the string

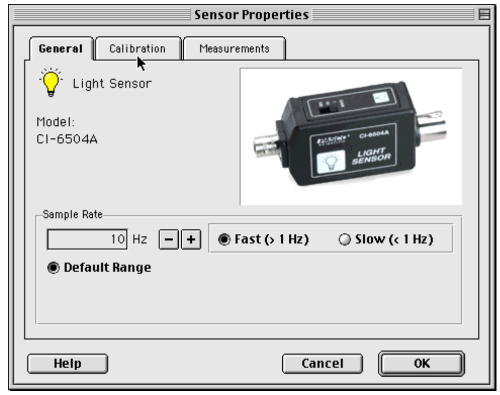


Name ____________________ Class _____________ Date _________

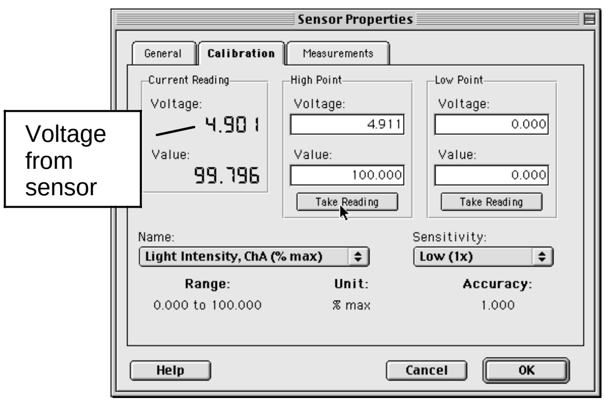
Sensor Calibration

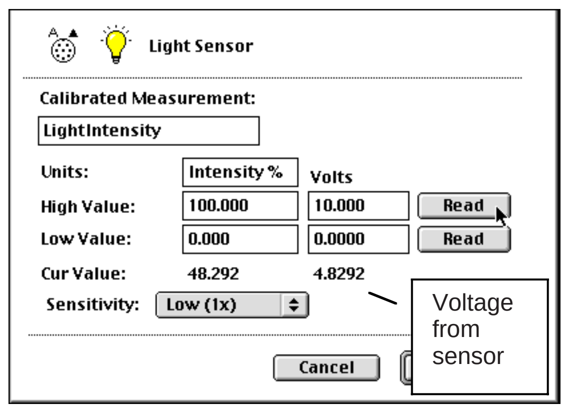
- Calibrate the Light Sensor so that it produces its maximum voltage when the sensor is as close as possible to the Light Source.

1. Turn on the Light Source.
2. Set the GAIN select switch on the top of the sensor to 1. Move the Light Source so its port is as close as possible to the Light Sensor.
3. In the Experiment Setup window, double-click the Light Sensor icon. (The Sensor Properties window opens in *DataStudio*. The Light Sensor setup window opens in *ScienceWorkshop*. In *DataStudio* click the 'Calibration' tab.)
4. Check the voltage from the Light Sensor.



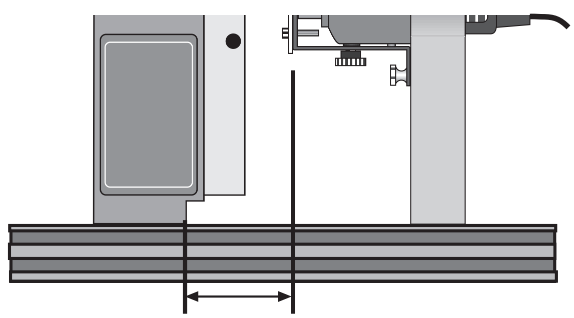
- Hint: In the *DataStudio* 'Calibration' window, the Current Reading of the voltage from the Light Sensor appears in the upper left corner. In the *ScienceWorkshop* Sensor Setup window, the current value of the voltage from the Light Sensor appears at the bottom of the column labeled Volts.





- If the value of voltage from the sensor is slight higher than 4.9 V, slowly move the Light Source away from the sensor until the value is 4.9 V (or slightly lower).

Measure the distance from the Light Sensor relative to the Light Source.



- If the value of voltage from the Light Sensor is less than 4.9 V but more than 0.49 V go to step #5. If the voltage value is below 0.49 V set the GAIN switch to 10. If the value is still below 0.49 V, set the GAIN switch to 100.

5. Keep this value of voltage as the maximum value (corresponding to 100% intensity). In *DataStudio* click 'Take Reading' below the 'High Point' column. In *ScienceWorkshop*, click the top Read button. Click 'OK' to return to the Experiment Setup window.

PART III: Data Recording

1. Move the Light Sensor to the position where you calibrated it for maximum intensity.
2. When you are ready, start recording data. (Note: Click 'Start' in *DataStudio* or 'REC' in *ScienceWorkshop*.)
3. Slowly slide the Light Sensor away from the Light Source.

- Hint: Hold the base of the Aperture Bracket Holder, squeeze the locking clip, and pull the holder away from the Light Source.

4. Continue to move the Light Sensor away from the Light Source until you reach the 25 cm distance (or the light intensity reaches 'zero').
5. Stop recording data.
6. Turn off the Light Source.

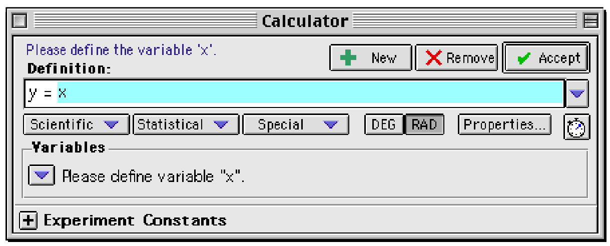
Analyzing the Data

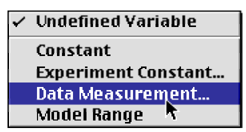
Create a Calculation for Position

Since the Light Sensor was not precisely next to the bulb inside the Light Source, the initial position of the Light Sensor was not 'zero' meters at the beginning of data recording. Create a calculation for the actual position of the Light Sensor relative to the bulb inside the Light Source. Use the distance you measured when you calibrated the Light Sensor.

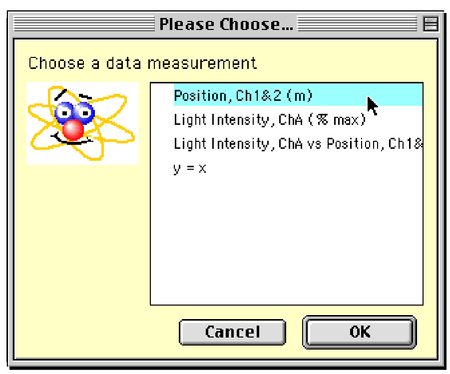
DataStudio

1. In *DataStudio*, click 'Calculate' in the toolbar. **Result**: The Calculator window opens.
2. Click the menu button under 'Variables' and select 'Data Measurement' from the menu. **Result**: The 'Please Choose… a data measurement' window opens.



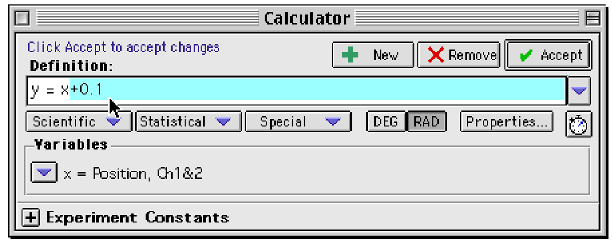


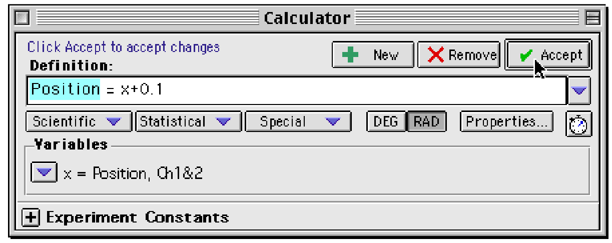
3. Select 'Position' from the list and click 'OK'. **Result**: 'Position' appears under 'Variables' in the Calculator window.



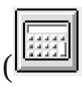
4. Modify the 'Definition' by adding the amount of distance that separated the Light Source and the Light Sensor at the beginning of data recording. (Note: In this example, the distance is 0.1 m.)

5. Change from 'y' to 'Position' and then click 'Accept' to save the calculation. **Result**: The 'Position' calculation appears in the Data list.





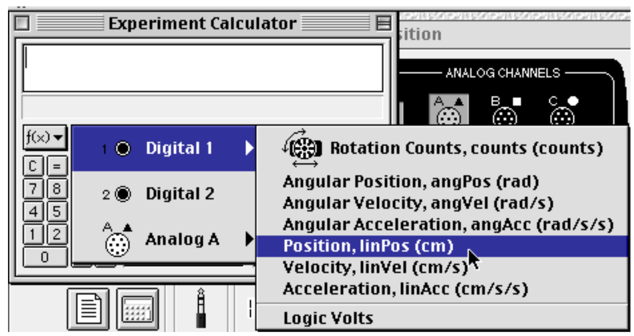
ScienceWorkshop

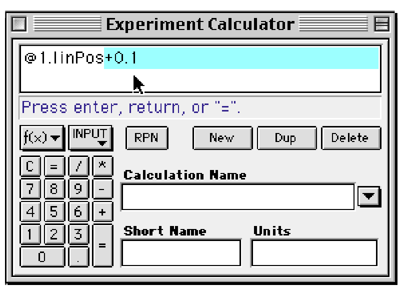
1. In *ScienceWorkshop*, click the 'Calculator' button () in the Experiment Setup window. Result: The Experiment Calculator window opens.

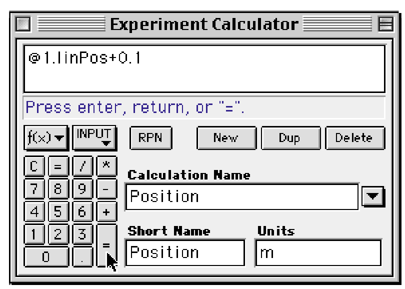
2. Select 'Digital 1, Linear Position' from the Input menu.

3. Add the amount of distance that separated the Light Source and the Light Sensor at the beginning of data recording. (Note: In this example, the distance is 0.1 m.)

4. Finish by typing 'Position' for the Calculation Name and for the Short Name. Type 'm' for Units. Click the 'equals' button to save the calculation.

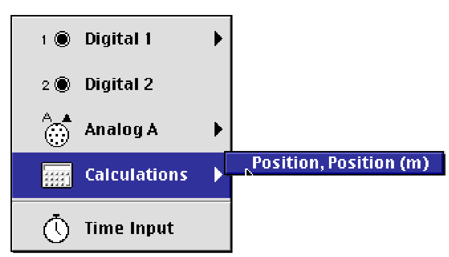






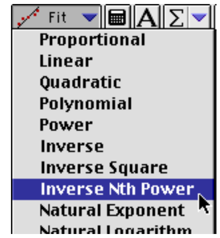
Change the Graph Display

- In *DataStudio*, click and drag the 'Position' calculation to the X-axis of the Graph display.
- In *ScienceWorkshop*, click the 'X-Axis Input' menu and select 'Calculations, Position, Position (m).

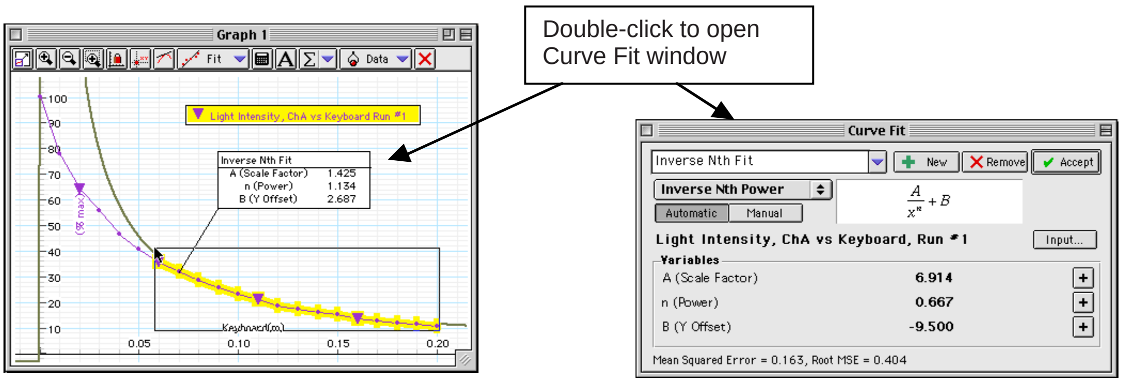


Fit a Curve to the Data

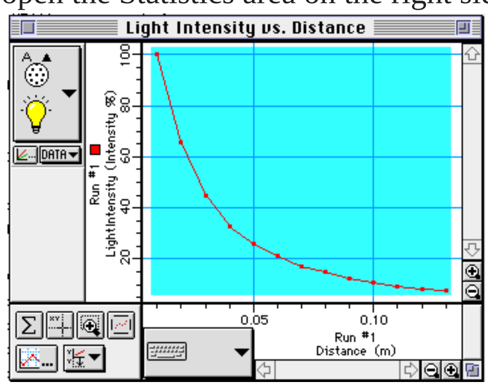
Use the Graph's built-in analysis tools to fit a mathematical formula to the data.



- In *DataStudio*, click the 'Fit' menu button (Fit). Select 'Inverse Nth Power'. Use the cursor to click-and-draw a rectangle around the region of smoothest data in the Graph. The DataStudio program will attempt to fit the data to a mathematical formula.
- Note: To see the mathematical formula and its parameters, double-click the curve fit text box in the Graph.



- In *ScienceWorkshop* click the 'Statistics' button to open the Statistics area on the right side of the Graph. Click the 'Autoscale' button to automatically rescale the Graph to fit the data.
- Use the cursor to click-and-draw a rectangle around the region of smoothest data in the Graph.
- In the Statistics area, select 'Curve Fit, Power Fit' from the Statistics Menu.
- The *ScienceWorkshop* program will attempt to fit the data to a mathematical formula based on the variable (distance) raised to a 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 that best fits your data. In the Statistics area, click the a4 coefficient to make it active. Type in -2 as the parameter value. Press <enter> or <return> on the keyboard to record your value.

- Examine the value of **chi^2**, the measure of closeness of fit. The closer the value is to "0.000", the better the data fit the mathematical formula shown in the Statistics area.

Answer the questions in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P33: Light Intensity versus Position

What Do You Think?

Does the total light energy that passes through an imaginary spherical boundary change as distance from the point light source increases?

Does the light intensity on the surface of an imaginary spherical boundary change as the distance from the point light source increases?

How does the change in light intensity with distance for a ‘real’ light source compare to the change in light intensity with distance for an ideal ‘point’ light source?

Questions

1. What is the relationship of light intensity to distance?

2. The light bulb is not really a point source. How does this affect the experiment (and what can be done to minimize this error)?

Name ____________________ Class _____________ Date ________

Appendix: Modify a *ScienceWorkshop* File

Modify an existing*ScienceWorkshop* file to add the Rotary Motion Sensor.

Open the *ScienceWorkshop* File

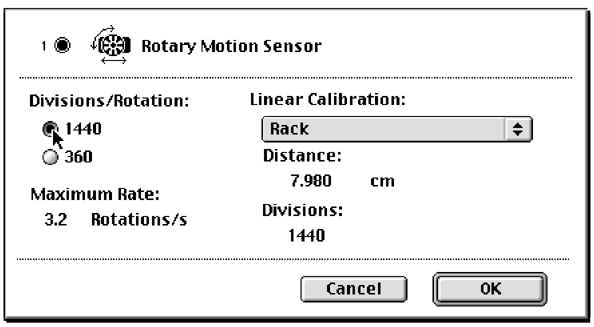
Open the file titled as shown:

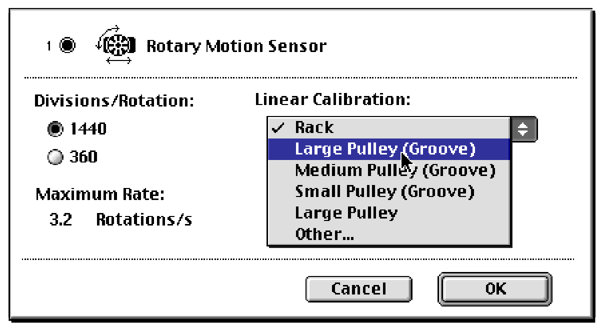
ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P55 Light vs. Position	P55_LTVM.SWS

- The *ScienceWorkshop* file has a Graph display of Light Intensity versus Position (using data from a Motion Sensor).
- You need to replace the Motion Sensor with the Rotary Motion Sensor in the Experiment Setup window and set up the Rotary Motion Sensor parameters. Then you need to change the Graph display.

Set Up the Rotary Motion Sensor

In the Experiment Setup window, click and drag the digital sensor plug to Channel 1. Select 'Rotary Motion Sensor' from the list of sensors. Click 'OK'. **Result**: The Rotary Motion Sensor setup window opens.





Click '1440' under 'Divisions/Rotation'. Under Linear Calibration, select 'Large Pulley (Groove). Click 'OK' to return to the Experiment Setup window.

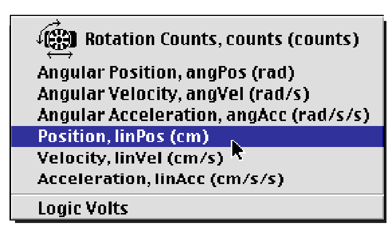
Set the Sampling Options

Click the 'Sampling Options' button in the Experiment Setup window or select 'Sampling Options' from the Experiment menu to open the Sampling Options window. **Result**: The Sampling Options window opens.

Under 'Periodic Samples' click the right arrow to set the sample rate at '20 Hz' (20 measurements per second). Click 'OK' to return to the Experiment Setup window.

Change the Graph Display

Click the 'X-Axis Input' menu and select 'Digital 1, Position, linPos (cm)'.



Name ____________________ Class ______________ Date _________

Activity P34: Polarization - Verify Malus' Law (Light Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Polarization	P34 Malus' Law.DS	(See end of activity)	(See end of activity)

Equipment Needed	Qty	Equipment Needed	Qty
Light Sensor (CI-6504A)	1	**Basic Optics System (OS-8515)**	1
Rotary Motion Sensor (CI-6538)	1	**Polarization Analyzer (OS-8533)**	1
Aperture Bracket (OS-8534)	1		

What Do You Think?

If the transmitted light is at maximum intensity when the two polarizers are parallel, and minimum intensity when the two polarizers are perpendicular, what is the relationship of the intensity of transmitted light to the angle of the polarizers between 0 and 90 degrees?

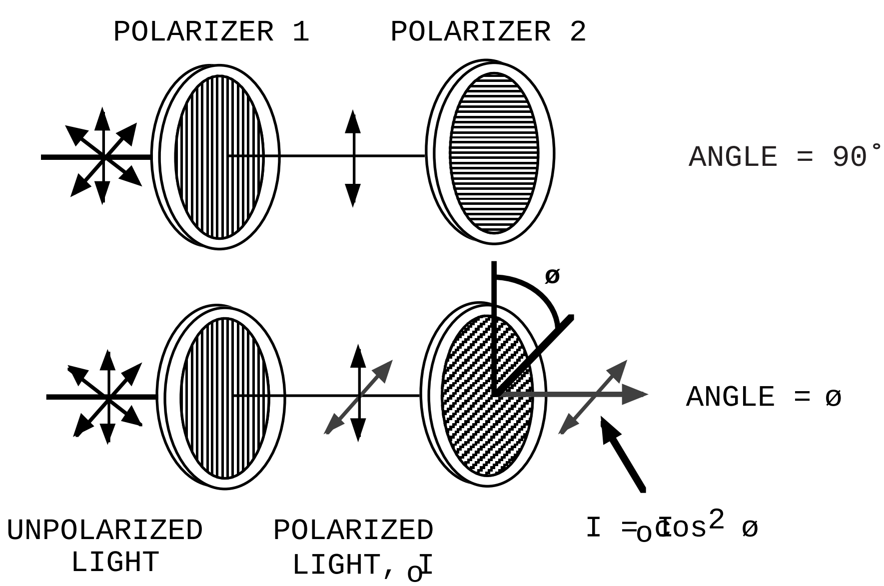
Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

The purpose of this activity is to determine the relationship between the intensity of the transmitted light through two polarizers and the angle, Ø, of the axes of the two polarizers.

Background

A polarizer only allows light that is vibrating in a particular plane to pass through it. This plane forms the "axis" of polarization. Unpolarized light vibrates in all planes perpendicular to the direction of propagation. If unpolarized light is incident upon an "ideal" polarizer, only half will be transmitted through the polarizer. Since in reality no polarizer is "ideal", less than half the light will be transmitted.

The transmitted light is polarized in one plane. If this polarized light is incident upon a second polarizer, the axis of which is oriented such that it is perpendicular to the plane of polarization of the incident light, no light will be transmitted through the second polarizer (see the top figure).



However, if the second polarizer is oriented at an angle so that it is not perpendicular to the first polarizer, there will be some component of the electric field of the polarized light that lies in the same direction as the axis of the second polarizer, thus some light will be transmitted through the second polarizer (see the bottom figure).

The component, $\boldsymbol{E}$, of the polarized electric field, $\boldsymbol{E_o}$, is found by:

$$E = E_o \cos\phi$$

Since the intensity of the light varies as the square of the electric field, the light intensity transmitted through the second filter is given by:

$$I = I_o \cos^2 \phi$$

where $\boldsymbol{I_o}$ is the intensity of the light passing through the first filter and **Ø** is the angle between the polarization axes of the two filters.

Consider the two extreme cases illustrated by this equation:

- If **Ø** is zero, the second polarizer is aligned with the first polarizer, and the value of $\cos^2$**Ø** is one. Thus the intensity transmitted by the second filter is equal to the light intensity that passes through the first filter. This case will allow maximum intensity to pass through.
- If **Ø** is 90˚, the second polarizer is oriented perpendicular to the plane of polarization of the first filter, and the $\cos^2(90˚)$ gives zero. Thus no light is transmitted through the second filter. This case will allow minimum intensity to pass through.
- These results assume that the only absorption of light is due to polarizer effects. In fact most polarizing films are not clear and thus there is also some absorption of light due to the coloring of the Polaroid filters.

SAFETY REMINDERS

- Follow directions for using the equipment.

THINK SAFETY
ACT SAFELY
BE SAFE!

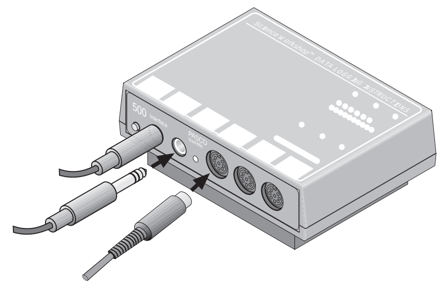
For You To Do

Use the Light Sensor to measure the relative intensity of light that passes through two polarizers. Change the angle of the second polarizer relative to the first polarizer. Use the Rotary Motion Sensor to measure the angle of the second polarizer relative to the first polarizer.

Use *DataStudio* or *ScienceWorkshop* to record and display the light intensity and the angle between the axes of the polarizers. Use the program's built-in calculator to compare the relative intensity to the angle and the cosine^2 of the angle.

Name ______________________ Class ______________ Date _________

PART I: Computer Setup



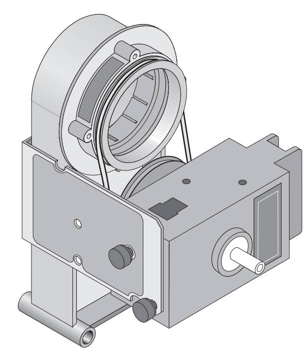
1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Light Sensor into Analog Channel A on the interface.
3. Connect the Rotary Motion Sensor stereo phone plugs to Digital Channels 1 and 2.
4. Open the document titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P34 Malus' Law.DS	(See end of activity)	(See end of activity)

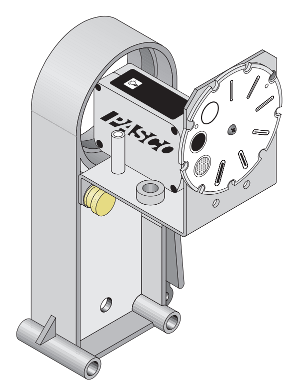
- The document opens with a Digits display of light intensity, a Graph display of light intensity versus the angle, and a Graph display of light intensity versus the cosine square of the angle.
- Data recording is set at 20 Hz. The Rotary Motion Sensor is set for 1440 divisions per rotation.
- See the pages at the end of this activity for information about modifying a *ScienceWorkshop* file.

PART II: Equipment Setup and Sensor Calibration

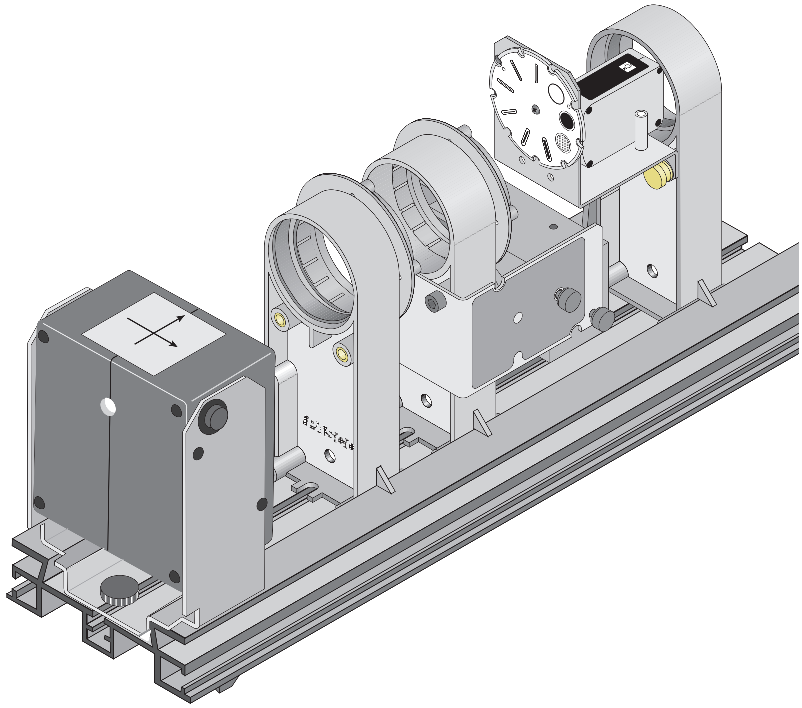
Equipment Setup



1. Assemble the Polarization Analyzer as shown in the instructions that came with the analzyer.
- Place the polarizer on the accessory holder.
- Mount the Rotary Motion Sensor onto the bracket.
- Loop the plastic belt over the Rotary Motion Sensor and the polarizer.
2. Mount the Polarization Analyzer on the Optics Bench.
3. Mount the Light Sensor on the Aperture Bracket and attach the Aperture Bracket to the Aperture Bracket Holder. Put the Aperture Bracket Holder onto the Optics Bench.
4. Rotate the Aperture Disk so the open circular aperture is in line with the opening to the Light Sensor



5. Put the Basic Optics Light Source and another polarizer in an accessory holder onto the Optics Bench.



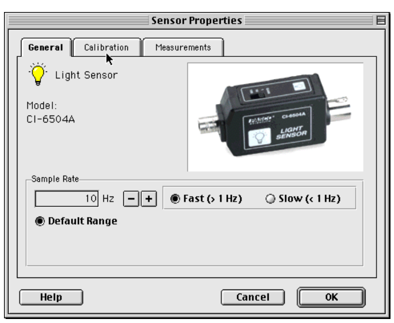
6. Turn on the Light Source. Move the Light Source and the Light Sensor so they are as close as possible to the polarizers.

Sensor Calibration

- Calibrate the Light Sensor so that it produces its maximum voltage when axes of the two polarizers are parallel (**Ø** = 0˚).

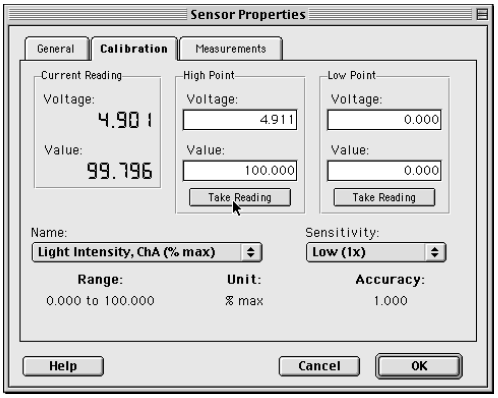
1. Set the GAIN select switch on the top of the sensor to 1. Move the Light Sensor so its port is as close as possible to the light source.

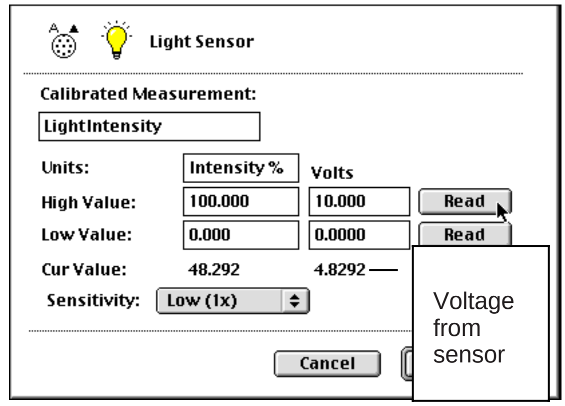
2. In the Experiment Setup window, double-click the Light Sensor icon. **Result**: The Sensor Properties window opens in *DataStudio*. The Light Sensor setup window opens in *ScienceWorkshop*. In *DataStudio* click the 'Calibration' tab.



3. Check the voltage from the Light Sensor.

- Hint: In the *DataStudio* 'Calibration' window, the Current Reading of the voltage from the Light Sensor appears in the upper left corner. In the *ScienceWorkshop* Sensor Setup window, the current value of the voltage from the Light Sensor appears at the bottom of the column labeled Volts.





4. Now adjust the polarizers so the light source shines as brightly as possible into the Light Sensor. For example, turn one polarizer so the zero degree mark is next to the reference peg on the accessory holder. Turn the second polarizer so it is parallel with the first polarizer (i.e., also at zero degrees). Adjust the second polarizer until the transmission is maximum as indicated by the voltage in the calibration window.

- If the value of voltage from the sensor is slightly higher than 4.9 V, slowly move the sensor away from the light source until the value is 4.9 V (or slightly lower).

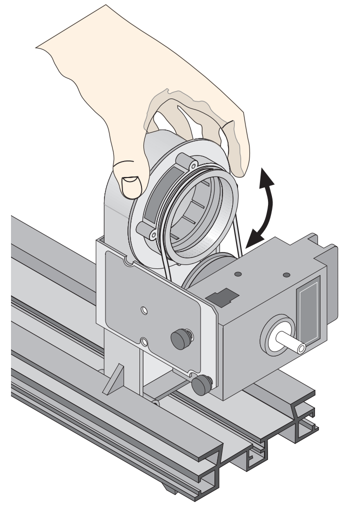
- If the voltage value is below 0.49 V set the GAIN switch to 10. If the value is still below 0.49 V set the GAIN switch to 100.

5. Keep this value of voltage as the maximum value (corresponding to 100% intensity). In *DataStudio* click 'Take Reading' below the 'High Point' column. In *ScienceWorkshop*, click the top Read button.

6. Now adjust the polarizers so the light transmission is as dim as possible. Turn the second polarizer to 90 degrees. Adjust the second polarizer so the transmission is minimum as indicated by the voltage in the calibration window.

7. Keep this value of voltage as the minimum value (corresponding to 0% intensity). In DataStudio click 'Take Reading' below the 'Low Point' column. In *ScienceWorkshop*, click the bottom Read button. Click 'OK' to return to the Experiment Setup window.

PART III: Data Recording

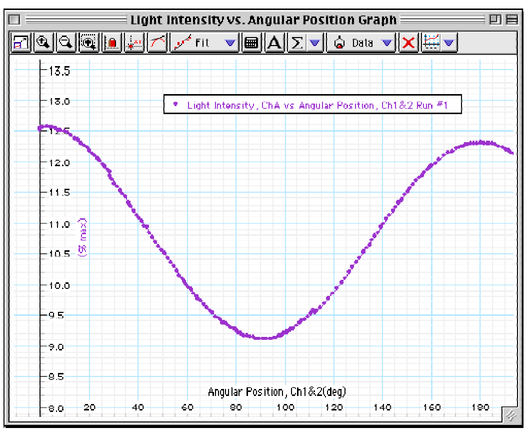


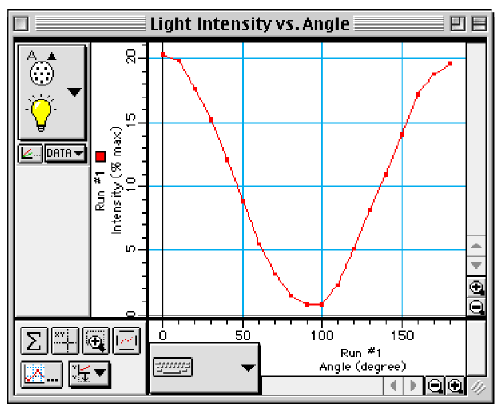
1. Adjust the polarizers for *maximum* transmission of light.
2. When you are ready, start recording data. (Hint: Click the 'Start' button in *DataStudio* or the 'REC' button in *ScienceWorkshop*.)
3. Begin turning the Polarization Analyzer slowly and smoothly. Watch the results in the Graph display. Continue to turn the polarizer for at least one full rotation (360 degrees).
4. After at least one full rotation, stop recording data.
5. Turn off the light source.

Analyzing the Data

Use the Graph displays to analyze your data.

1. Examine the Graph display for 'Light Intensity versus Angular Position'.





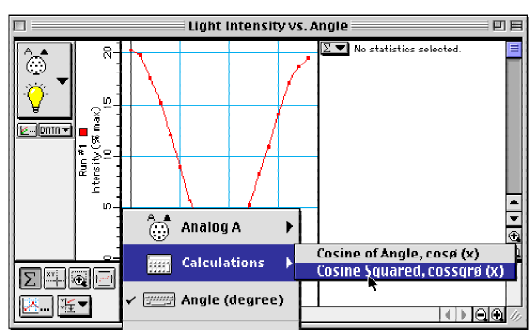
2. Try to fit the data to a mathematical model.

- Hint: In *DataStudio*, click the 'Fit' menu button and select 'Polynomial'. In *ScienceWorkshop*, click the 'Statistics' button and then select 'Curve Fit, Polynomial Fit' from the Statistics menu. Note whether or not the 'Polynomial' model is a 'good fit'.

3. Next, examine the Graph display for 'Light Intensity versus cosine (angle)'.

- In *DataStudio*, click the second graph to make it active. In *ScienceWorkshop*, select 'Calculations, Cosine squared' from the X-axis Input menu.

4. Try to fit the data to a new mathematical model. In *DataStudio*, click the 'Fit' menu button and select 'Linear'. In *ScienceWorkshop*, click the 'Statistics' menu and select 'Curve Fit, Linear Fit'.



Answer the questions in the Lab Report section.

Name ____________________ Class ______________ Date _________

Lab Report - Activity P34: Polarization – Verify Malus' Law

What Do You Think?

If the transmitted light is at maximum intensity when the two polarizers are parallel, and minimum intensity when the two polarizers are perpendicular, what is the relationship of the intensity of transmitted light to the angle of the polarizers between 0 and 90 degrees?

Questions

1. What is the shape of the graph of the Light Intensity versus the Angular Position?

2. What is the shape of the graph of the Light Intensity versus the square of the cosine of the angle?

3 Theoretically, what percentage of incident plane polarized light would be transmitted through three polarizers which each have their axes rotated 17 degrees from each other? Assume ideal polarizers and assume that the first polarizer's axis is 17 degrees from the axis of the second polarizer.

Name ____________________ Class ______________ Date _________

Appendix: Modify a *ScienceWorkshop* File

Modify an existing*ScienceWorkshop* file to add the Rotary Motion Sensor.

Open the *ScienceWorkshop* File

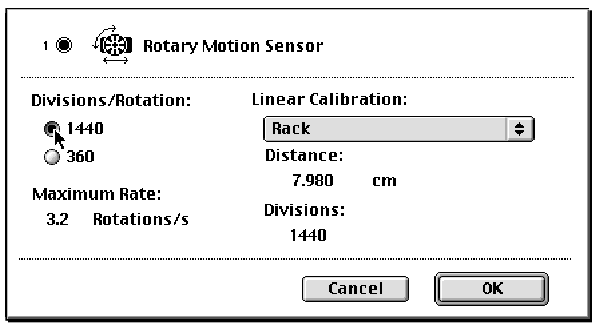
Open the file titled as shown:

ScienceWorkshop (Mac)	*ScienceWorkshop* (Win)
P57 Malus' Law	P57_POLA.SWS

- The *ScienceWorkshop* file has a Graph display of Light Intensity versus Angle (where the angle is entered from the keyboard.)
- You need to add the Rotary Motion Sensor to the Experiment Setup window, change the Sampling Options, and create a calculation of 'cosine squared' of the angular position data from the sensor.

Set Up the Rotary Motion Sensor

In the Experiment Setup window, click and drag the digital sensor plug to Channel A. Select 'Rotary Motion Sensor' from the list of sensors. Click 'OK'. **Result**: The Rotary Motion Sensor setup window opens.

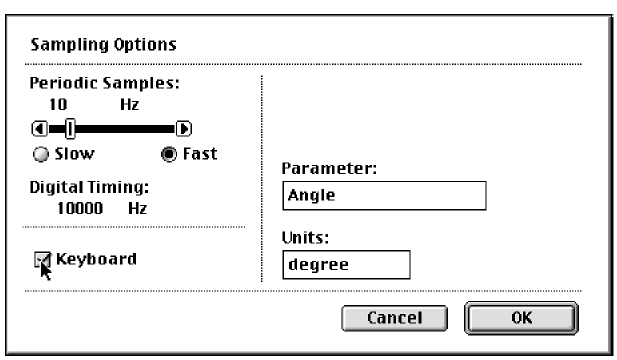


Click '1440' under 'Divisions/Rotation' and then click 'OK' to return to the Experiment Setup window.

Set the Sampling Options

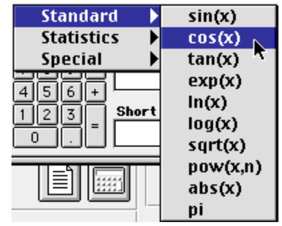
Click the 'Sampling Options' button in the Experiment Setup window or select 'Sampling Options' from the Experiment menu to open the Sampling Options window. **Result**: The Sampling Options window opens.

De-select 'Keyboard' by clicking the checkmark. Under 'Periodic Samples' click the right arrow to set the sample rate at '20 Hz' (20 measurements per second). Click 'OK' to return to the Experiment Setup window.

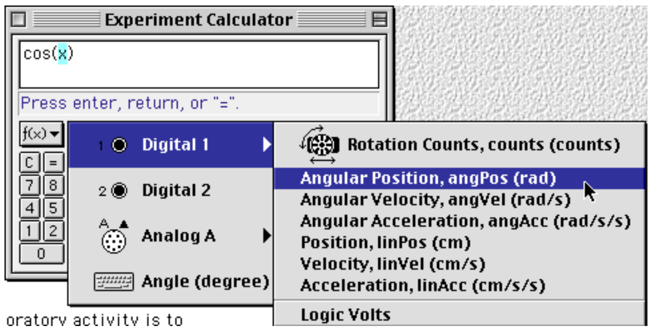


Set Up the Calculation

Open the Experiment Calculator window. Select ‘cos(x)’ from the ‘f(x), Standard’ menu.

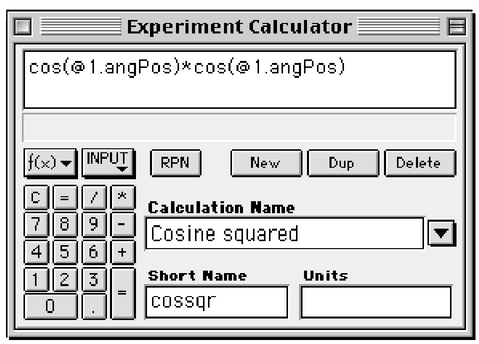


Select ‘Digital 1, Angular Position’ from the ‘Input’ menu.



Copy the calculation (cos (@1.angPos) and paste the copy next to the original. Add a multiplication symbol (*) between the original and the copy.

Type ‘Cosine squared’ for the Calculation Name and ‘cossqr’ for the Short Name. Click the ‘equals’ button to finish the calculation.



Name ____________________ Class ______________ Date _________

Activity P35: Light Intensity in Double-Slit and Single-Slit Diffraction Patterns (Light Sensor, Rotary Motion Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Interference	P35 Diffraction.ds	P58 Diffraction Patterns	P58_DIFF.SWS

Equipment Needed	Qty	Equipment Needed	Qty
Light Sensor (CI-6504A)	1	**Diode Laser (OS-8525)**	1
Rotary Motion Sensor (CI-6538)	1	**Linear Translator (OS-8535)**	1
Aperture Bracket (OS-8534)	1	**Slit Accessory (OS-8523)**	1
Basic Optics System (OS-8515)	1		

What Do You Think?

The wave nature of light can be investigated by studying diffraction patterns. What is diffraction and just how can the observance of diffraction patterns be used to verify the wave nature of light?

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

Background: Part One

In 1801, Thomas Young obtained convincing evidence of the wave nature of light. Light from a single source falls on a slide containing two closely spaced slits. If light consists of tiny particles (or "corpuscles" as described by Isaac Newton), we might expect to see two bright lines on a screen placed behind the slits. Young observed a series of bright lines. Young was able to explain this result as a wave interference phenomenon. Because of diffraction, the waves leaving the two small slits spread out from the edges of the slits. This is equivalent to the interference pattern of ripples produced when two rocks are thrown into a pond.

In general, the distance between slits is very small compared to the distance from the slits to the screen where the diffraction pattern is observed. The rays from the edges of the slits are essentially parallel. Constructive interference will occur on the screen when the extra distance that rays from one slit travel is a whole number of wavelengths in difference from the distance that rays from the other slit travel. Destructive interference occurs when the distance difference is a whole number of half-wavelengths.

For two slits, there should be several bright points (or "maxima") of constructive interference on either side of a line that is perpendicular to the point directly between the two slits.

Background: Part Two

The interference pattern created when monochromatic light passes through a single slit is similar to the pattern created by a double slit, but the central maximum is measurably brighter than the maxima on either side of the pattern. Compared to the double-slit pattern, most of the light intensity is in the central maximum and very little is in the rest of the pattern.

The smaller the width of the slit, the more intense the central diffraction maximum.

SAFETY REMINDER

- Follow all safety instructions.

THINK SAFETY
ACT SAFELY
BE SAFE!

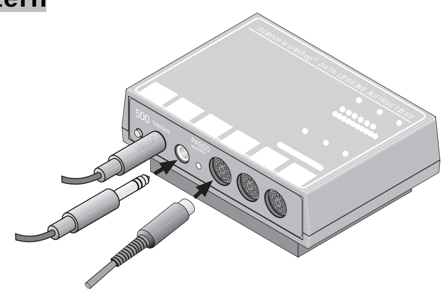
For You To Do

In Part A of this activity, use the Light Sensor to measure the intensity of the maxima in a double-slit diffraction pattern created by monochromatic laser light passing through a double-slit. Use the Rotary Motion Sensor (RMS) to measure the relative positions of the maxima in the diffraction pattern.

In Part B, use the Light Sensor to measure the intensity of the maxima in a single-slit diffraction pattern created by monochromatic laser light passing through a single-slit. Use the Rotary Motion Sensor (RMS) to measure the relative positions of the maxima in the diffraction pattern.

Use *DataStudio* or *ScienceWorkshop* to record and display the light intensity and the relative position of the maxima in the pattern and to plot intensity versus position.

PART IA: Computer Setup – Double-Slit Diffraction Pattern



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Light Sensor into Analog Channel A on the interface.
3. Connect the Rotary Motion Sensor stereo phone plugs to Digital Channels 1 and 2.
4. Open the document titled as shown:

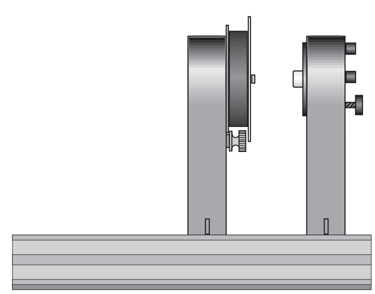
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
P35 Diffraction.ds	P58 Diffraction Patterns	P58_DIFF.SWS

- The *DataStudio* document has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document opens with a Graph display of light intensity vs. position.
- Data recording is set at 50 measurements per second (50 Hz).

PART IIA: Sensor Calibration & Equipment Setup – Double-Slit Diffraction Pattern

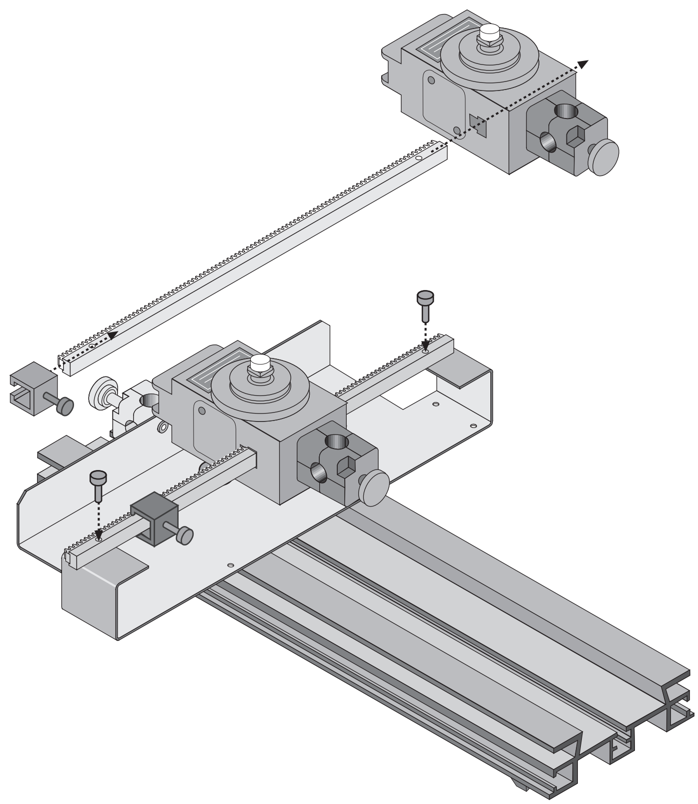
- You do not need to calibrate the sensors.

Equipment Setup

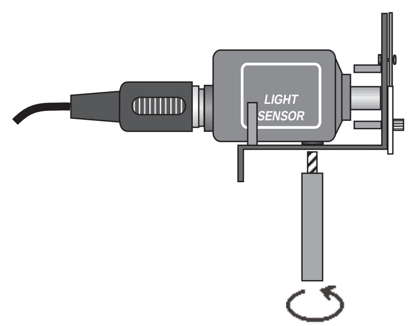


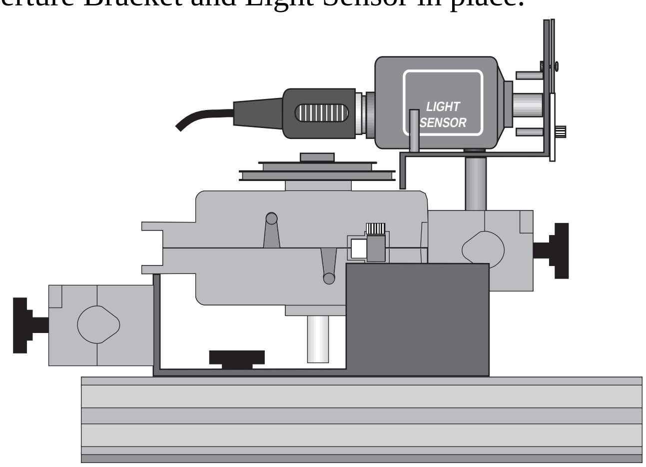
1. Mount the Diode Laser on one end of the Optics Bench. Connect the power supply to the laser.
2. Place the MULTIPLE SLIT SET into the Slit Accessory holder. Mount the Slit Accessory holder in front of the Diode Laser on the bench.

3. Put the rack from the Linear Translator through the slot in the side of the Rotary Motion Sensor. Put the rack clamp onto the rack and tighten its thumbscrew.
4. Place the rack with the sensor onto the Linear Translator so the back end of the sensor rests on the upright edge of the base of the Linear Translator. Use the thumbscrews to attach the rack to the translator.

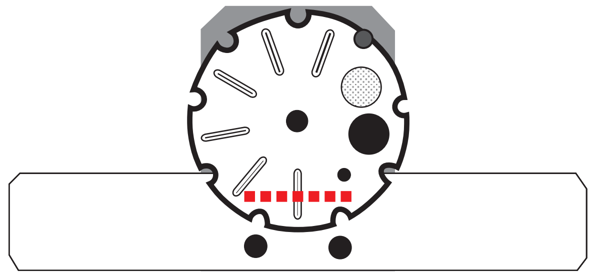


5. Remove the 'O' ring and thumbscrew from the Rotary Motion Sensor pulley so they will not interfere with the Aperture Bracket.
6. Mount the Light Sensor onto the Aperture Bracket by screwing the Aperture Bracket post into the threaded hole on the bottom of the Light Sensor.
7. Put the post into the rod clamp on the end of the Rotary Motion Sensor. Tighten the rod clamp thumbscrew to hold the Aperture Bracket and Light Sensor in place.



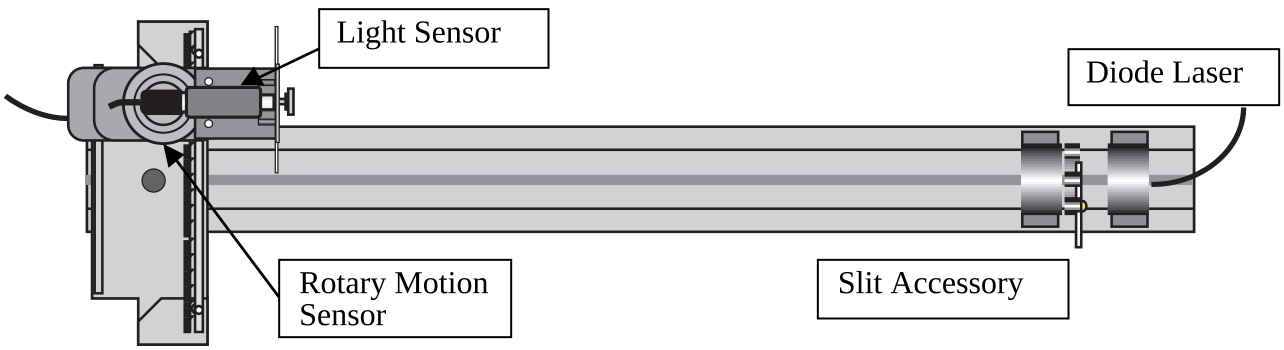


8. Turn on the power switch on the back of the Diode Laser. Adjust the position of the laser and the MULTIPLE SLIT SET on the Slit Accessory so that the laser beam passes through one of the double-slit pairs on the SLIT SET and forms a clear, horizontal diffraction pattern on the white screen of the Aperture Bracket.



9. Record the slit width "a" and slit spacing "d" of the double-slit pattern you use in the Lab Report section.

10. Rotate the Aperture Disk on the front of the Aperture Bracket until the narrowest slit is in front of the Light Sensor opening.



Preparing to Record Data

- Before recording any data for later analysis, you should experiment with the Rotary Motion Sensor and Light Sensor setup.
- Move the Rotary Motion Sensor/Light Sensor along the rack until the maximum at one edge of the diffraction pattern is next to the slit in front of the Light Sensor.
- Begin recording data.
- Slowly and smoothly, move the Rotary Motion Sensor/Light Sensor so that the maxima of the diffraction pattern move across the slit on the Aperture Disk.
- When the entire interference pattern has been measured, stop recording data. 'Run #1' will appear in the Data List.
- Rescale the Graph to fit the data. Examine the plot of light intensity versus position..
- Erase your data. Select Run #1 in the Data List and press the 'Delete key on the keyboard.

PART IIIA: Data Recording – Double-Slit Diffraction Pattern

- Move the Rotary Motion Sensor/Light Sensor along the rack until the maximum at one edge of the diffraction pattern is next to the slit in front of the Light Sensor.

1. Begin recording data.
2. Slowly and smoothly, move the Rotary Motion Sensor/Light Sensor so that the maxima of the diffraction pattern move across the slit on the Aperture Disk.
3. When the entire diffraction pattern has been measured, stop recording data.

Name ____________________ Class _____________ Date ________

PART IB: Computer Setup – Single-Slit Diffraction Pattern

- Use the same computer setup as in Part A.

PART IIB: Sensor Calibration & Equipment Setup – Single-Slit Diffraction Pattern

1. Replace the MULTIPLE SLIT SET with the SINGLE SLIT SET on the Slit Accessory Holder.
2. Record the slit width "a" of the single-slit pattern you use in the Lab Report section.
3. Re-align the laser beam with one of the single slits on the SINGLE SLIT SET. Adjust the positions of the laser and the Rotary Motion Sensor/Light Sensorif necessary so that the diffraction pattern is at the same height for the double-slit.

PART IIIB: Data Recording – Single-Slit Diffraction Pattern

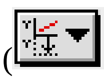
1. Repeat the procedure for collecting data as in Part A.

- Run #2 will appear in the Data List in the Experiment Setup window.

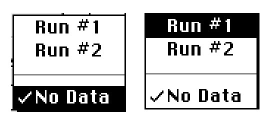
2. Turn off the laser.

Analyzing the Data

1. Rescale the Graph to fit the data.
2. Examine the shape of the plots of light intensity versus position for both the double-slit and the single-slit patterns.

- In *ScienceWorkshop*, the Graph will display the most recent run of data. Use the 'Add Plot Menu' to create a second plot on the Graph. Click the 'Add Plot Menu' button () and select 'Analog A, Intensity' from the Add Plot Menu.
- Both plots will show the most recent run (Run #2) of data. Use the 'DATA Menu' in the top plot of the Graph to display Run #1. Click the 'DATA Menu' button (

) in the top plot of the Graph. Select 'No Data' to clear Run #2. Click the DATA Menu button again and select Run #1. **Result**: The top plot will display Run #1 and the bottom plot will display Run #2.



Name ____________________ Class ______________ Date _________

Lab Report - Activity P58: Diffraction Patterns

What Do You Think?

The wave nature of light can be investigated by studying diffraction patterns. What is diffraction and just how can the observance of diffraction patterns be used to verify the wave nature of light?

Data

	Slit Width (a)	Slit Spacing (d)
Part A – Double-slit		
Part B – Single-Slit		

Question

1. How does the plot of light intensity versus position for the double-slit diffraction pattern compare to the plot of light intensity versus position for the single-slit diffraction pattern?