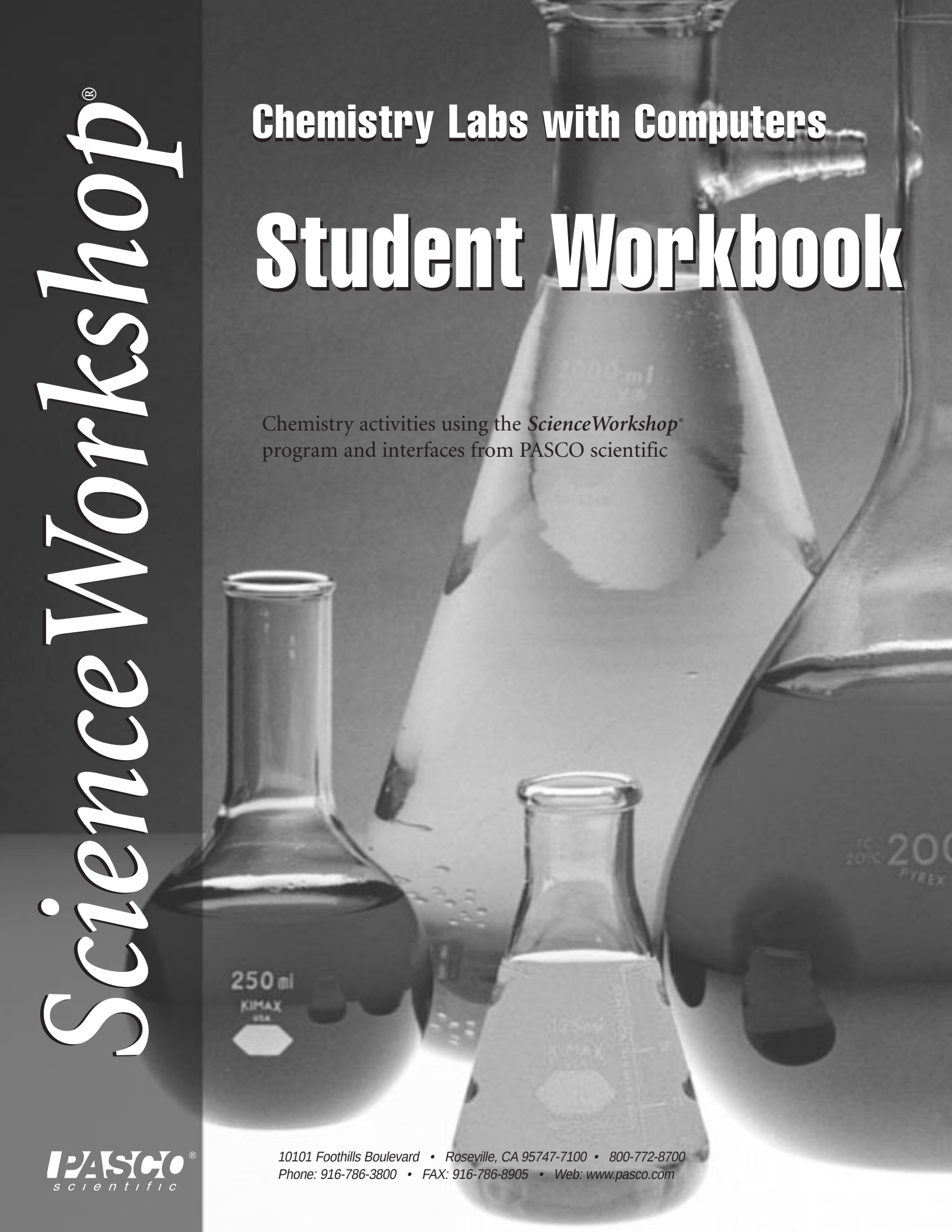
ScienceWorkshop®

Chemistry Labs with Computers

Student Workbook

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



PASCO® scientific

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Chemistry Labs with Computers: Student Workbook
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Edited by David A. Griffith.

Contents

Reactions and Energy

The Mole

Chemical Unknown

Electrochemistry

Acids, Bases and Salts

Preface

I. Overview of Chemistry Labs with Computers Student Workbook (CI-7021)

This manual has thirty-three activities in the following areas: phase change, gas laws, rate of reactions, reactions and energy, the mole, unknowns, electrochemistry, and acid-base reactions. Most of the activities can be done with the sensors that are included in the Chemistry Bundles: colorimeter, pH, pressure, temperature, thermocouple, and voltage.

Each activity has the following parts:

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

Equipment List

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

Purpose (What Do You Think?)

The purpose includes a question for 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, taking precautions when handling glassware or chemicals, and wearing protective gear (e.g., splash shield or goggles, gloves, and an apron).

Procedure

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

- Set up the interface.
- Open the *DataStudio* or *ScienceWorkshop* file.
- Set up the equipment.
- Do the experiment (record the data).

Analyzing the Data

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

Lab Report

The Lab Report section is where students can record their data and answer the questions. The Student Workbook pages are perforated so the student can remove these pages and turn them in.

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 equipment, glassware, and especially chemicals.
- In every activity be sure to wear protective gear such as a lab coat or apron, gloves, and protective goggles or a splash shield to protect your eyes and face.
- Never pipette by mouth. Use a pipette bulb or a pipette pump whenever you need to pipette solutions.
- 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.
- Dispose of all chemicals and solutions properly.

For more information about usage, storage, and disposal of chemicals, you can refer to the Flinn Scientific Catalog. You can contact Flinn Scientific at:

P.O. Box 219
131 Flinn Street
Batavia, IL 60510
Phone: (708) 879-6962 or (800) 452-1261 toll-free in the U.S.A.
E-mail: flinnsci@aol.com

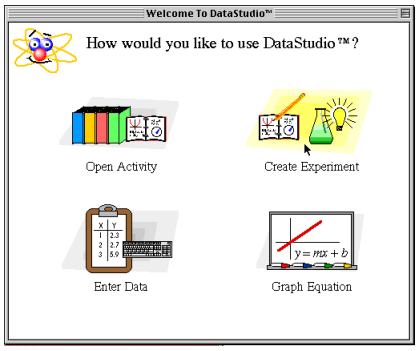
III. Acknowledgements

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

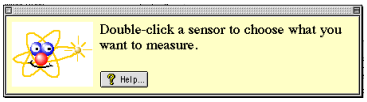
May 22, 1999.

Quick Reference Guide for *DataStudio*

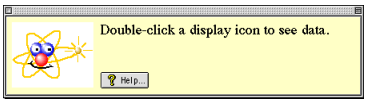
Create an Experiment



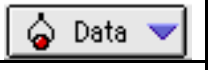
(1) Double-click a sensor.



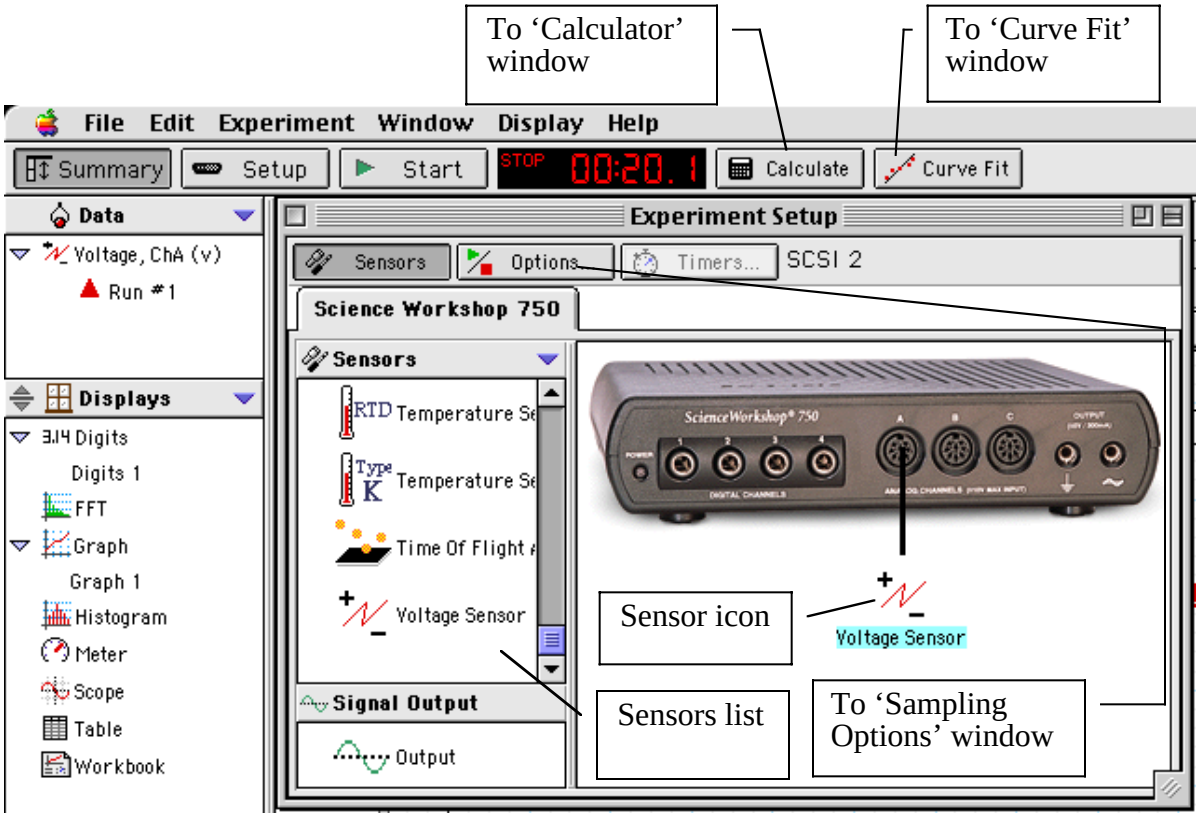
(2) Double-click a display.



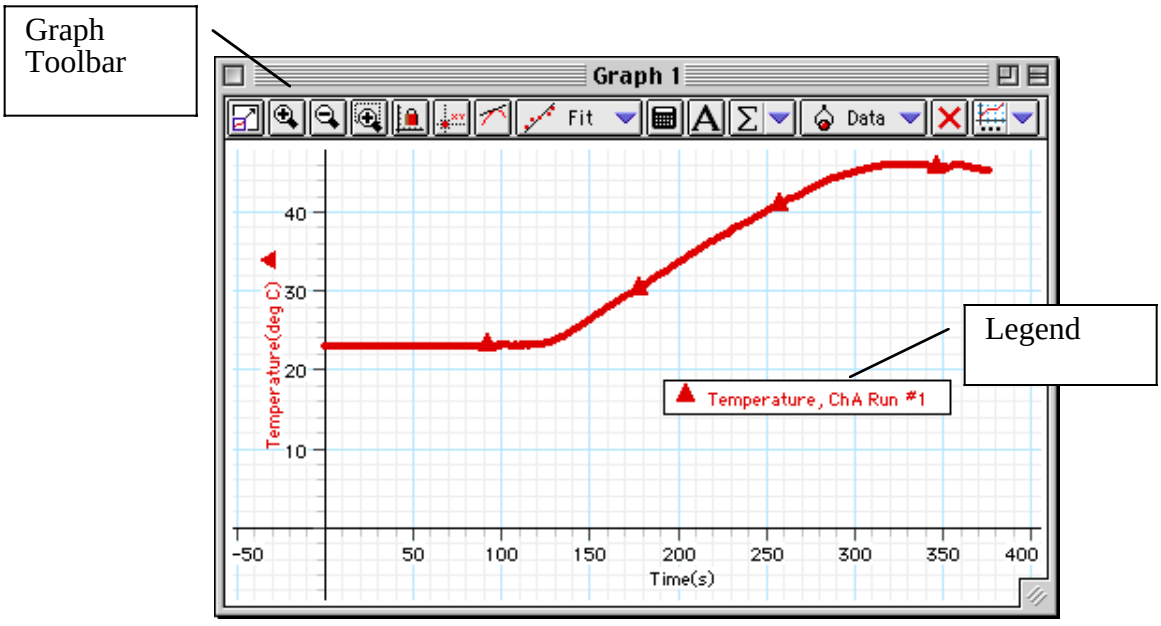
What You Want To Do	How You Do It	Button
Start recording data	Click the 'Start' button or select 'Start Data' on the Experiment menu (or on the keyboard press CTRL - R (Windows) or Command - R (Mac))	
Stop recording (or monitoring) data	Click the 'Stop' button or select 'Stop Data' on the Experiment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

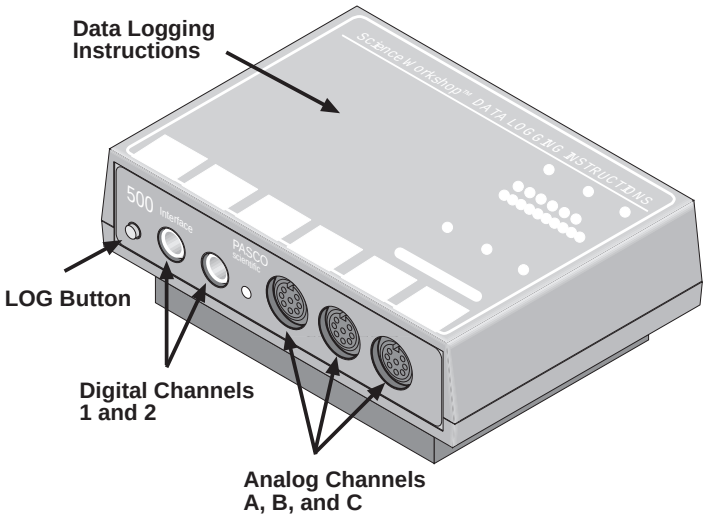
Hint: Working at a computer with *DataStudio* up and running while reading these instructions will bring a "hands-on" experience to the user and enhance the learning process.

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).

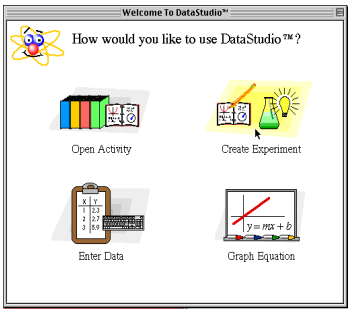
The **Analog Channels** allow up to three analog sensors to be plugged into the *500* interface. You can plug in an analog sensor's DIN plug in only one way. The Starter Bundle includes three analog sensors: Light, Temperature, and Voltage.

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

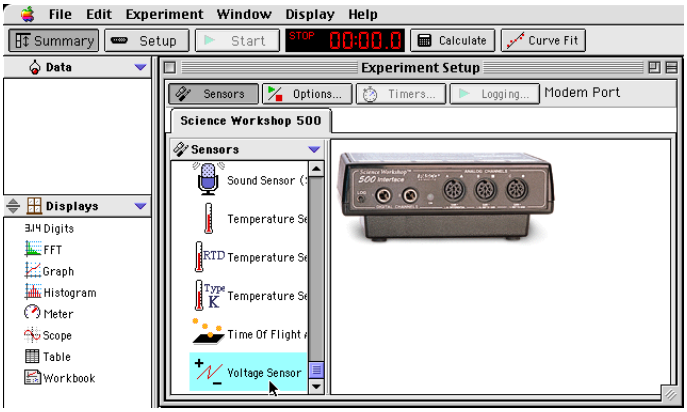
Section #2: Setting Up Your Own Experiment in DataStudio

The Summary List and the Setup Window

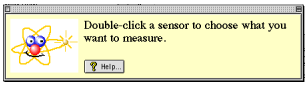
Start *DataStudio*. In the 'Welcome to DataStudio™' window, click 'Create Experiment'.



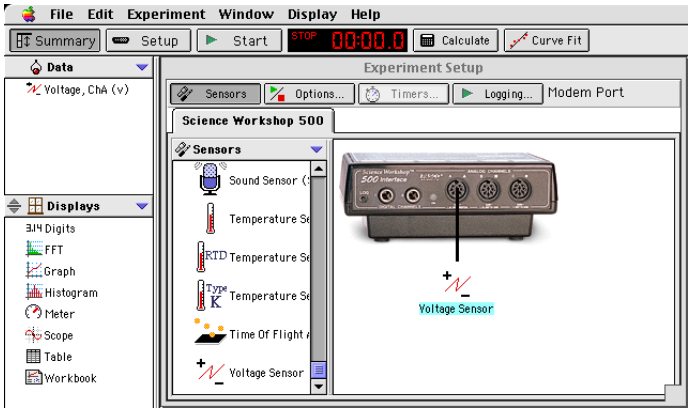
The first step to becoming proficient with *DataStudio* is to understand the Summary List and the Experiment Setup window. The Summary List shows runs of data (under 'Data') and the available displays (under 'Displays'). The Experiment Setup window shows the list of sensors (under 'Sensors') and the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



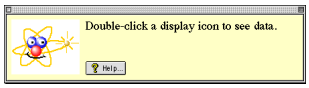
Select a sensor. The sensors are listed by name. Scroll through the list to find the 'Voltage Sensor', and then double-click the sensor to select it.



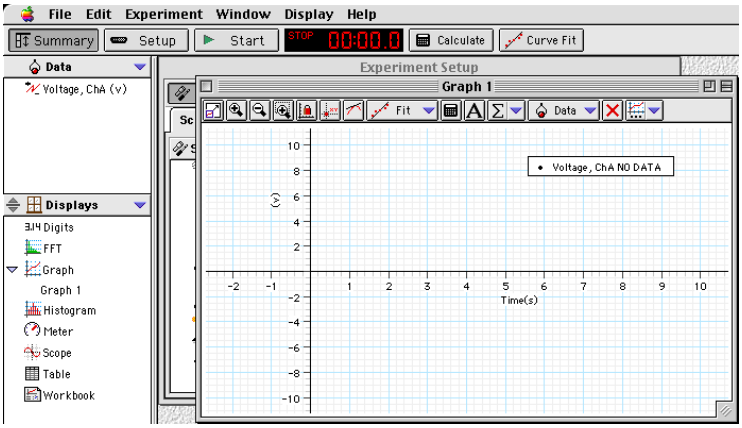
The Voltage Sensor icon appears below Channel A of the interface, and 'Voltage, ChA (v)' appears in the Data list.



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



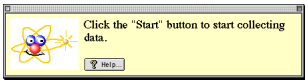
Graph 1 opens, and 'Graph 1' appears in the Displays list. Also, 'Voltage, ChA NO DATA' appears in the Graph's legend.



Finally, click the 'Start' button (

) 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 (

), a button to open the 'Timers' window (

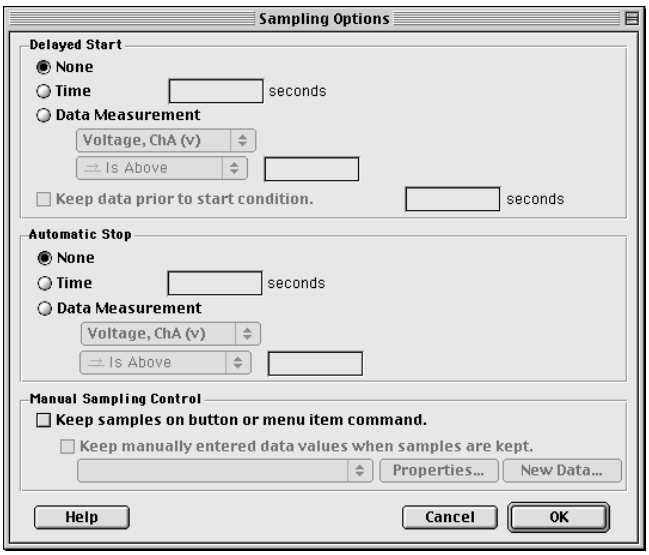
) (for use with Photogates), and a 'Logging' button (

) for use when you disconnect the interface for data logging.

Note: After you click the 'Logging' button, a 'Connect' button (

) 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'.

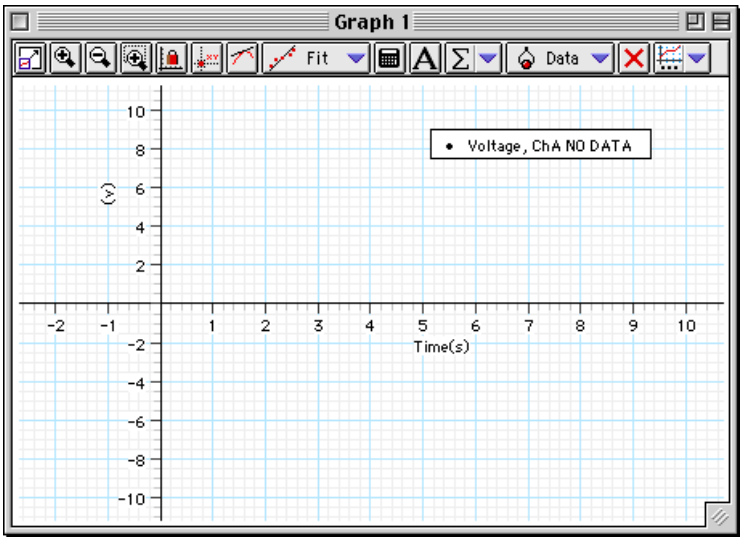


Section #3: Data Analysis

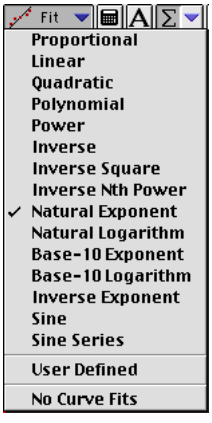
DataStudio offers several ways to analyze data:

- 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 ().

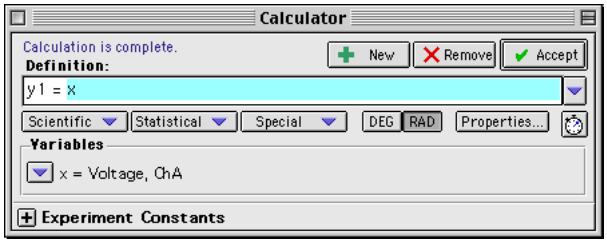


- Use the 'Smart Tool' to see the coordinates of any point.
- Use the 'Slope Tool' to see the slope of a line tangent to a point on a curve.
- Use the 'Fit' menu button to select a mathematical model.
- Use the 'Calculate' button to create a calculation on the data in your Graph.
- Use the 'Statistics' 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 (

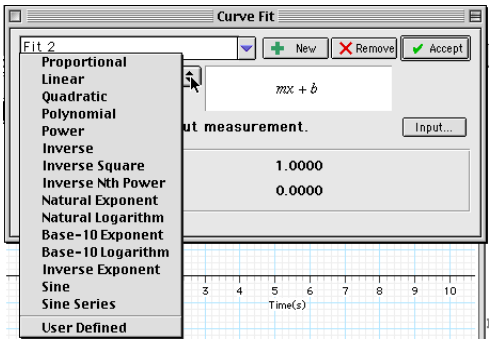
) to open the ‘**Calculator**’ window:



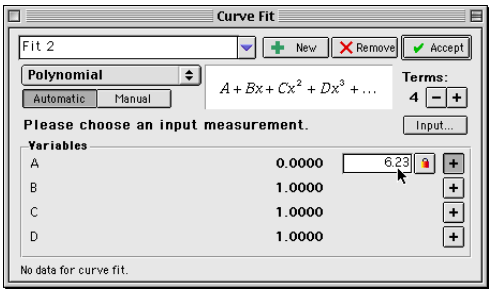
Use the ‘Definition:’ area to create your own calculation, or use the ‘Scientific’, ‘Statistical’, or ‘Special’ menus to select a specific calculation to apply to your data. After you have created the calculation, click ‘Accept’. Your calculation will appear in the Data list. You can drag your calculation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

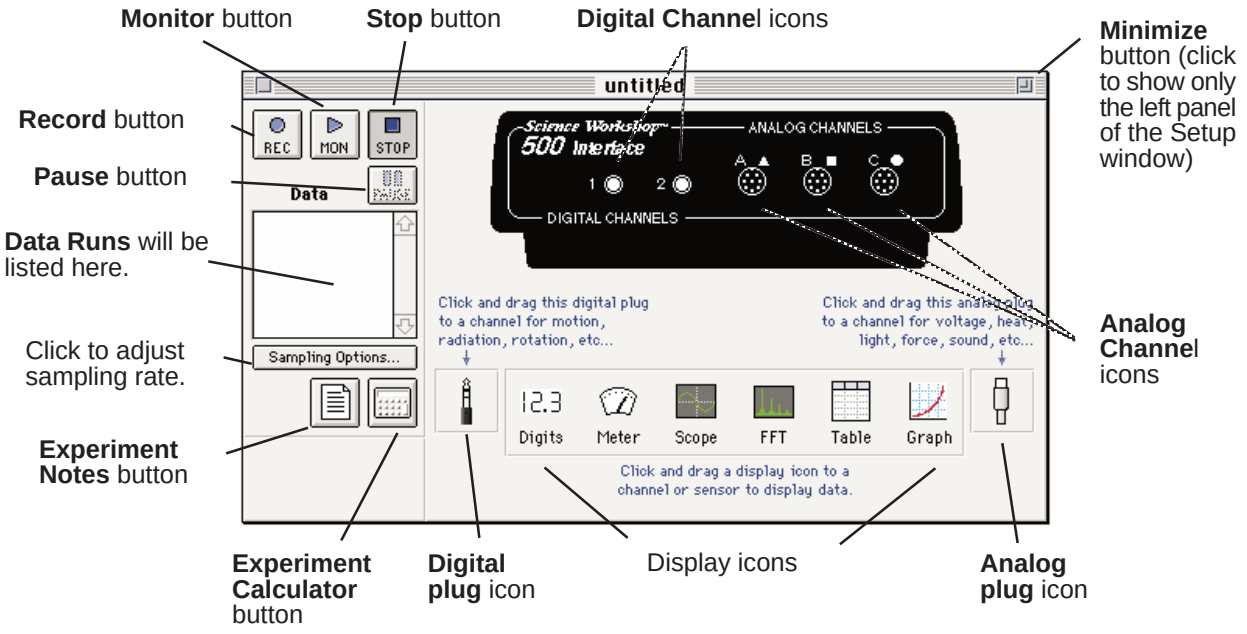
In the Experiment Setup Window:

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))	

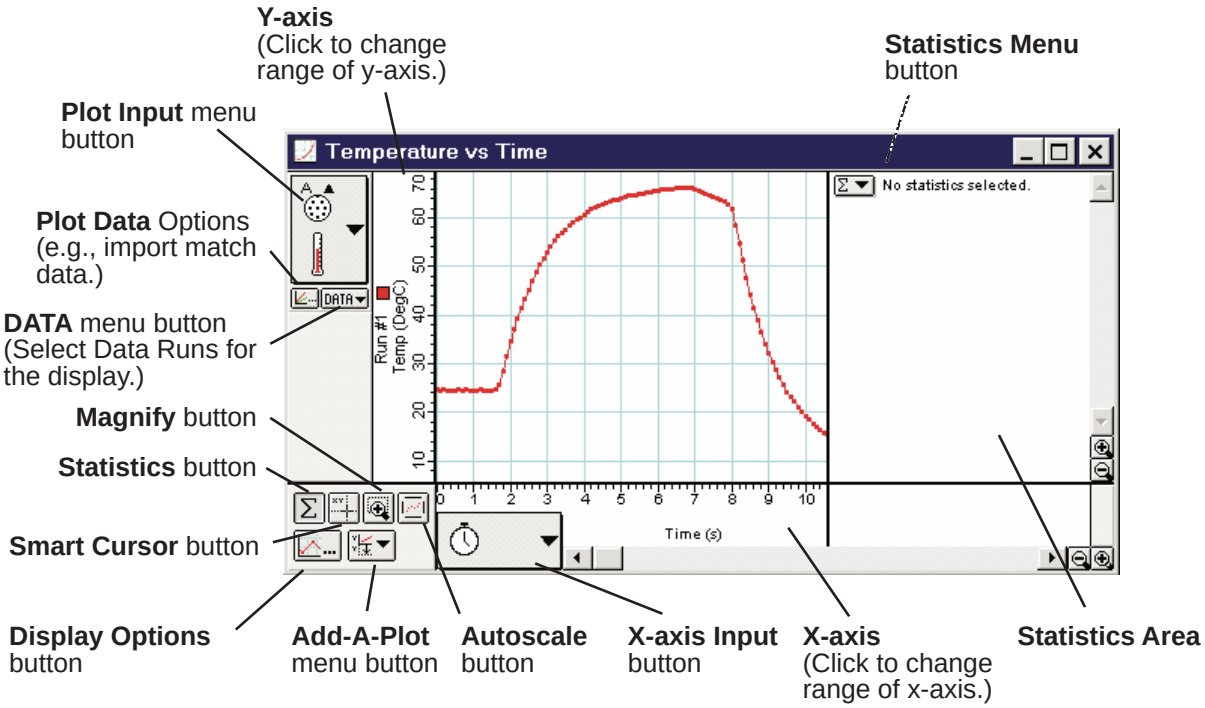
On the Graph Display:

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®*

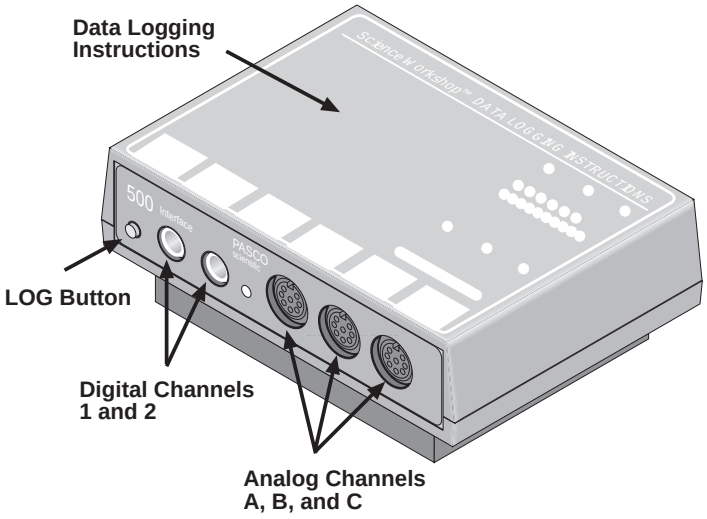
There are several features that make *ScienceWorkshop* a unique and powerful teaching tool for science and math. Section #1 covers the mechanics of the software and hardware. Section #2 covers the data analysis tools in more detail.

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.

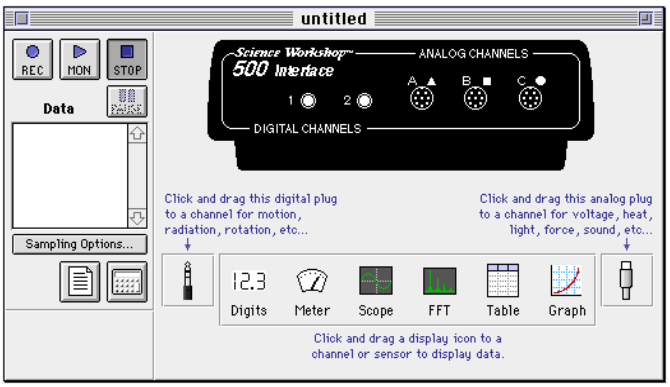
The **green LED (light-emitting diode)** on the front of the interface box indicates the mode of the interface box. A green light indicates that the power is ON. When you disconnect the interface for remote data logging the light will flash slowly when in the sleep mode and rapidly when you are collecting 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 Starter Bundle includes three analog sensors: Light, Temperature, and Voltage.

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

The Experiment Setup Window

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



The Menu Bar File Edit Experiment Display

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

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

  You can also use the Experiment menu to **Record**, **Monitor**, **Pause,** or **Stop** data collection (as if you had used the buttons in the Experiment Setup window). You can use this menu to access the sampling options, disconnect/connect (for remote data logging), display the Experiment Setup window, or go to the Experiment Notes and Calculator windows.
- Use the **Display** menu to select any of the six display windows (either to set up a new display or toggle to a display already in use).

Features of the Experiment Setup Window

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

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

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

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

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

Suggested Periodic Sampling rates for common measurements:

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

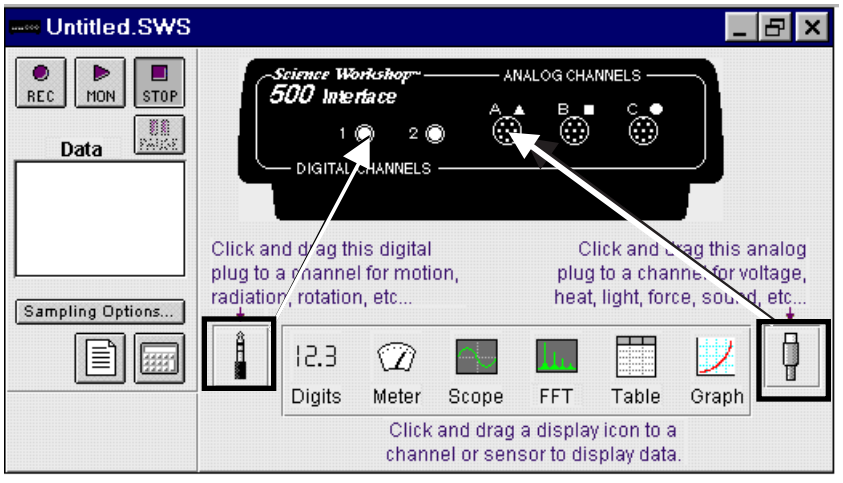
Press the **Experiment Calculator button** to open the Experiment Calculator window that allows you to do mathematical operations on collected data. You can also use it as a stand-alone calculator.

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

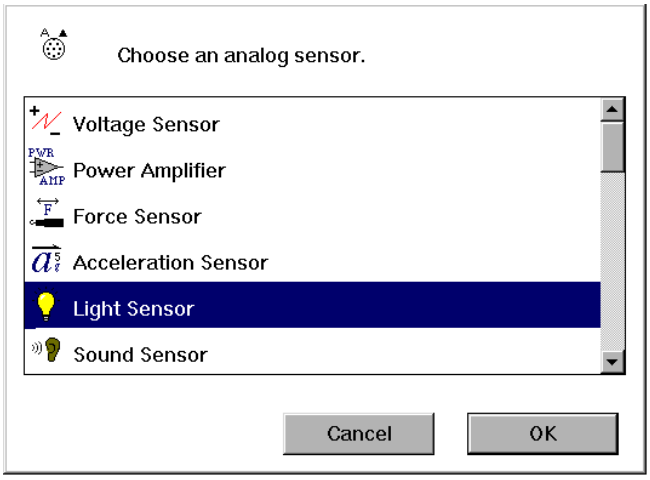
Drag the **analog plug icon** to Analog Channel A, B, or C to add an analog sensor to the Experiment Setup window. Then select the correct analog sensor from the list of sensors than opens. Click **OK** to return to the Experiment Setup window.

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.

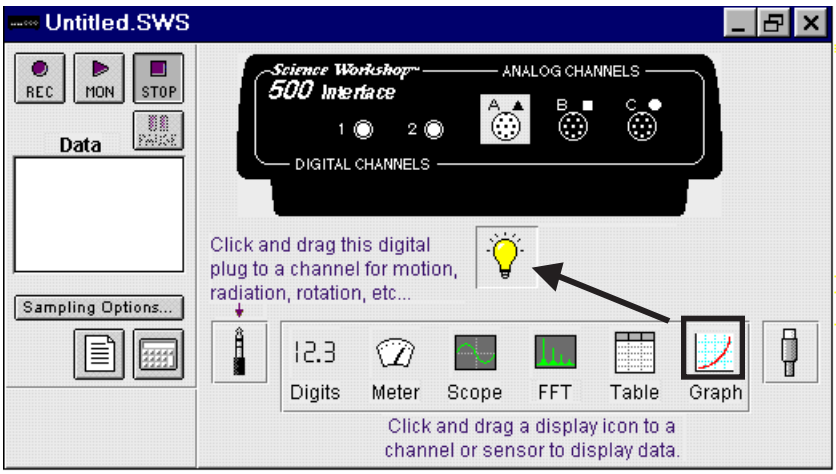


2. Choose the sensor from the sensor list that pops up. Click **OK** to return to the Experiment Setup window.



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

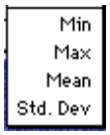
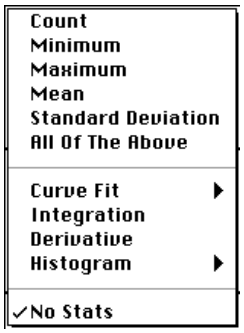
Analysis: The Smart Cursor 

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.

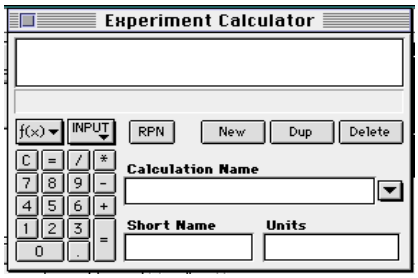
Statistics menu for a Table display	
In the Graph display, click the Statistics Menu button to see the statistics options.	
Statistics menu for a Graph display	
Curve Fit submenu	
Linear Fit will generate a basic slope equation with the slope of the best-fit line being the **a 2** value in the display.	

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



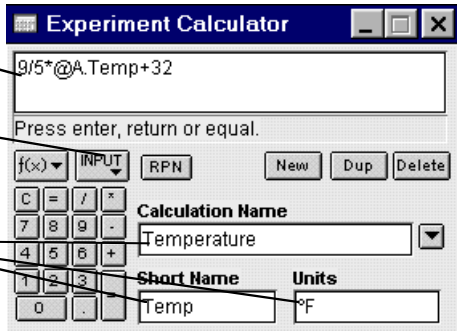
Example:
Converting the temperature data from degrees Celsius to degrees Fahrenheit for plotting on the Graph display.

1. Type the formula here

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

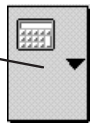
2. Fill in these dialog boxes

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.

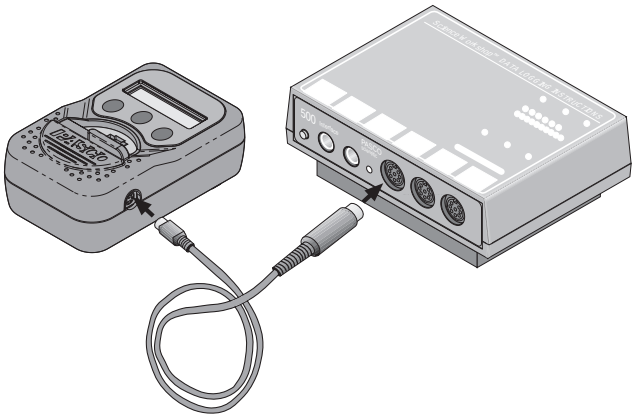
Tutorial Activities – Exploration of Sensors

Practice using the six sensors included in the Chemistry Bundles.

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

Colorimeter

The Colorimeter measures the amount of light that is transmitted through a liquid. The intensity of the light passing through the liquid can often be used to determine properties of the liquid such as the concentration of chemicals in the liquid. Substances absorb different amounts of certain colors of light and transmit other colors. Some substances absorb red but not blue, or green but not orange. The Colorimeter can shine the following colors of light through a liquid: orange (630 nm), green (565 nm), blue (460 nm), and red (697 nm). The Colorimeter uses a small container called a cuvette that holds a small amount of liquid. When you want to measure how much colored light can pass through the liquid, put some of the liquid in a cuvette and place it inside the Colorimeter.

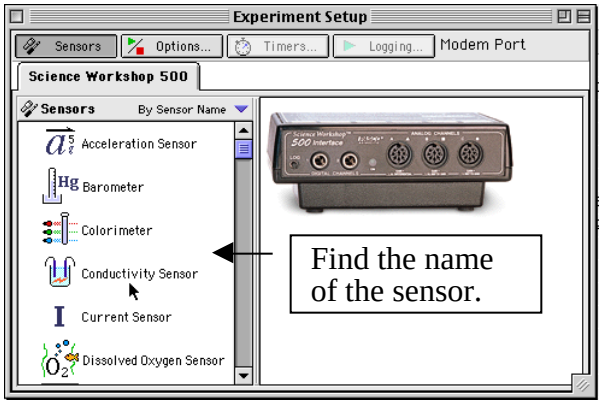


Set up the sensor with the interface.

- The sensor's connector cable has a mini-DIN plug at one end and a regular DIN plug at the other. Plug the mini-DIN end of the cable into the sensor and then connect the other end of the cable into **Analog Channel A** on the interface.
- Note: The Colorimeter turns on automatically when it is connected to the interface. The sensor's liquid crystal display (LCD) shows "Please calibrate" on the second row.

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. The sensor's parameters (e.g., Transmittance, Absorbance.) will appear in the Data list.

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

Calibrate the Colorimeter.

The general method for calibrating the Colorimeter is as follows:

- First, calibrate the Colorimeter with a clear cuvette containing distilled water.
- Second, calibrate the software (either *DataStudio* or *ScienceWorkshop*) for one of the four colors of light that can be selected in the Colorimeter. (You can select RED, GREEN, BLUE, or ORANGE.)

Note: The cuvette has two clear sides and two ridged sides.

- All cuvettes should be wiped clean and dry on the outside with a tissue.
- Handle cuvettes only by the top edge of the ridged sides.
- All solutions should be free of bubbles.
- Always position the cuvette so the light beam will pass through the *clear* sides.

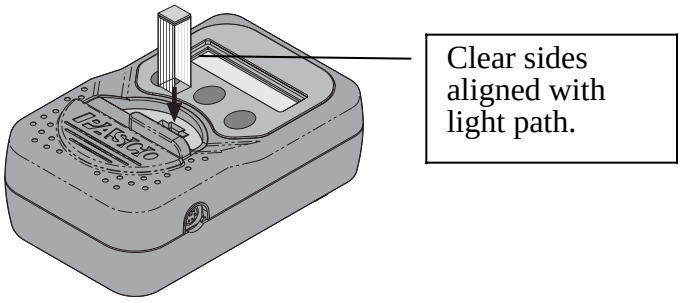
When the Colorimeter comes on, the liquid crystal display (LCD) shows "Please calibrate" on the second row.

Fill a clean cuvette with distilled water and cap the cuvette. (The clear cuvette is a control or 'reference' that accounts for the small amount of light scattered or reflected by the walls of the cuvette.)

On the Colorimeter, press the 'Select' button (Select) and the 'Start/Stop' button (Start/Stop) at the same time.

Result: The Colorimeter's LCD will show "Insert reference then push SELECT".

Place the capped cuvette inside the Colorimeter. Make sure that the clear sides of the cuvette (without ridges) are lined up with the light path in the Colorimeter. Close the lid on the Colorimeter.



On the Colorimeter, press the 'Select' button.

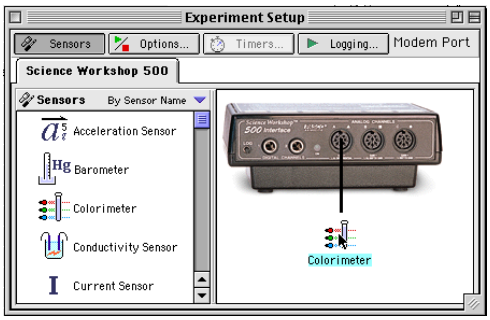
Result: The Colorimeter will *automatically* calibrate itself for all four wavelengths assuming that the light passing through the clear cuvette represents "100% Transmittance". (The automatic calibration takes only a few seconds.)

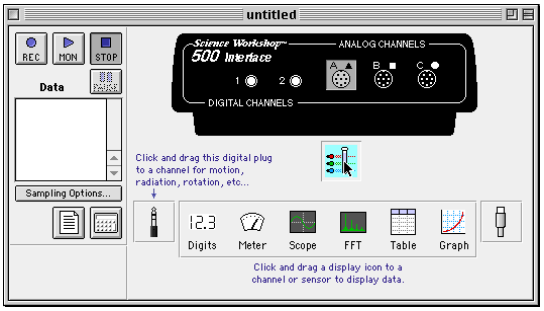
The Colorimeter's LCD will show "CAL done, push SELECT or START".

Calibrate the Software

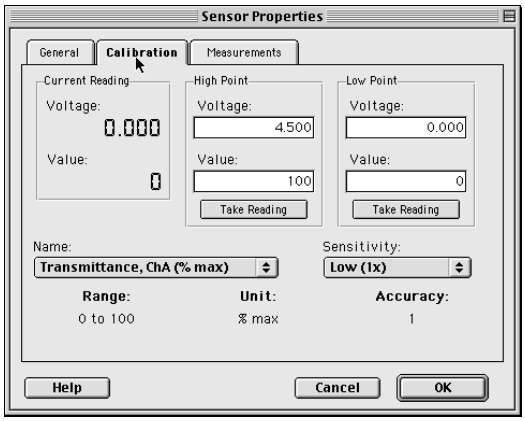
Follow these steps to calibrate the software for one of the four colors of light:

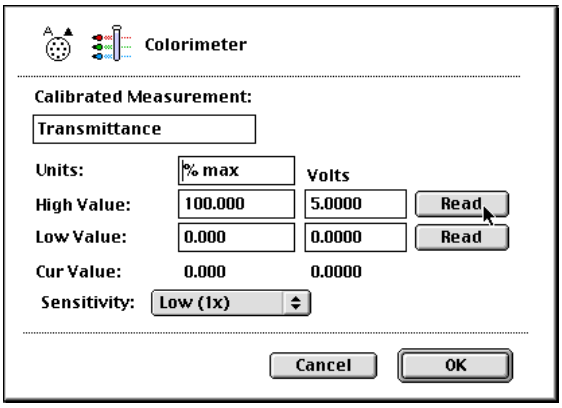
1. Leave the cuvette with distilled water inside the Colorimeter.
2. In the Experiment Setup window, double-click the Colorimeter icon.





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





3. Select the color of light. The default color is RED.

To change to a different color, press the 'Select' button. The LCD shows the color and wavelength.

4. Calibrate the software.

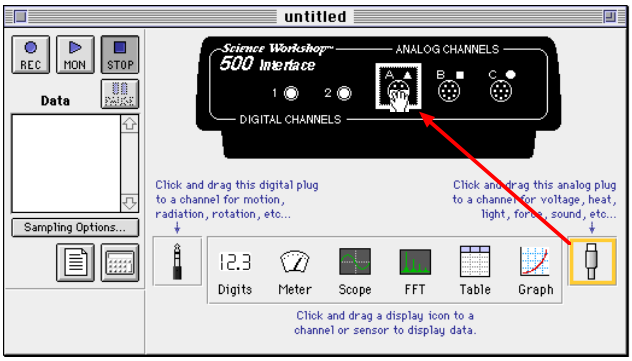
- **First**, press the 'Start/Stop' button (Start/Stop) to start the Colorimeter. (The LCD shows the color and wavelength, the percent transmittance, and "RUN".)
- **Second**, check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*.
- **Third**, when the voltage stabilizes, click the 'Take Reading' button under 'High Point' in *DataStudio* or the 'Read' button in the row for 'High Value:' in *ScienceWorkshop*.
- **Fourth**, press the 'Start/Stop' button to stop the Colorimeter. (The LCD changes to "STOP".)

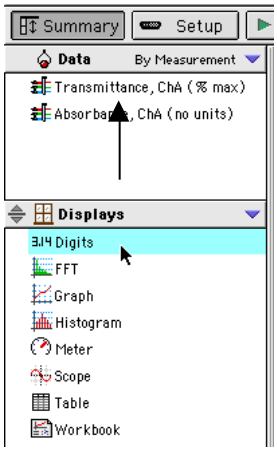
5. Click 'OK' to return to the Experiment Setup window.

- The software is now calibrated for the Colorimeter.

Set up a Digits display of 'Transmittance'.

- In *DataStudio*, click-and-drag the 'Digits' icon from the Displays list and drop it on 'Transmittance' in the Data list.





- In *ScienceWorkshop*, click-and-drag the 'Digits' display icon to the sensor's icon in the Experiment Setup window.

Start recording data.

- Remove the cuvette and empty it. Fill the cuvette with a liquid (e.g., coffee), put a cap on the cuvette, place the cuvette inside the Colorimeter, and close the lid.
- Press the 'Start/Stop' button (

) to start the Colorimeter. (The LCD shows the color and wavelength, the percent transmittance, and "RUN".)
- In *DataStudio*, click the 'Start' button (

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

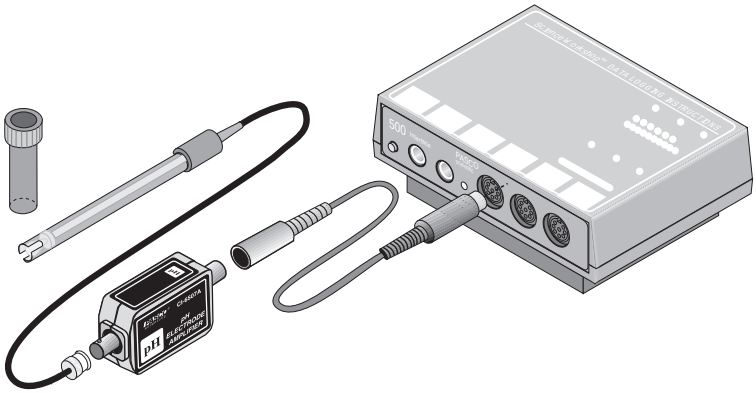
).
- Note the transmittance in the Digits display.

Stop recording data.

- Click 'Stop' to end data recording. Press the 'Start/Stop' button to stop the Colorimeter.

pH Sensor

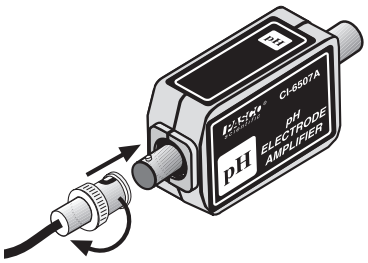
The pH Sensor has an amplifier and a pH electrode. The electrode produces a voltage that is proportional to the hydrogen ion concentration in a solution. (Store the electrode in its soaker bottle when you are not using it.) The amplifier converts the electrode voltages into the voltages required by the *ScienceWorkshop* interface.



For this activity you will need a cup or beaker, some cranberry juice (or other fruit juice), and an antacid tablet (e.g., Alka-Seltzer®). Fill the cup about half full with juice. Break the antacid tablet in half.

1. Set up the sensor.

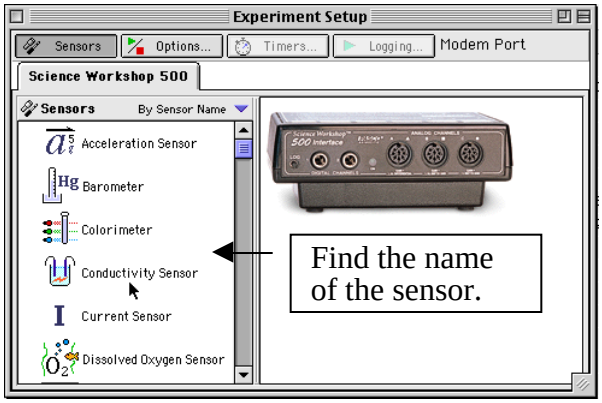
- Plug the DIN connector cable into the sensor's DIN plug and then connect the cable into **Analog Channel A** on the interface.



- Connect the pH electrode to the BNC port on the pH 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.
- Put the end of the pH electrode into the juice.

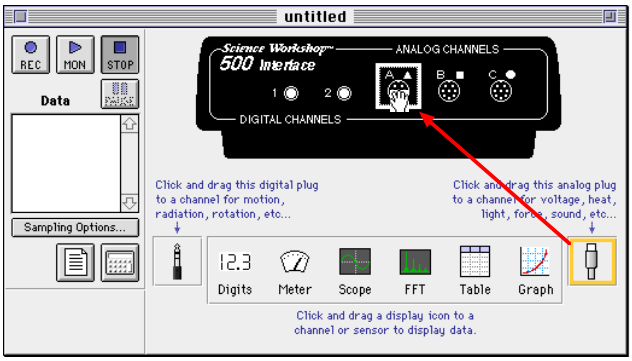
2. Set up the sensor in the software.

- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window.

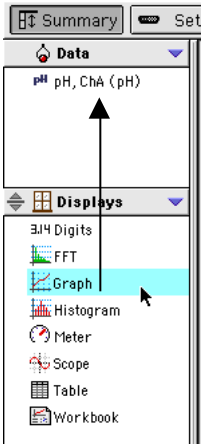


- The sensor icon will appear below Channel A of the interface. The sensor's parameters (e.g., pH, Voltage, etc.) will appear in the Data list.

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



3. Set up a Graph display of pH versus Time.



- In *DataStudio*, click-and-drag the 'Graph' icon from the Displays list and drop it on 'pH' in the Data list.
- In *ScienceWorkshop*, click-and-drag the 'Graph' display icon to the sensor's icon in the Experiment Setup window. Select 'pH (pH)' and click 'Display.

4. Start recording data.

- Put half of an antacid tablet into the fruit juice and stir with the end of the pH electrode.
- In *DataStudio*, click the 'Start' button (

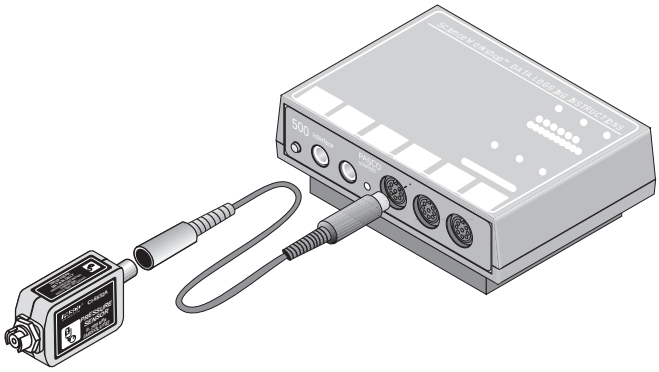
). In *ScienceWorkshop*, click the 'REC' button (

).
- Note the change in pH in the Graph display.

5. After two minutes, 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.

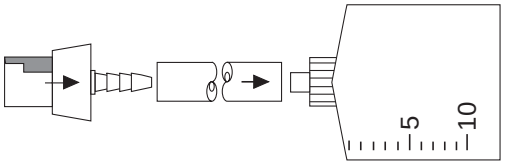


The sensor can measure pressures as high as 700 kilopascals, or about seven atmospheres. It is designed for non-corrosive gases. Do not put liquids into the sensor.

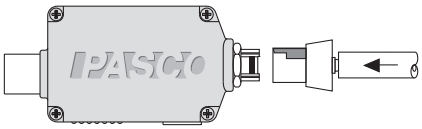
For this activity you will need two drops of glycerin, the syringe, a short piece of tubing, and a quick-release connector.

1. 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.

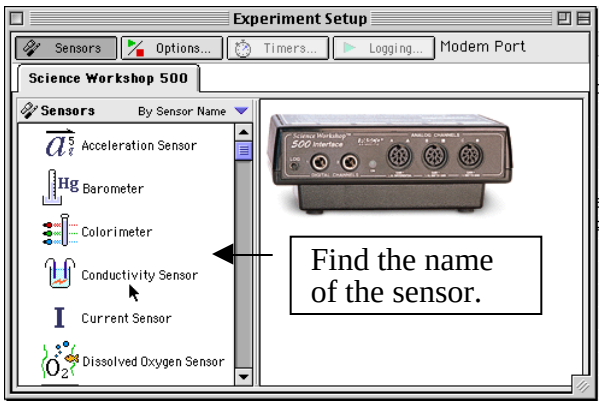


- Connect the syringe to the sensor. Line up the quick-release connector with the pressure port on the sensor. Push the connector onto the port and turn the connector clockwise until it clicks.



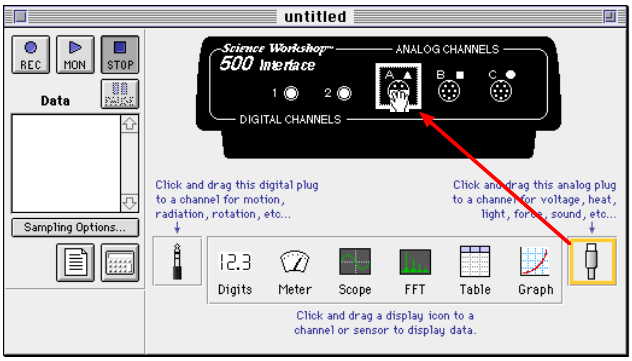
2. Set up the sensor in the software.

- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window.

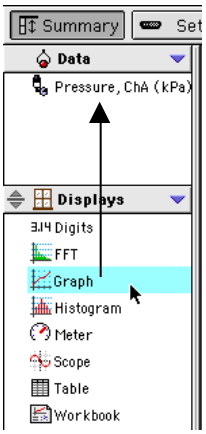


- The sensor icon will appear below Channel A of the interface. The sensor's parameters (e.g., Pressure) will appear in the Data list.

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



3. Set up a Graph display of Pressure versus Time.



- In *DataStudio*, click-and-drag the 'Graph' icon from the Displays list and drop it on 'Pressure' in the Data list.
- In *ScienceWorkshop*, click-and-drag the 'Graph' display icon to the sensor's icon in the Experiment Setup window.

4. Start recording data.

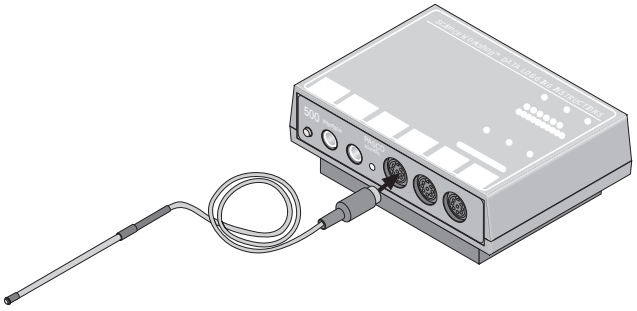
- In *DataStudio*, click the 'Start' button (

). 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.

5. Stop recording data. (Click 'Stop' to end data recording.)

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.

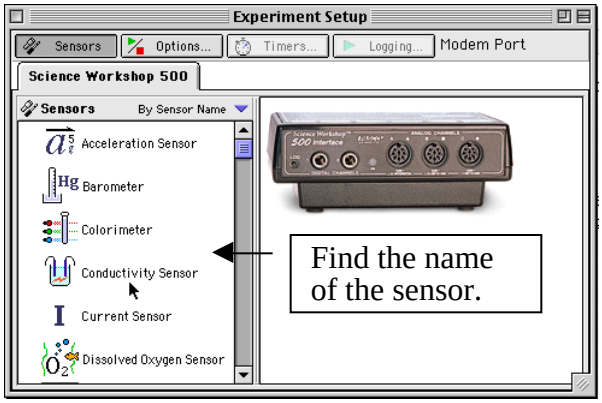
The sensor's operating range is from –5 ˚C to 105 ˚C. Do not use the sensor in a direct flame or on a hot plate.

1. Set up the sensor.

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

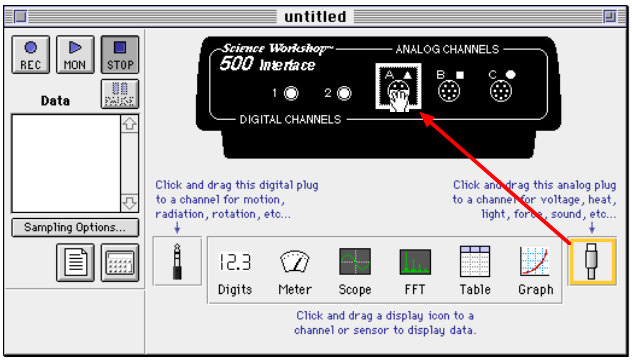
2. Set up the sensor in the software.

- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window.

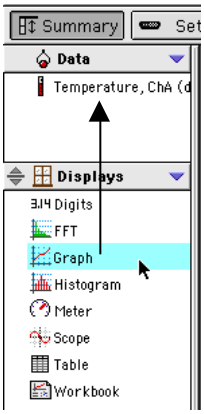


- The sensor icon will appear below Channel A of the interface. The sensor's parameters (e.g., Temperature) will appear in the Data list.

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



3. Set up a Graph display of Temperature versus Time.



- In *DataStudio*, click-and-drag the ‘Graph’ icon from the Displays list and drop it on ‘Temperature’ in the Data list.
- In *ScienceWorkshop*, click-and-drag the ‘Graph’ display icon to the sensor’s icon in the Experiment Setup window.

4. Start recording data.

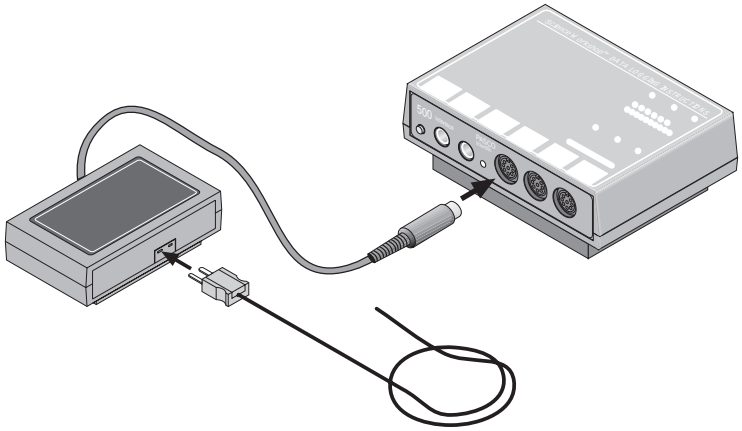
- In *DataStudio*, click the ‘Start’ button (

). 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 wait 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. Notice the change in temperature as you move the sensor.
- Measure the temperature of your face. Move the sensor to the end of your nose. Slowly move the tip of the sensor along your face to your cheek, your chin, and your forehead. Note the change in temperature.

5. Stop recording data. (Click ‘Stop’ to end data recording.)

Type K Thermocouple



The Type K Thermocouple temperature sensor has a tip made of a chromel and alumel wire junction. The thermocouple works because junctions between dissimilar metals or alloys in an electrical circuit produce a voltage if they are at different temperatures. The sensor consists of the Type K probe and the sensor electronics box. The sensor includes a removable Teflon cover that is highly chemical resistant.

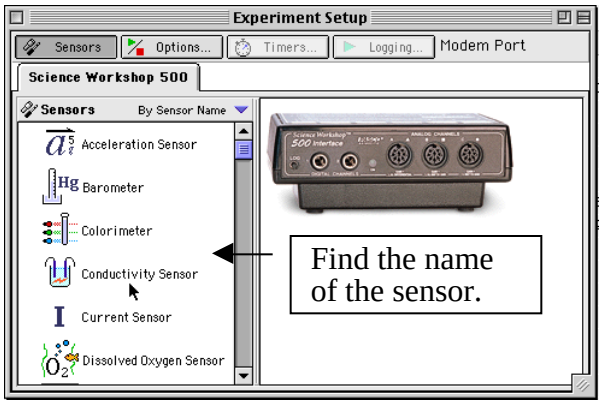
The sensor's operating range is from –180 ˚C to 482 ˚C.

1. Set up the sensor.

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

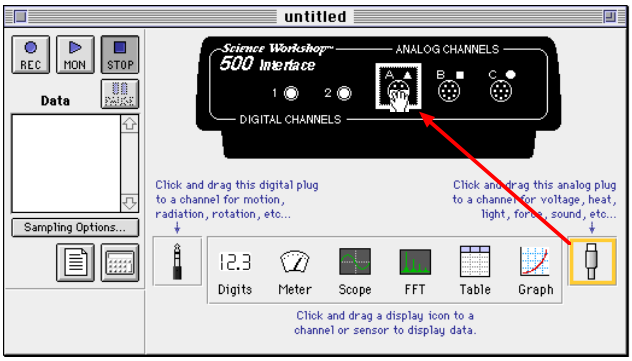
2. Set up the sensor in the software.

- In *DataStudio*, double-click the name of the sensor in the Sensors list in the Experiment Setup window.

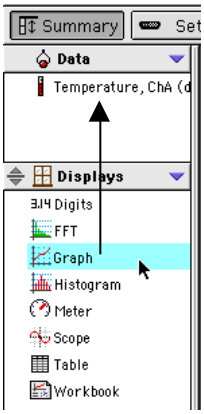


- The sensor icon will appear below Channel A of the interface. The sensor's parameters (e.g., Temperature) will appear in the Data list.

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



3. Set up a Graph display of Temperature versus Time.



- In *DataStudio*, click-and-drag the ‘Graph’ icon from the Displays list and drop it on ‘Temperature’ in the Data list.
- In *ScienceWorkshop*, click-and-drag the ‘Graph’ display icon to the sensor’s icon in the Experiment Setup window.

4. Get a cup of hot water and a cup of ice water.
5. Start recording data.

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

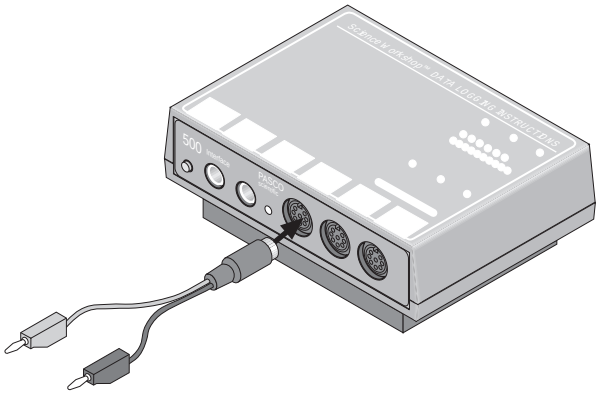
). In *ScienceWorkshop*, click the ‘REC’ button (

).
- Measure the temperature of a cup of hot water. Place the tip of the thermocouple into the hot water for several seconds. Note the temperature in the Graph display.
- Measure the temperature of a cup of ice water. Place the tip of the thermocouple into the ice water for several seconds. Note the temperature in the Graph display.

6. Stop recording data. (Click ‘Stop’ to end data recording.)

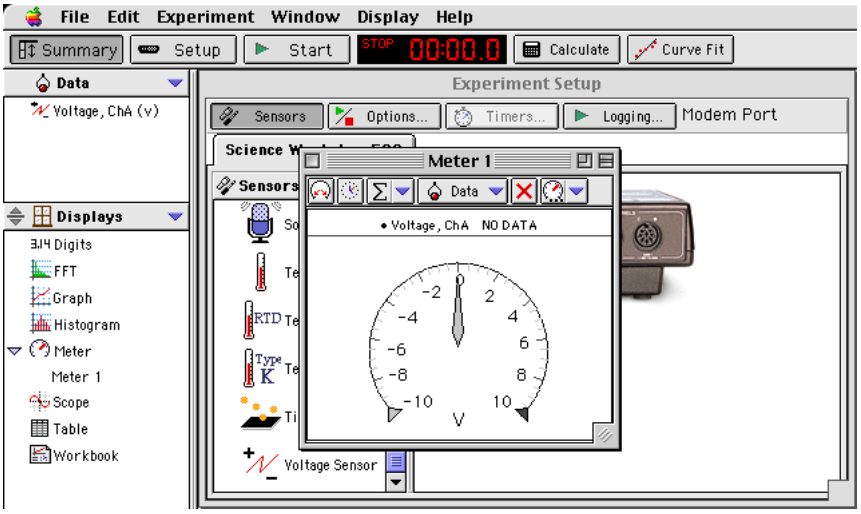
Voltage Sensor

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.

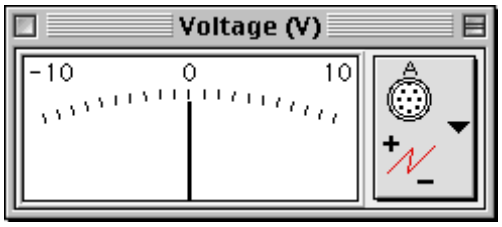


1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Get a 1.5 volt battery.
3. Connect the Voltage Sensor's DIN plug into **Analog Channel A** on the interface.
4. Start the software and set up the Voltage Sensor. (See the first section.)
5. Set up a 'Meter' display.

- In *DataStudio*, double-click 'Meter' in the Display list (or drag the 'Meter' icon to 'Voltage, ChA' in the Data list. The Meter display shows 'Voltage, ChA' and 'Meter 1' appears in the Display list.



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



6. Start recording data. Touch the red Voltage Sensor lead to one end of the battery and the black Voltage Sensor lead to the other end. If the Meter display shows negative volts, reverse the Voltage Sensor leads on the battery.
7. After about 90 seconds, stop recording data.

Remember to Use the Online Help

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

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

Name _____ Class _____ Date _____

Activity C01: Mapping a Flame
(Type K Thermocouple Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Reactions	C01 Map a Flame.DS	C01 Mapping a Flame	C01_MAP.SWS

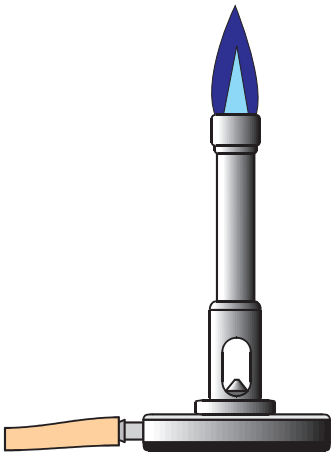
Equipment Needed	**Qty**	**Chemicals and Consumables**	**Qty**
Type K Thermocouple (CI-6526)	1	Candle	1
Bunsen burner and gas supply (optional)	1	Cardboard square, 10 by 10 cm	1
Tongs	1 pair	Matches	1 book
Protective gear			

What Do You Think?

Where is the hottest region of a flame? Where is the coolest region of a flame? Does the temperature in a particular region of a flame remain relatively constant?

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

Background



A flame is low temperature plasma. Plasma is the most common form of matter in the universe. Stars consist of high temperature plasmas. The temperature range in a flame can vary significantly depending on the location in the flame.

A flame is visible evidence of a highly energetic chemical reaction. A candle is made of a solid hydrocarbon called paraffin. The solid has a formula of C_nH_{2n+2}. When a candle burns, the hydrocarbon reacts with oxygen to form carbon dioxide and water. The reaction is exothermic. This means that the reaction produces heat along with the chemical products of carbon dioxide and water.

$$C_nH_{2n+2} + 0.5O_2 \rightarrow nCO_2 + (n+1)H_2O$$

The energy generated by the reaction produces heat to melt the solid. The liquid hydrocarbon is drawn up the wick and is burned at the surface of the wick. A candle is a very inefficient source of light. Most of the candle's energy is given off as heat energy.

On the other hand, the gas supply for a Bunsen burner usually contains many combustible components. Methane is a primary component. The chemical reaction of the complete combustion of methane is:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

When the burner flame is adjusted for a bluish-colored two-cone structure, it is noisy. To achieve this, air comes from the region around the barrel and is mixed with gas at the base of the burner. By closing the holes at the base of the burner, all the oxygen used for burning comes from the space near the top of the barrel. The flame is quiet. Combustion is not complete and particles of carbon are heated in the flame to produce a yellow color (called a "luminous flame").

SAFETY REMINDERS

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

SAFETY PRECAUTIONS

In addition to the normal safety procedures, do the following:

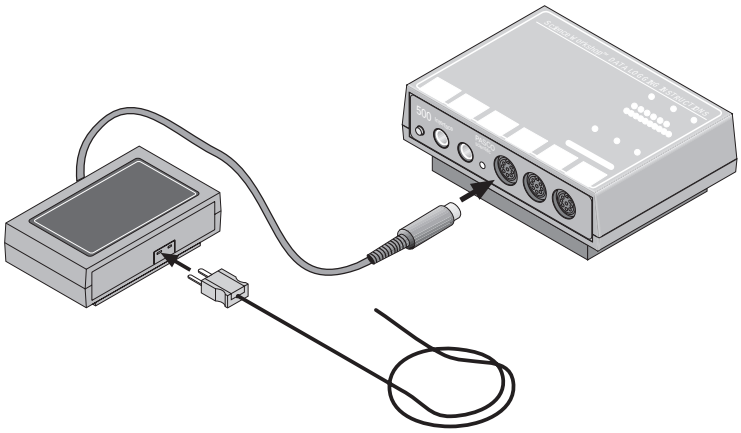
- Remove flammable and combustible materials from the vicinity of the flame.
- Keep a fire extinguisher nearby.
- Use the back of your hand to determine whether an object has been heated. Do not touch a heated object until you feel no heat on the back of your hand when you hold it an inch or two above the object.

For You To Do

Use the Type K Thermocouple Temperature Sensor to measure the temperatures across a flame at the bottom, middle, and top of the flame. Then measure the temperatures of the flame vertically from bottom to top. Use *DataStudio* or *ScienceWorkshop* to record and display 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 Type K probe into the Thermocouple's sensor box.
3. Connect the sensor's DIN plug into Analog Channel A on the interface.
4. Open the file titled as shown:



DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C01 Map a Flame.DS	C01 Mapping a Flame	C01_MAP.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of temperature versus time.
- Data recording is set for ten measurements per second (10 Hz).

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensor.

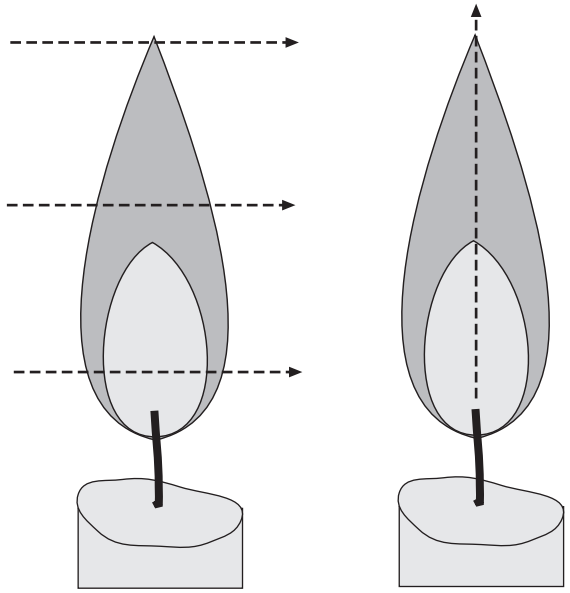
- If you would like to calibrate the Type K Thermocouple, refer to the instruction sheet for the sensor.

Name _____ Class _____ Date _____

SAFETY ALERT!

- Review the procedure for lighting a Bunsen burner. If you have a question – ask for help.
- Use tongs to hold the probe in the flame. Do not use your fingers to hold the probe in the flame.
- The exposed end of the Type K Thermocouple probe can withstand temperatures above 1000 ˚C. However, the insulation material cannot withstand temperatures above 400 ˚C. Therefore, do not put the insulation material into the flame.

- Study the diagrams. The general procedure for data recording for Run #1 through Run #3 is to start with the end of the probe on one side of the flame and then slowly and steadily move the end of the probe along a horizontal line through the flame. Move the probe parallel to the tabletop and finish on the other side of the flame. The procedure for Run #4 is to start with the end of the probe at the bottom of the flame and then slowly move the probe vertically to the top of the flame.



1. Place the candle on a cardboard square to catch any dripping paraffin.
2. Light the candle and let the flame stabilize. (Hint: Set up a windscreen around the flame if necessary.)

PART IIIA: Data Recording – Measure Temperatures at Bottom, Middle, and Top

1. Get ready to record data. Put the probe in position near the bottom of the flame.
2. When everything is ready, start recording data. (Hint: In *DataStudio*, click 'Start'. In *ScienceWorkshop*, click "REC".)
3. Slowly and steadily move the end of the probe through the flame along a horizontal line.
4. When the probe is through the flame, stop recording data.

Let the end of the probe cool down each time before you record more data.

5. Repeat the data recording process across the middle of the flame.
6. Repeat the data recording process across the top of the flame.

PART IIIB: Data Recording – Measure Temperatures Vertically

1. Get ready to record data. Put the probe in position near the bottom of the flame.
2. When everything is ready, start recording data.
3. Slowly and steadily move the end of the probe vertically through the flame along a straight line.
4. When the probe is completely above the flame, stop recording data.

- If you are finished with data recording, turn off the gas supply to the burner. Make sure that the flame is completely extinguished.

NOTE

If you do Option Part B, be sure to clean off any soot from the probe between each run of data.

OPTION: Bunsen Burner Flames

PART A: "Hot" Flame

Adjust the air openings on the Bunsen burner so the flame has a bluish-colored two-cone structure and the flame is 'noisy'. Repeat the data recording procedure.

When you are finished collecting data, turn off the gas supply to the burner and make sure the flame is completely out.

PART B: Luminous Flame

Close the air openings on the Bunsen burner so the flame is mostly yellow and is 'quiet'. Repeat the data recording procedure.

When you are finished collecting data, turn off the gas supply to the burner and make sure the flame is completely out.

Analyzing the Data

1. Set up your Graph display so you can examine each run of data. (Hint: In *DataStudio*, the Graph display can show all the data runs. In *ScienceWorkshop*, use the 'DATA' menu (

) to select up to three runs at a time.)
2. Use the Graph's built-in statistics to determine the maximum temperature and the average temperature ('mean') for each run.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C01: Mapping a Flame

What Do You Think?

Where is the hottest region of a flame? Where is the coolest region of a flame? Does the temperature in a particular region of a flame remain relatively constant?

Data Table

Run #	Description	Maximum Temp. (˚C)	Mean Temp. (˚C)
1	Bottom of candle flame		
2	Middle of candle flame		
3	Top of candle flame		
4	Bottom-to-top of candle flame		

Questions

1. Where is the hottest part of the flame? What is the temperature there?

2. Where is the coolest part of the flame? What is the temperature there?

Optional Questions

3. Where is the maximum temperature of a 'noisy' bluish-colored Bunsen burner flame? What is the temperature there?

4. Where is the maximum temperature of a 'quiet' yellow-colored Bunsen burner flame? What is the temperature there?

5. Why is the maximum temperature of a 'noisy' bluish-colored flame different from the maximum temperature of a 'quiet' yellow-colored flame?

Name _____ Class _____ Date _____

Activity C02: Freezing and Melting of Water (Temperature Sensor)

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

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

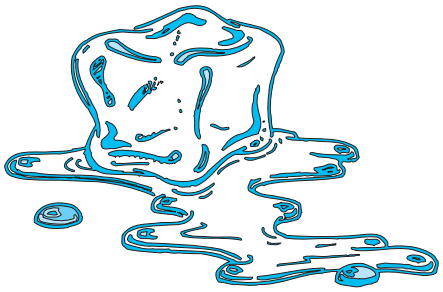
What Do You Think?

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

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

Background

Freezing temperature, the temperature at which a substance turns from liquid to solid, and melting temperature, the temperature at which a substance turns from a solid to a liquid, are characteristic physical properties of a substance at constant pressure.



SAFETY REMINDERS

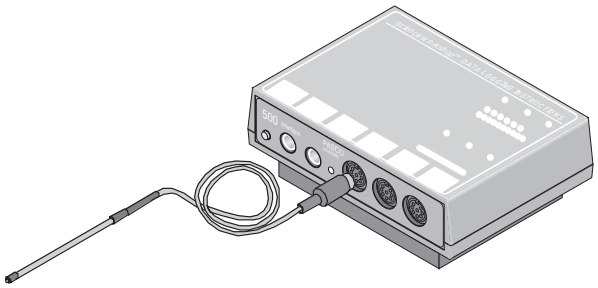
- Wear protective gear while handling chemicals.
- Follow directions for using the equipment.
- Dispose of all chemicals and solutions properly.

For You To Do

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

PART I: Computer Setup

1. Connect the *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 of the interface.



3. Open the file titled as shown:

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

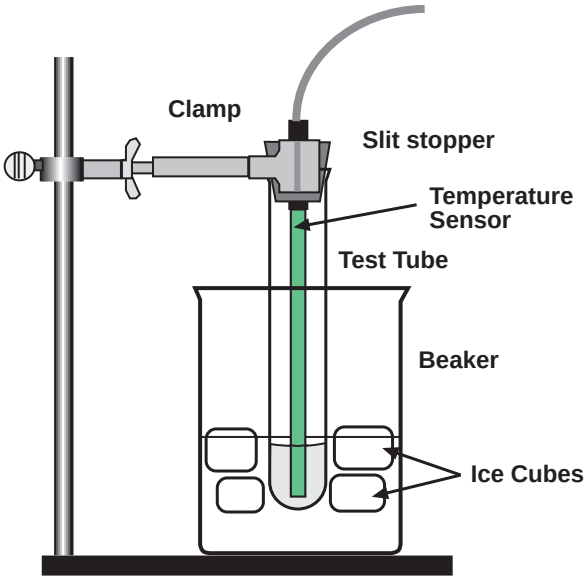
- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* file has a Digits display, a Graph display, and a Table display of Temperature versus Time.
- Data recording is set for one measurement per 30 seconds. Data recording stops automatically at 1800 seconds (30 minutes).

Name _____ Class _____ Date _____

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensor.

1. Set up the equipment as shown. Put about 100 mL of water and 5 or 6 ice cubes into a 500-mL beaker.



2. Put 5 mL of water into a test tube. Set up the test tube so it is *above* the ice water bath at the beginning.
3. Place the Temperature Sensor into a slit stopper and place the stopper in the test tube so the end of the sensor is in the water inside the test tube.

PART IIIA: Data Recording for Freezing

1. When everything is ready, start recording data. Then *lower the test tube* into the ice-water bath. (The computer will record data for a total of 30 minutes.)
2. Soon after lowering the test tube, add about 40 mL of salt to the beaker while stirring with a stirring rod. Continue to stir the ice-water bath during this part of the procedure.

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

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

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

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

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

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

5. Continue recording data until the data recording stops automatically at 30 minutes.
6. Keep the test tube submerged in the ice-water bath for now.

PART IIIB: Data Recording for Melting

1. Get ready for a second run of data recording.
2. Start recording data. Then raise the test tube and fasten it into position *above* the edge of the beaker.
3. Do not move the sensor during this part of the procedure. (Let it stay in the ice.)
4. Dispose of the ice water in the beaker as directed.
5. Put about 250 mL of warm water in the beaker and get ready to place the beaker under the test tube. *When 10 minutes have passed*, lower the test tube and its contents into this warm-water bath.
6. When 15 minutes have passed, stop the data recording.

Analyzing the Data

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

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

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

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

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C02: Freezing and Melting of Water

What Do You Think?

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

Questions

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

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

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

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

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

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

   b. when temperature remains constant in Part IIIA

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

   d. when temperature remains constant in Part IIIB

Name _____ Class _____ Date _____

Activity C03: Heat of Fusion for Ice (Temperature Sensor)

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

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Temperature Sensor (CI-6505A)	1	Tongs	1
Balance (SE-8723)	1	Protective gear	PS
Base and Support Rod (ME-9355)	1		
Beaker, 250 mL	2	**Chemicals and Consumables**	**Qty**
Clamp, Buret (SE-9446)	1	Ice, cubes	12 to 15
Graduated cylinder, 100 mL	1	Styrofoam cup	2
Slit stopper	1	Towel, paper	2 or 3
Stirring rod	1	Water, warm (about 60˚ C)	1 L

What Do You Think?

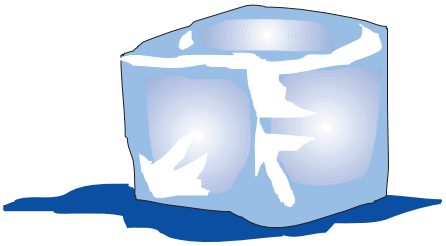
How does water in the solid phase (ice) become water in the liquid phase, in terms of energy transfer? Does this phase change require energy and does it occur at various temperatures or at a *fixed* temperature for a pure crystalline solid?

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

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

Background

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



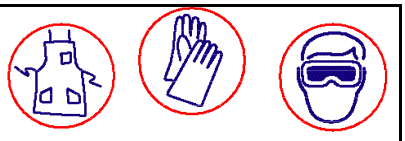
Ice made from uncontaminated water can be considered a pure crystalline solid.

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

To calculate the energy that flows from the melting ice, you can use the relationship
$\mathbf{q = C_p \cdot m \cdot \Delta T}$

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

SAFETY REMINDERS



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

For You To Do

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

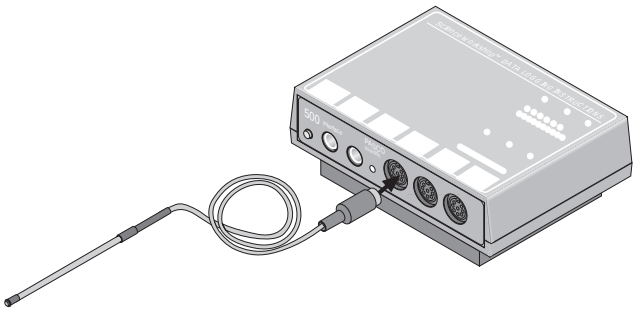
In the first part of the activity, observe a phase change for ice while measuring the temperature of the system. Use the Temperature Sensor to measure the temperature of a container of ice as small amounts of warm water are added to the ice. Use *DataStudio* or *ScienceWorkshop* to record and display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

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

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

PART I: Computer Setup

1. Connect the *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 of the interface.
3. Open the file titled as shown:



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

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* file has a Digits display and a Table display of Temperature.
- Data recording is set for one measurement each ten seconds.

Sensor Calibration

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

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

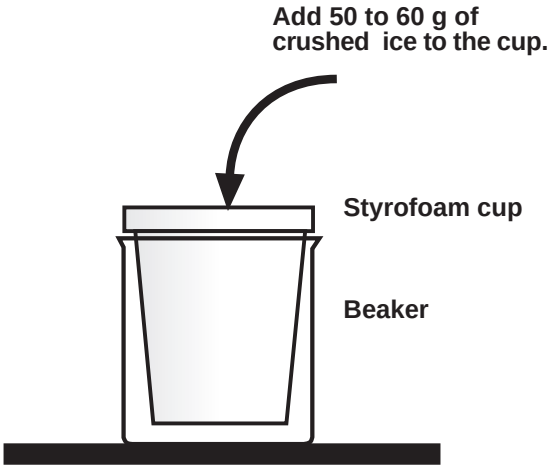
Hint: Refer to the instruction sheet for the Temperature Sensor, the On-Line Help file for *DataStudio*, or the User's Guides for *ScienceWorkshop*.

Name _____ Class _____ Date _____

PART IIA: Equipment Setup – Add Hot Water to Ice

1. Set up a Styrofoam cup, beaker, and Temperature Sensor as shown.
2. Put approximately 50 or 60 g of crushed ice into the cup.

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



PART IIIA: Data Recording – Add Hot Water to Ice

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

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

   What do think the temperature of the ice will be?

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

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

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

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

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

4.

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

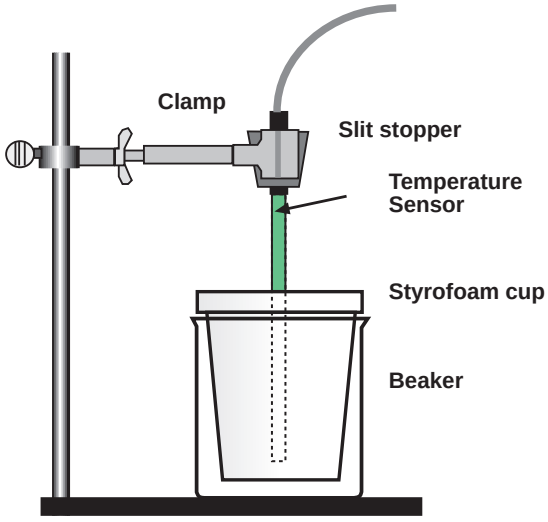
   Carefully observe the mixture and note if there is any remaining ice in the container.

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

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

PART IIB: Equipment Setup – Add Ice to Water

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



2. Pour 100.0 mL of water at about 60˚ C into the Styrofoam cup.
3. Get several (7 or 8) large ice cubes.
4. Lower the Temperature Sensor into the warm water (to about 1 cm from the bottom).

PART IIIB: Data Recording – Add Ice to Water

1. Start recording temperature data. (Hint: Click 'Start' in *DataStudio* or 'REC' in *ScienceWorkshop*.)
2. Watch the Digits display. Wait until the temperature reaches a maximum. This maximum will determine the initial temperature, T_1, of the water.

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

3. As soon as this maximum temperature is reached, put ice cubes into the Styrofoam cup.
4. Record the maximum temperature, T_1, in your data table.
5. Use a stirring rod to stir the mixture as the temperature approaches 0˚ C.

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

6. When the temperature reaches about 0˚ C, use tongs to quickly remove the unmelted ice cubes.
7. Continue stirring until the temperature reaches a minimum (and begins to rise again). This minimum temperature is the final temperature, T_2, of the water.
8. Record T_2 in your data table.
9. Stop the data recording.
10. Use the 100-mL graduated cylinder to measure the volume of water remaining in the Styrofoam cup to the nearest 0.1 mL. Record this as V_2.

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Analyzing the Data for PART B – Add Ice to Water

1. Use the Statistics tool in the Table display to check your minimum and maximum temperature values.
2. Subtract T_2 - T_1 to determine ΔT, the change in water temperature.
3. Calculate the volume of ice that was melted ($V_2 - V_1$).
4. Find the mass of ice melted (use 1.00 g/mL as the density of water).
5. Calculate the energy (in joules) released by the 100 g of liquid water as it cooled (**$q = C_p \cdot m \cdot \Delta T$**).
6. Now calculate the heat of fusion, the energy required to melt one gram of ice (in J/g H_2O).
7. Use your answer to Step 6 and the molar mass of water to calculate the molar heat of fusion for ice (in kJ/mol H_2O).

Equations

$$\Delta T = T_2 - T_1$$

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

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

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

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

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

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

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C03: Heat of Fusion for Ice

What do you think?

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

Data Table: Heat of Fusion

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

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

Questions

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

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

Equations

$$\Delta T = T_2 - T_1$$

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

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

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

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

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

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

Name _____ Class _____ Date _____

Activity C04: Heat of Vaporization of a Liquid (Temperature Sensor)

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

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

What Do You Think?

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

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

Background

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

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

- Rubbing alcohol feels "cold" to the touch even if it is at room temperature. Rubbing alcohol is often used to "sponge bath" a patient who is suffering from a high fever.
- Acetone, the main component of many fingernail polish removers, also feels "cold" to the touch, even when it is at room temperature. (* Acetone is a toxic substance and should not be placed on the skin and it should only be used in a chemical fume hood)
- Your body uses water (a coating of sweat on your skin) to cool down the body when it is overheating.

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

SAFETY REMINDERS

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

For You To Do

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

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

Compare the rate of evaporation of the three liquids.

Pre-Lab

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

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

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

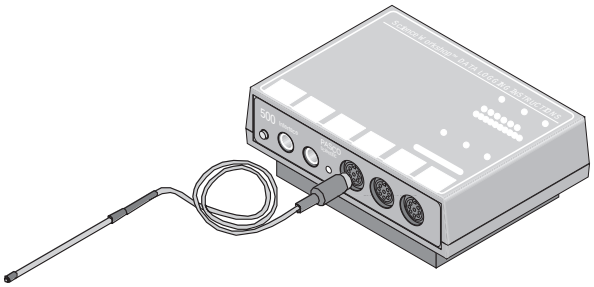
Fill in the table below with data obtained from a reference resource (such as the Handbook of Chemistry and Physics).

Property	Acetone	Isopropyl alcohol	Water
Molecular mass (g/mole)			
Freezing point (˚C)			
Boiling point (˚C)			
Heat of vaporization (cal/g)			

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

PART I: Computer Setup

1. Connect the *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 of the interface.
3. Open the file titled as shown;



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

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook
- The *ScienceWorkshop* file has a Graph display of Temperature versus Time.

PART II: Sensor Calibration and Equipment Setup

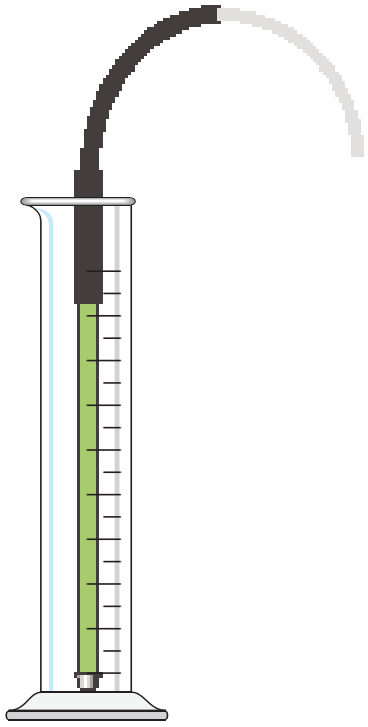
You do not need to calibrate the sensor.

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

PART IIIA: Data Recording for Acetone

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

1. Place the Temperature Sensor into the cylinder with the acetone until the sensor touches the bottom of the cylinder. When everything is ready, start recording data. Leave the sensor in the liquid for 10 seconds.
2. After 10 seconds, remove the sensor from the liquid. Hold the sensor vertically. The liquid will evaporate and the evaporation will take about 2 minutes.
3. Continue collecting data until the liquid on the sensor appears to be completely evaporated and then stop recording data.
4. Rinse the Temperature Sensor.



PART IIIB: Data Recording for Isopropyl Alcohol

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

PART IIIC: Data Recording for Isopropyl Alcohol

7. Repeat the procedure of cooling the Temperature Sensor with water instead of alcohol.
8. Rinse the Temperature Sensor.
9. Dispose of the liquids in the graduated cylinders as directed.

Analyzing the Data

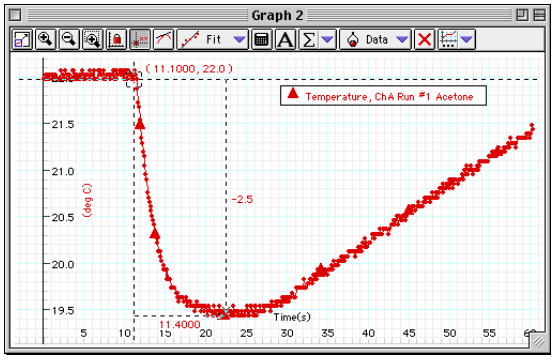
1. Set up your Graph display so it shows the data for the first liquid (acetone).

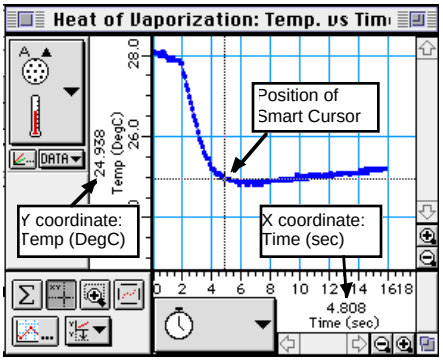
   Hint: Rescale the Graph to fit the data.

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

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

   Hint: Use the Smart Tool in *DataStudio* or the Smart Cursor in *ScienceWorkshop*. Click and drag the cursor from the beginning point to the minimum temperature.





3. Repeat the data gathering process for the other two liquids: alcohol and water.

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

Record your results in the Lab Report section.

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Lab Report - Activity C04: Heat of Vaporization of a Liquid

What Do You Think?

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

Data Table: Heat of Vaporization – Liquid

Liquid	Slope (rate of cooling)
Acetone	Greatest slope / rate of cooling
Alcohol	Second highest slope / rate of cooling
Water	Smallest slope/ rate of cooling

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

Questions

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

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

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

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

Name _____ Class _____ Date _____

Activity C05: Evaporation and Intermolecular Attractions (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Phase change	C05 Evaporation.DS	C05 Evaporation	C05_EVAP.SWS

Equipment Needed	Qty
Temperature Sensor (CI-6505A)	2
Test tube, 20 by 150 mm	6
Protective gear	PS

Chemicals and Consumables	Qty
Ethanol (ethyl alcohol)	10 mL
Methanol (methyl alcohol)	10 mL
1-butanol	10 mL
1-propanol	10 mL
n-hexane	10 mL
n-pentane	10 mL
Filter paper (2.5 by 2.5cm)	6
Rubber band, small	2
Tape, masking	1 roll

What Do You Think?

The purpose of this experiment is to study temperature changes caused by evaporation of several liquids and relate the temperature changes to the strength of the forces of attraction between molecules of the liquid. What do you think the relationship will be between the strength of intermolecular attraction for a liquid and the amount of temperature change caused by evaporation of the liquid?

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

Background

Evaporation is an endothermic process that results in a temperature decrease. Evaporating molecules carry away thermal energy when they leave a liquid. The amount of temperature decrease is related to the strength of intermolecular forces of attraction.

Alkanes and alcohols are two types of organic compounds. Alkanes have carbon and hydrogen atoms. The two alkanes used in this activity are pentane, C_5H_{12}, and hexane, C_6H_{14}. In addition to carbon and hydrogen atoms, alcohols also contain the -OH functional group. Two of the alcohols used in this activity are methanol, CH_3OH, and ethanol, C_2H_5OH.

Pre-Lab

Complete the Pre-Lab table before beginning the activity. Examine the molecular structure of alkanes and alcohols for the presence and relative strength of two intermolecular forces — hydrogen bonding and dispersion forces. The name and formula are given for each compound. Draw a structural formula for a molecule of each compound and determine the molecular mass of each molecule. Dispersion forces exist between any two molecules, and generally increase as the molecular mass of the molecule increases. Next, examine each molecule for the presence of hydrogen bonding. Before hydrogen bonding can occur, a hydrogen atom must be bonded directly to an N (nitrogen), O (oxygen), or F (fluorine) atom within the molecule. Indicate whether or not each molecule has hydrogen-bonding capability in the pre-lab table.

Pre-Lab Table

Substance	Formula	Structural Formulas	Molecular Mass	Hydrogen Bond (Yes or No)
ethanol	C_2H_5OH			
1-propanol	C_3H_7OH			
1-butanol	C_4H_9OH			
n-pentane	C_5H_{12}			
methanol	CH_3OH			
n-hexane	C_6H_{14}			

SAFETY REMINDERS

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

SAFETY ALERT

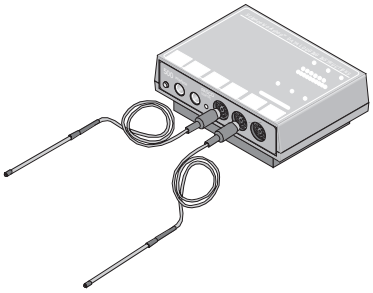
Keep flammable substances away from flames.

For You To Do

Use Temperature Sensors to measure the change in temperature of pieces of filter paper that have been soaked in various organic liquids. After measuring the change in temperature for ethanol and 1-propanol, make a prediction for the change in temperature for 1-butanol and n-pentane. Use Temperature Sensors to test your prediction. Then make a prediction for the change in temperature for methanol and n-hexane. Use the sensors to test your prediction.Use *DataStudio* or *ScienceWorkshop* to record, display, and analyze your 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 DIN plug of one Temperature Sensor into Analog Channel A and the DIN plug of the other sensor to Analog Channel B on the interface.



3. Open the file titled as shown:

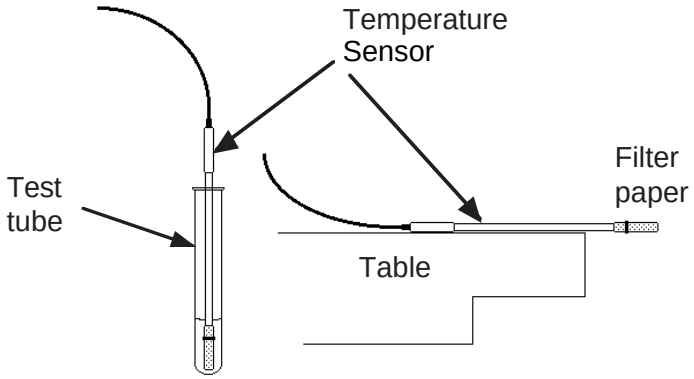
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C05 Evaporation.DS	C05 Evaporation	C05_EVAP.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* file has two Digits displays and three Table displays of Temperature versus Time.

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensors.

1. Wrap the ends of Sensor A and Sensor B with square pieces of filter paper secured by small rubber bands as shown in the diagram. Roll the filter paper around the sensor tip in the shape of a cylinder. (Hint: First slip the rubber band up on the sensor, wrap the paper around the sensor, and then slip the rubber band over the wrapped paper.) The lower edge of the paper should be even with the sensor end.
2. Stand Sensor A in the ethanol container and Sensor B in the 1-propanol container. Make sure the containers do not tip over.
3. Cut 2 pieces of masking tape, about 10-cm long, to be used to tape the sensors in position during Data Recording.



Evaporation and Intermolecular Attractions

PART IIIA: Data Recording – Ethanol and 1-propanol

1. After the sensors have been in the liquids for at least 45 seconds, start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
2. Observe the Digits displays until the temperature stabilizes.
3. Record this temperature as the initial temperature of each liquid. Then simultaneously remove the sensors from the liquids and tape them so the sensor tips extend 5 cm over the edge of the tabletop as shown in the diagram.
4. Stop data recording at 200 seconds.
5. Dispose of the filter paper as directed by your teacher.

Analyzing the Data for Ethanol and 1-propanol

1. Set up the Table display to show 'Statistics' for the temperature data for ethanol and 1-propanol.
2. Record the minimum and maximum temperature for ethanol (sensor A) and 1-propanol (sensor B). Subtract the minimum temperature from the maximum temperature to determine ΔT, the temperature change during evaporation.

Make a Prediction for 1-butanol and n-pentane

1. Based on the ΔT values you obtained for ethanol and 1-propanol, plus information in the Pre-Lab exercise, *predict* the size of the ΔT value for 1-butanol. (Hint: Compare its hydrogen-bonding capability and molecular mass to those of ethanol and 1-propanol. It is not important that you predict the exact ΔT value; simply estimate a logical value that is higher, lower, or between the previous ΔT values.)
2. Record your predicted ΔT, then explain how you arrived at this answer in the space provided.
3. Make a prediction for n-pentane and record your predicted ΔT and explanation.

PART IIIB: Data Recording – 1-butanol and n-pentane

1. Test your prediction by repeating the data recording procedure using 1-butanol for Sensor A and n-pentane for Sensor B.
2. Start recording data. Record the initial temperature of each liquid. Then simultaneously remove the sensors from the liquids and tape them so the sensor tips extend 5 cm over the edge of the tabletop as shown in the diagram.
3. Stop data recording at 200 seconds.
4. Dispose of the filter paper as directed by your teacher.

Make a Prediction for methanol and n-hexane

1. Using your measured ΔT values, *predict* the ΔT values for methanol and n-hexane. Compare the hydrogen-bonding capability and molecular mass of methanol and n-hexane to those of the previous four liquids.
2. Record your predicted ΔT, then explain how you arrived at your answer.
3. Test your prediction by repeating the data recording procedure using methanol for Sensor A and n-hexane for Sensor B.

PART IIIC: Data Recording – methanol and n-hexane

1. Test your prediction by repeating the data recording procedure using 1-butanol for Sensor A and n-pentane for Sensor B.
2. Start recording data. Record the initial temperature of each liquid. Then simultaneously remove the sensors from the liquids and tape them so the sensor tips extend 5 cm over the edge of the tabletop as shown in the diagram.
3. Stop data recording at 200 seconds.
4. Dispose of the filter paper as directed by your teacher.

Analyzing the Data

Complete the Data Table and answer the questions in the Lab Report section.

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Lab Report - Activity C05: Evaporation and Intermolecular Attractions

What Do You Think?

What do you think the relationship will be between the strength of intermolecular attraction for a liquid and the amount of temperature change caused by evaporation of the liquid?

Data Table: Evaporation

Substance	T_2 (°C)	T_1 (°C)	ΔT ($T_2 - T_1$) (°C)
ethanol			
1-propanol			
1-butanol			
n-pentane			
methanol			
n-hexane			

Predicted ΔT (°C)	Explanation

Questions

1. N-pentane and 1-butanol have almost the same molecular mass, but significantly different ΔT values. Explain the difference in ΔT values of these substances, based on their intermolecular forces.

2. Which of the alcohols studied has the strongest intermolecular forces of attraction? The weakest intermolecular forces? Explain using the results of this experiment.

3. Which of the alkanes studied has the strongest intermolecular forces of attraction? The weakest intermolecular forces? Explain using the results of this experiment.

4. Plot a graph of ΔT values of the four alcohols versus their respective molecular masses. Plot molecular mass on the horizontal axis and ΔT on the vertical axis. How does molecular mass correspond to ΔT?

Name _____ Class _____ Date _____

Activity C06: Determine the Vapor Pressure of a Compound (Pressure, Temperature Sensors)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Phase change	C06 Vapor Pressure.DS	C06 Determine Vapor Pressure	C06_VAPO.SWS

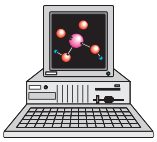
Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Pressure Sensor (CI-6532A)	1	**Thermometer (SE-9084)**	1
Temperature Sensor (CI-6505A)	1	**Tubing, plastic (w/sensor)**	1
Beaker, 400 mL	2	Protective gear	PS
Connector, rubber stopper (w/sensor)	1		
Coupling, quick release (w/sensor)	1	**Chemicals and Consumables**	**Qty**
Flask, 250 mL	1	Acetone	10 mL
Graduated cylinder	1	Ethanol	10 mL
Hot plate	1	Glycerin	1 mL
Rubber stopper, two-hole	1	Water	1 L

What Do You Think?

How does the vapor pressure of a pure liquid change as the temperature of the liquid changes? Will the type of liquid have an effect on the rate of change of the vapor pressure as the temperature changes?

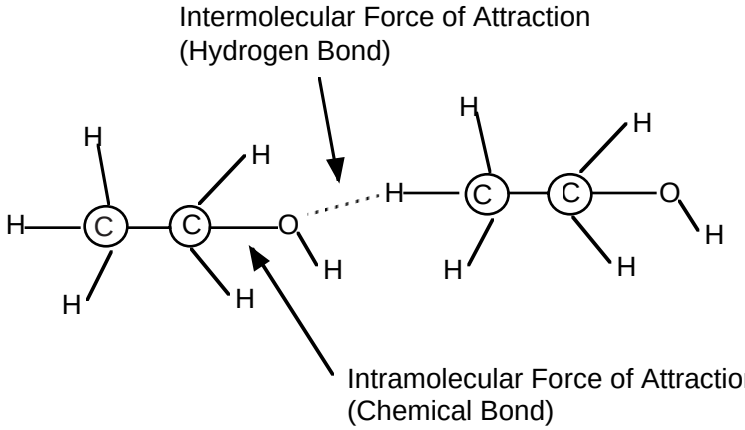
Take time to answer the 'What Do You Think?' question(s) in the Lab Report section.

Background



Most substances have characteristic melting and boiling points at a given pressure. If the temperature of the surroundings is higher than the temperature of the substance, the surroundings give thermal energy to the molecules of matter that make up the substance. The thermal energy causes the molecules to rotate (spin), vibrate and translate (move from place to place). The intermolecular forces of attraction that hold the molecules of a substance together are strained by an increase in any movement of the molecules. Strong intermolecular forces of attraction are more difficult to break and as a result require a higher temperature to cause molecular movement.

The higher the temperature of a liquid, the greater the average kinetic energy of the molecules. When the molecules of solid matter absorb enough energy, the substance melts and forms a liquid. When liquid matter absorbs enough energy, the molecules move with enough speed and momentum to separate from each other and escape into the vapor or gas phase. As more and more molecules break from the liquid state into the vapor or gaseous state, the pressure they exert increases in a closed system. This is the vapor pressure of a liquid. The vapor pressure of all liquids is directly related to the temperature of the liquid.



SAFETY REMINDERS

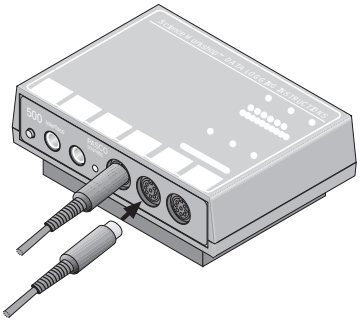
- Wear protective gear.
- Follow directions for using the equipment.
- Dispose of all chemicals and solutions properly.

SAFETY ALERT

Keep flammable substances away from flames.

For You To Do

Use the Pressure Sensor to measure the vapor pressure of the liquid inside a flask. Use the Temperature Sensor to measure the temperature of the liquid. Use *DataStudio* or *ScienceWorkshop* to record and display 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 DIN plug of the Temperature Sensor into Analog Channel A of the interface. Connect the DIN plug of the Pressure Sensor into Analog Channel B of the interface.
3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C06 Vapor Pressure.DS	C06 Determine Vapor Pressure	C06_VAPO.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* file has a Graph display with a plot of Temperature versus Time and a plot of Pressure versus Time.
- Data recording is set for ten measurements per second (10 Hz).

Name _____ Class _____ Date _____

PART II: Sensor Calibration and Equipment Setup

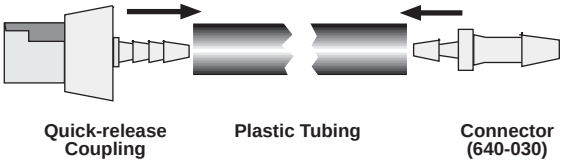
You do not need to calibrate the sensors.

Set Up Two Water Baths

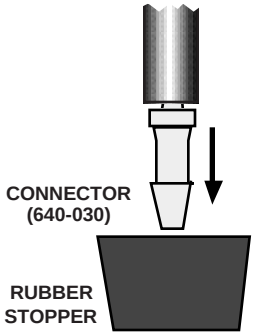
1. Set up a cool water bath. Half fill one beaker with cool water.
2. Set up a warm water bath. Half fill a second beaker with water and place the beaker on the hot plate. Start heating the second water bath to a temperature of 60 ˚C. Use the thermometer to check the temperature occasionally as you set up the rest of the equipment.

Set Up the Equipment

1. Put a drop of glycerin on the barb end of the quick-release coupling and insert the barb into one end of the plastic tubing.
2. Put a drop of glycerin on the smaller diameter end of the coupling that will go into the rubber stopper. Insert the small diameter end into the plastic tubing.



3. Put a drop of glycerin on the larger diameter end of the connector that will go into the rubber stopper, and insert the end into one of the holes in the rubber stopper.
4. Place a drop of glycerin in the other hole of the rubber stopper. Slide the Temperature Sensor through the hole in the rubber stopper.

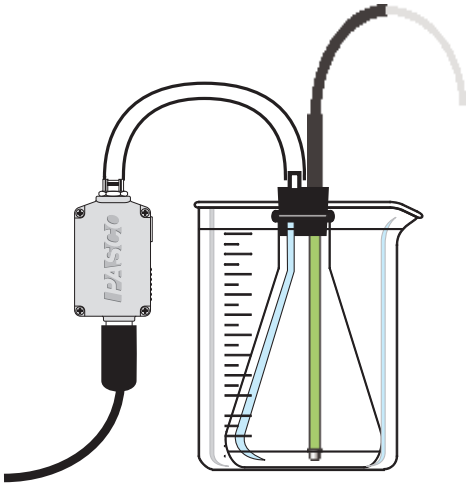


NOTE: Do not put the rubber stopper into the flask yet.

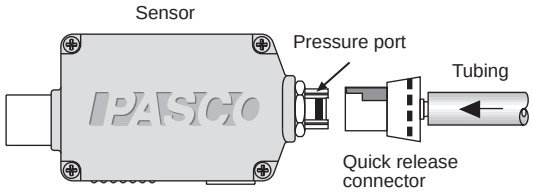
5. Put 10 mL of acetone in the flask. Hold the flask in the hot water bath.
6. Leave the flask in the water bath for four minutes to allow the acetone to vaporize and purge air from the flask.

PART IIIA: Data Recording - Acetone

1. Place the two hole stopper firmly into the top of the flask with the acetone. Adjust the Temperature Sensor in the rubber stopper so the tip of the sensor is in the liquid.



2. Align the quick-release connector on the end of the plastic tubing with the connector on the pressure port of the Pressure Sensor. Push the connector onto the port, and then turn the connector clockwise until it clicks (about one-eighth turn).



3. Remove the flask from the water bath.

4. Start recording data. (Hint: In *DataStudio*, click 'Start' (

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

).)

5. Observe the change in temperature and pressure as the flask cools.

   What do you expect the temperature vs. time and the pressure vs. time graphs will look like?

6. After four minutes immerse the flask in the cool water bath.
7. Continue recording data until the temperature reaches about 30 ˚C. (Hint: Click 'Stop' to end the data recording.)
8. Slowly remove the two hole stopper to allow air to enter the flask.
9. Dispose of the remaining acetone by rinsing the acetone down the drain with a large volume of water following. Rinse and dry the flask.

PART IIIB: Data Recording - Ethanol

1. Heat the hot water bath to 75 ˚C.
2. Put 10 mL of ethanol in the flask. Hold the flask in the hot water bath.
3. Leave the flask in the water bath for four minutes to allow the ethanol to vaporize and purge air from the flask.
4. Place the two hole stopper firmly into the top of the flask with the ethanol. Adjust the Temperature Sensor in the rubber stopper so the tip of the sensor is in the liquid.
5. Repeat the data recording procedure for the ethanol.

How will the graphs for ethanol differ from the graphs for acetone?

Analyzing the Data

1. Set up your Graph display to show the data for acetone and for ethanol.

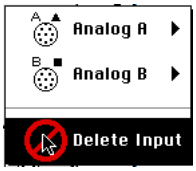
• (Hint: Rescale the Graph to the data if necessary.)

2. Use the Graph display to determine the relationship between pressure and temperature for the two liquids.

• (Hint: In *ScienceWorkshop*, change the Graph display to show Pressure on the vertical axis versus Temperature on the horizontal axis.

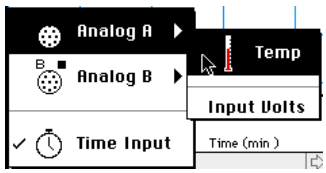
• Click on the "Input" menu button () for the vertical axis of the temperature plot of the Graph.

• Select "Delete Input" from the Input menu for the temperature plot.

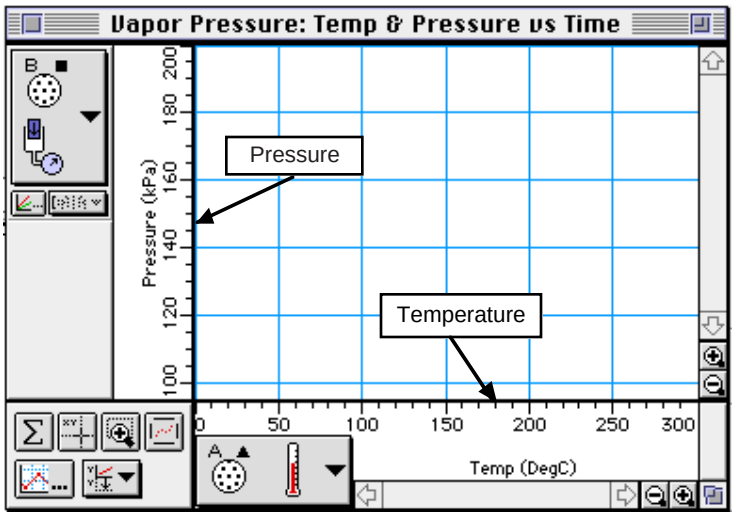


• Click on the "Input" menu button () for the horizontal axis of the Graph.

• Select "Analog A, Temp" from the Input menu for the horizontal axis.



- (Click on the "Autoscale" button () to rescale the Graph to the data if necessary.)



Use your observations to help you answer the questions in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C06: Determine the Vapor Pressure of a Compound

What Do You Think?

How does the vapor pressure of a pure liquid change as the temperature of the liquid changes? Will the type of liquid have an effect on the rate of change of the vapor pressure as the temperature changes?

Questions

1. What is the general relationship between the vapor pressure of acetone and the temperature of the liquid?

2. Is the relationship linear? Why or why not?

3. What is the general relationship between the vapor pressure of ethanol and the temperature of the liquid?

4. Is the relationship between acetone and temperature and ethanol and temperature the same? How are they different?

5. Which would you predict has the higher boiling point, acetone or ethanol? Clearly state your reasons.

6. From the results of your experiment which liquid, acetone or ethanol, has the stronger intermolecular forces of attraction. Clearly state your reasons.

7. Using what you learned in this experiment, sketch the pressure vs. temperature for methanol, water, and methane.

Name _____ Class _____ Date _____

Activity C07: Boyle's Law: Pressure – Volume Relationship in Gases (Pressure Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Gas laws	C07 Boyle's Law.DS	C07 Boyle's Law	C07_BOYL.SWS

Equipment Needed	Qty	Chemicals and Consumables	Qty
Pressure Sensor (CI-6532)	1	Glycerin	1 mL
Coupling, quick-release (w/sensor)	1		
Syringe (w/sensor)	1		
Tubing (w/sensor)	1		

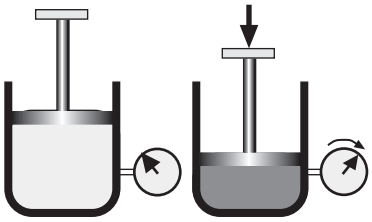
What Do You Think?

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.



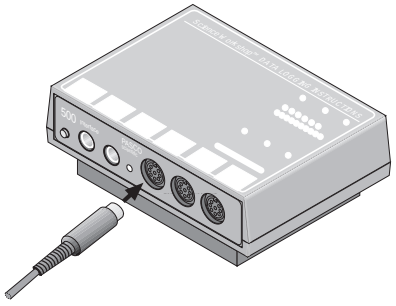
SAFETY REMINDERS

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

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.

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:

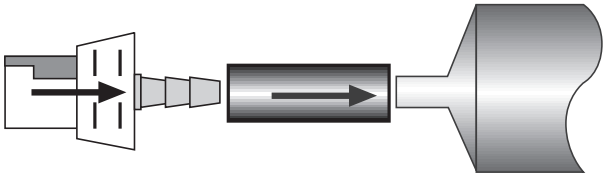
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C07 Boyle's Law.DS	C07 Boyle's Law	C07_BOYL.SWS

- 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.
- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- Data recording is set for one measurement per second. Use the keyboard to enter the volume of the air inside the syringe (in milliliters).

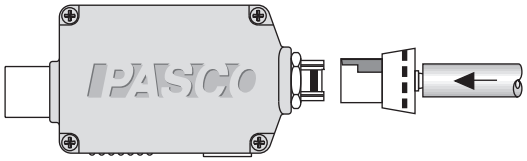
PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensor.

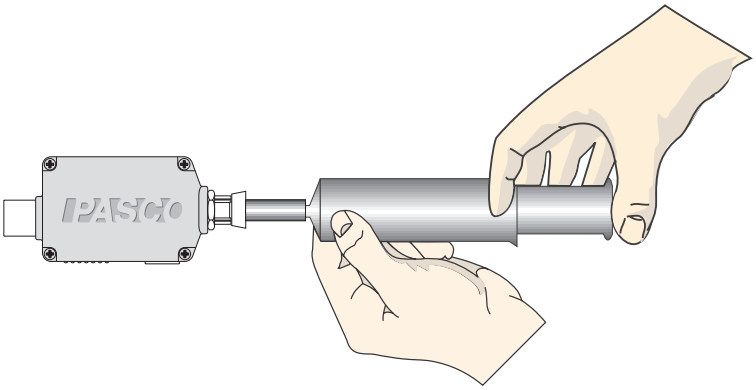
1. Put a drop of glycerin on the barb end of a quick release coupling. Put the end of the coupling into one end of a short piece (about 2.5 cm) of plastic tubing that comes with the Pressure Sensor.
2. Put a drop of glycerin on the end of the syringe. Connect the end of the syringe to the other end of 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.

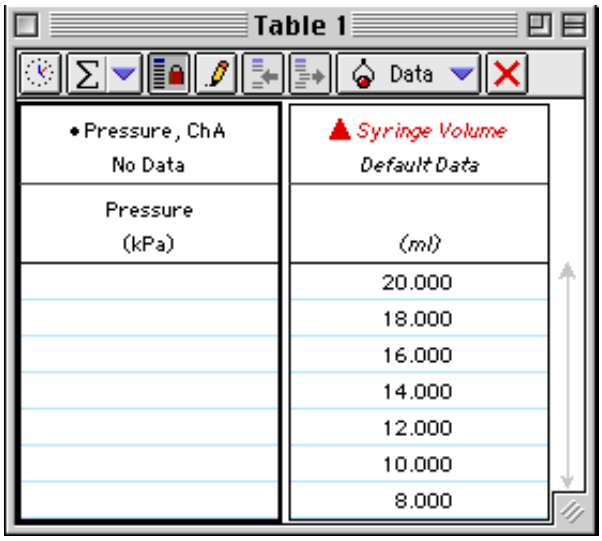


5. Adjust the volume of air in the syringe to 20.0 mL. (Note: To set the initial position of the piston in the syringe, disconnect the quick-release connector from the sensor, move the piston to the first position (20 mL), and then re-connect the quick-release connector to the sensor.)

Name _____ Class _____ Date _____

PART III: Data Recording (for *DataStudio*)

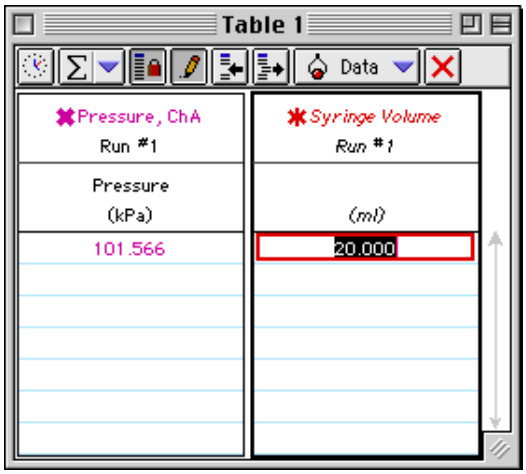
- In *DataStudio*, the Table display shows values for the gas volume in the syringe (for example, 20, 18, 16 and so on).

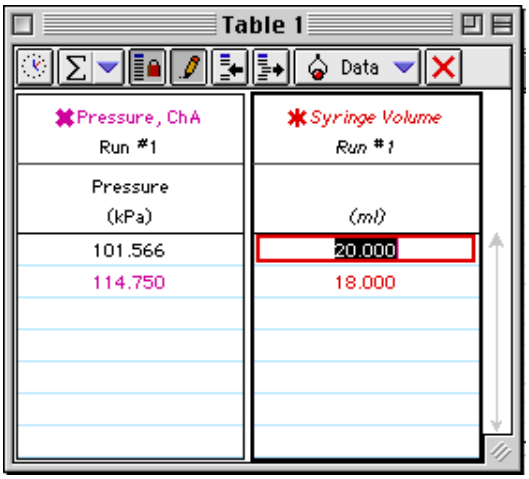


1. When everything is ready, start recording data. (Hint: In *DataStudio*, click 'Start').

- 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.

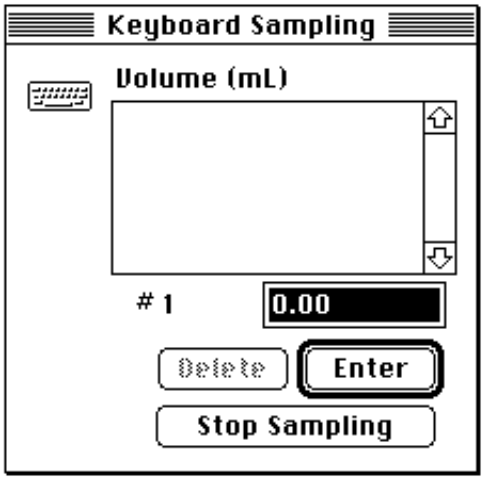
- The Table display changes to show the next value of volume (18 mL).

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 help you answer the questions in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C07: Boyle's Law: Pressure – Volume Relationship in Gases

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 C08: Charles' Law: Volume - Temperature Relationship in Gases (Temperature Sensor)

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

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

What Do You Think?

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

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

Background

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

SAFETY REMINDERS

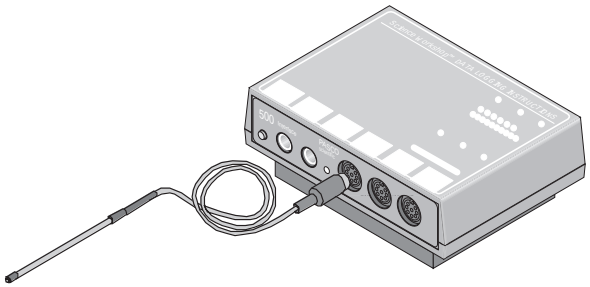
- Wear protective gear during this activity.
- Follow directions for using the equipment.
- Be very careful using a burner or hot plate to heat water.

For You To Do

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

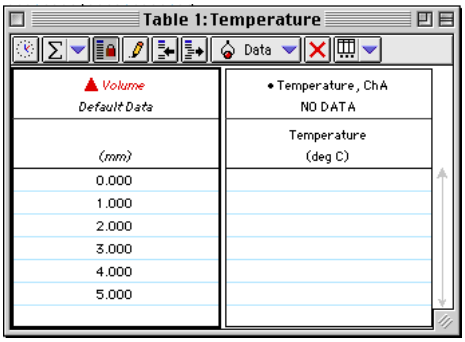
PART I: Computer Setup

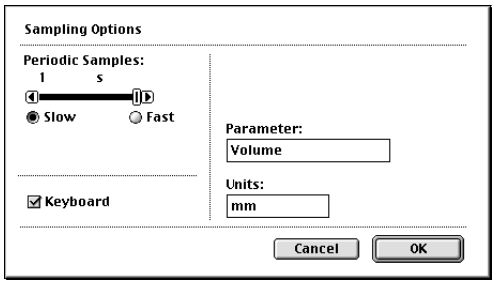
1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the DIN plug of the Temperature Sensor to Analog Channel A on the interface.
3. Open the file titled as shown;



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

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook
- The *ScienceWorkshop* file has a Digits, Table, and Graph display of Temperature versus Time.
- Data recording is set so there is one measurement of temperature per second. You will use the default data for the volume measurements in the *DataStudio* Table or 'Keyboard Sampling' in *ScienceWorkshop* using Parameter = Volume and Units = mm.
- The 'Default Data' numbers under 'Volume' in the *DataStudio* Table actually represent the position of the piston in the Heat Engine/Gas Law Apparatus.



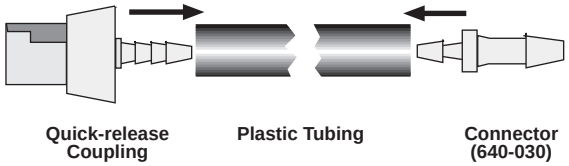


Name _____ Class _____ Date _____

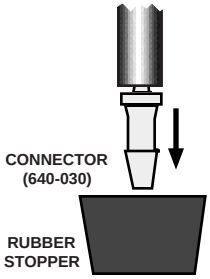
PART II: Sensor Calibration and Equipment Setup

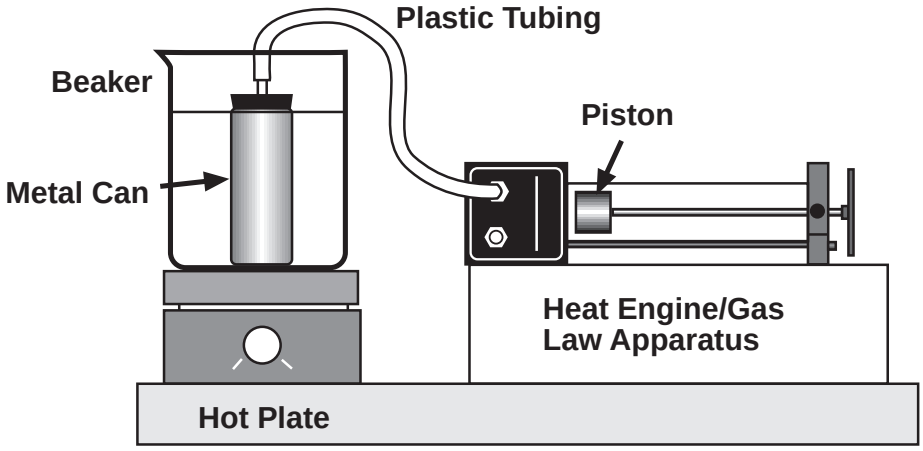
You do not need to calibrate the sensor.

1. Fill a 1000-mL beaker about three fourths full of water. Place the Temperature Sensor in the water. Put the beaker onto the hot plate, but don't start heating the water yet.
2. Set up the Heat Engine/Gas Law Apparatus. Close the clamp on the tubing to one of the pressure ports. Place the Heat Engine/Gas Law Apparatus on its side so the cylinder is horizontal. Set the piston at the zero millimeter mark.
3. Set up the tubing that will connect the Heat Engine/Gas Law Apparatus to the metal can. You will need a quick-release coupling, a connector, a piece of plastic tubing about 12" (30 cm) long, and glycerin. Put a drop of glycerin on the barb of the quick-release coupling and insert the barb into one end of the plastic tubing. Put a drop of glycerin on the barb end of the connector and put the barb into the other end of the tubing.



4. Set up the metal can. You will need a one-hole rubber stopper. Put a drop of glycerin on the end of the connector and insert the connector into the rubber stopper. Put the rubber stopper tightly into the can.
5. Connect the quick-release coupling to the open pressure port on the base of the Heat Engine/Gas Law Apparatus.
6. Put the metal can into the beaker of water. Use tongs to hold the can in the water.
7. Turn on the hot plate to start heating the water in the beaker.





PART III: Data Recording

1. Start recording data. In *DataStudio*, the 'Start' button changes to a 'Keep' button 

.

   Note: For *ScienceWorkshop* instructions, see the appendix at the end of the activity.

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

- The first temperature value is displayed in the data Table next to "0" in the Volume column.
- Stir the water in the beaker with the sensor.

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

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

4. When the piston reaches the 2 millimeter mark, click 'Keep' to record the value of temperature.
5. Repeat the data recording procedure at each millimeter mark until the piston reaches the 5 millimeter mark and you have 5 data points. Do not go above 95 ˚C. When you are done, stop data recording.

Analyzing the Data

Determine the relationship between volume and temperature.

1. In the Graph display of Volume versus Temperature, rescale the graph to fit the data.
2. Use the Graph's analysis tools to determine whether the plot of Volume versus Temperature is linear or not.

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

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C08: Charles' Law: Volume – Temperature Relationship in Gases

What Do You Think?

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

Question

How well did your results correspond to Charles' Law?

Optional:

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

Volume of can + tubing = _____ mL

Find a value for Absolute Zero based on your data.

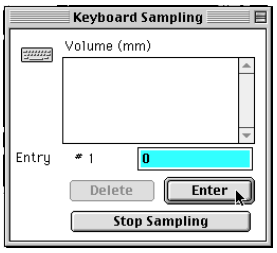
- To determine the value for Absolute Zero, plot *total* volume versus temperature.
- Hint: Use the software's calculator to determine the total volume. Remember that the volume of a cylinder is the area of its base multiplied by its height. The area of the piston in the Heat Engine/Gas Law Apparatus is 8.29 square centimeters.
- Hint: The height is the piston position. Convert the piston position from millimeters to centimeters.
- Hint: The value for Absolute Zero is the temperature where the plot on the Graph intersects the X-axis.

Data

Experimental value for Absolute Zero (°C)	

Name _____ Class _____ Date _____

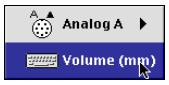
Appendix (*ScienceWorkshop*)



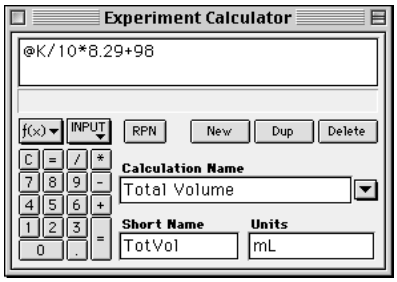
1. When you are ready, start recording data. In *ScienceWorkshop*, the Keyboard Sampling window will open. Adjust its position on your screen so you can also see the Digits display of temperature.
2. Stir the water in the beaker with the sensor.
3. Since the piston of the Heat Engine/Gas Law Apparatus is at the 0 millimeter mark, type in "0" and click the "Enter" button in the Keyboard Sampling window.
4. Watch the piston closely. When it reaches the 1 millimeter mark, type in "1" and click the "Enter" button in the Keyboard Sampling window.
5. Continue to stir the water with the sensor during the time that you record data.
6. When the piston reaches the 2 millimeter mark, click the "Enter" button in the Keyboard Sampling window.
7. Repeat the data recording procedure until you have at least 5 data points. Do not go above 95 ˚C. When you are done, click the "Stop Sampling" button to stop data recording.

Create a Calculation (*ScienceWorkshop*)

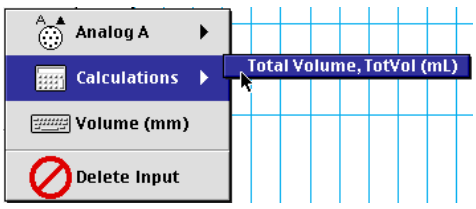
1. Click the Calculator icon or select Calculator Window from the Experiment menu to open the Experiment Calculator.
2. Create a formula for the total volume. First, click on the INPUT menu button and select "Volume (mm)".



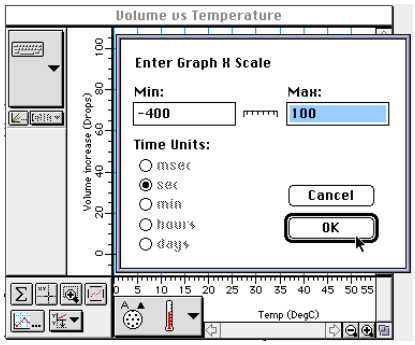
3. Use the cursor to click the "divide" button (/) in the calculator keypad. Then type in "10" (to convert from millimeters to centimeters).
4. Use the cursor to click the "multiply" button (*) in the calculator keypad. Then type in "8.29"(the surface area of the piston in square centimeters).
5. Use the cursor to click the "addition" button (+) in the calculator keypad. Then type in *your* number for the volume of the metal can plus the plastic tubing.
6. Fill in the Calculation Name, Short Name, and Units as indicated. Finally click the "equals" button (=) on the calculator.



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



9. Click on the axis labels to adjust the maximum and minimum values for the vertical and horizontal axes.



10. For the vertical axis set the minimum volume to 0 and the maximum to a value slightly bigger than your largest volume.
11. For the horizontal axis start with -400 and 100. Later you can fine-tune it when you know where your V vs. T line intersects the temperature axis.)
12. To determine your estimate of Absolute Zero, find the point on the horizontal axis where the "best fit" line for Linear Fit intersects the horizontal Temperature axis.
13. If needed, can either change the minimum value for that axis or click on the Zoom Out button in the lower right corner (a circle with a minus sign in it ).
14. Click the "Smart Cursor" button (). Move the Smart Cursor to the point at which the V vs. T line intersects the Temperature axis. This temperature that corresponds to a volume of zero is your experimental value for Absolute Zero. Record your experimental value for Absolute Zero.

Name _____ Class _____ Date _____

Activity C09: The Ideal Gas Law
(Pressure Sensor, Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Gas laws	C09 Ideal Gas Law.DS	(See Appendix)	(See Appendix)

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	**Chemicals and Consumables**	**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

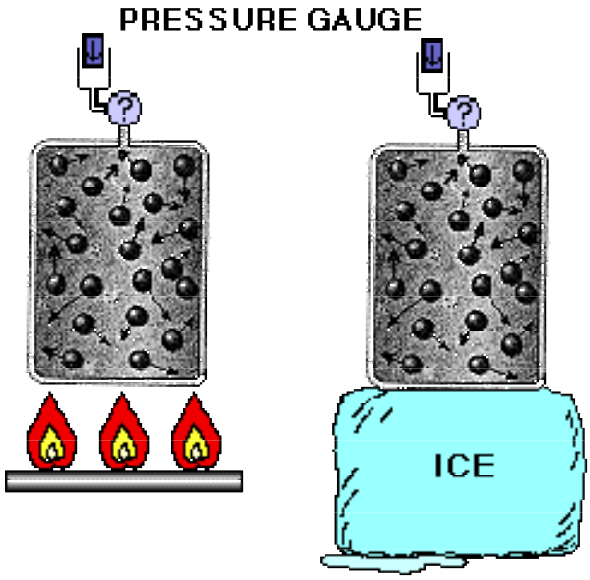
What Do You Think?

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:

$$V = T \bullet k_2$$

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

$$P = T \bullet k_3$$

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

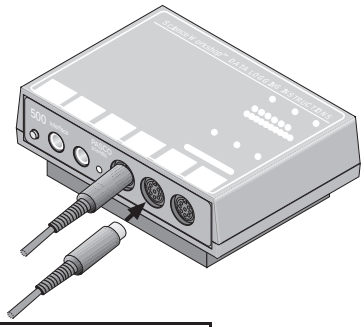
Set Up a Boiling Water Bath

- 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)
C09 Ideal Gas Law.DS	(See Appendix)	(See Appendix)

- 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 Appendix 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.

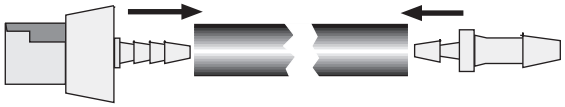
PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensors.

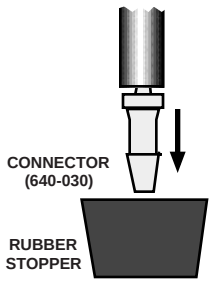
Set Up the Equipment

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

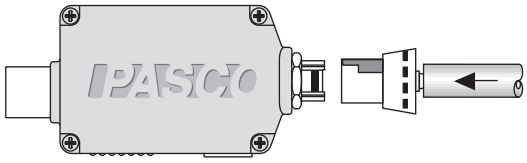
1. Put a drop of glycerin on the barb end of a quick release coupling. Put the end of the quick release coupling into one end of a piece of plastic tubing (about 15 cm) that comes with the Pressure Sensor.

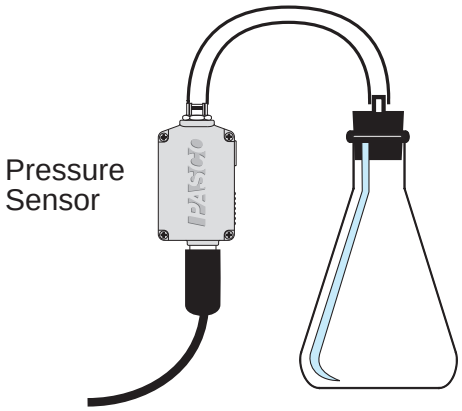


Quick-release Coupling | Plastic Tubing | Connector (640-030)



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.

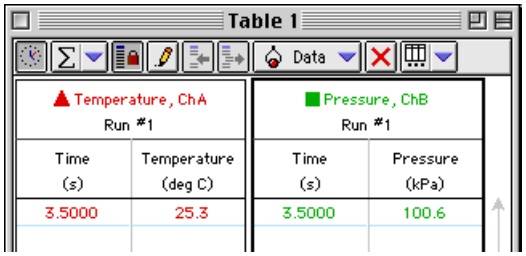
1. Fill one beaker with about 600 mL of cold tap water and add ice.
2. Fill a second beaker with about 600 mL of room temperature water (approximately 20 ˚C).
3. Fill the third beaker with about 600 mL of hot tap water.

PART III: Data Recording

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

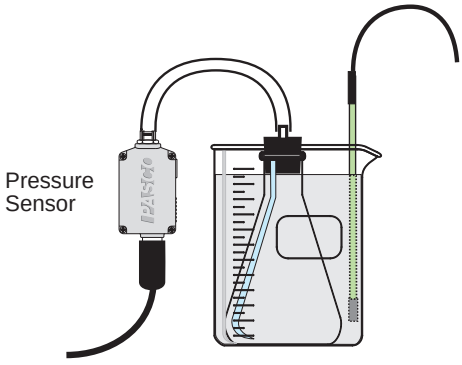
- (Hint: For *ScienceWorkshop*, see the Appendix at the end of this write-up. In *DataStudio*, click 'Start'. The 'Start' button changes to a 'Keep' button (

))
- The Table display shows the temperature and the pressure in the first row.



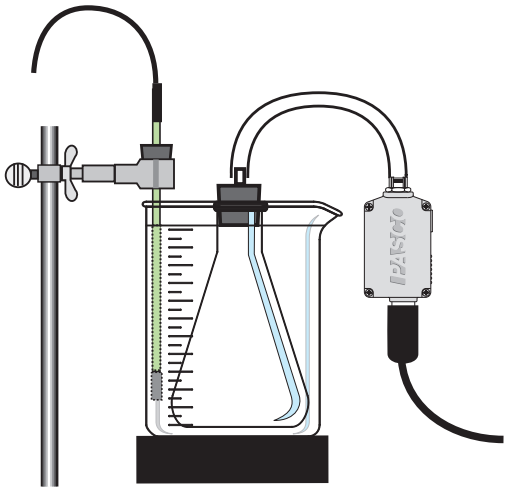
2. Put the flask into the ice water bath so the flask is covered. Put the Temperature Sensor into the ice water and stir gently.
3. When the temperature and pressure values stabilize in the Table display, click 'Keep' to record the data.

- The recorded values of temperature and pressure will appear in the first row of the Table display.



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.

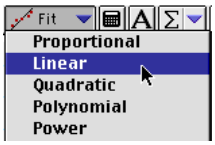
- For the next part, use a base and support rod, clamp, and slit stopper to hold the Temperature Sensor in the water bath with the boiling water. Use a pair of tongs to hold the flask.



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 C09: The Ideal Gas Law

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)?

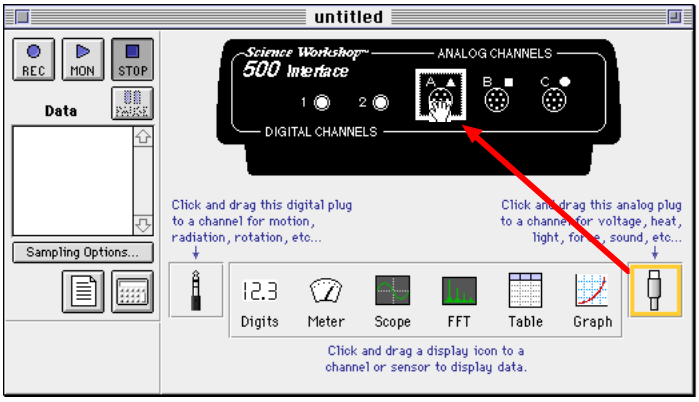
Name _____ Class _____ Date _____

Appendix: Set Up *ScienceWorkshop*

Create a *ScienceWorkshop* file to measure and display temperature and pressure.

Set Up the Sensors

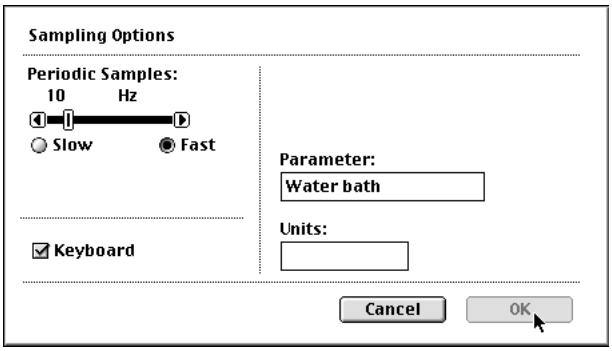
1. In the Experiment Setup window, click and drag the analog sensor plug to Channel A.



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.

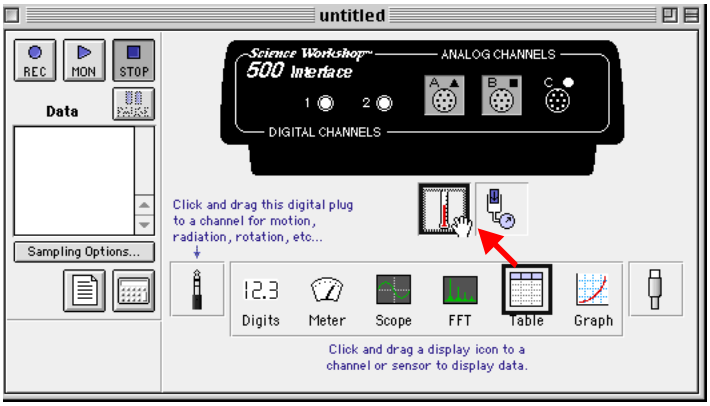
Set Up the Sampling Options

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.

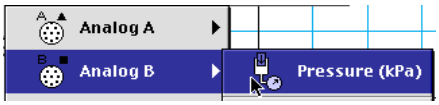


Set Up the Displays

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.



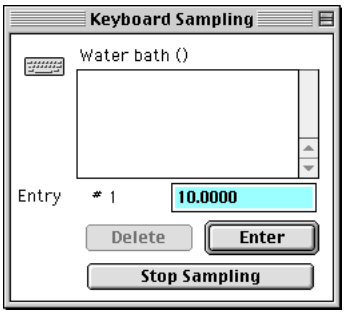
3. In the Experiment Setup window, click and drag the Digits display icon to the Temperature Sensor icon. Repeat the process to make another Digits display. Click and drag the Digits display icon to the Pressure Sensor icon.
4. In the Experiment Setup window, click and drag the Graph display icon to 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.

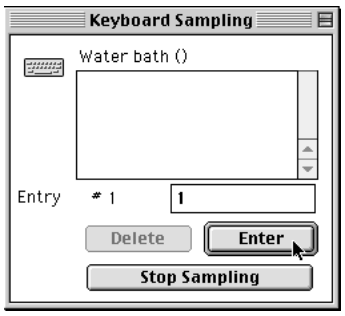
Record Data

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.

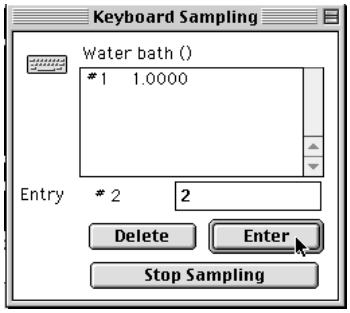
• The 'Keyboard Sampling' window will open. Arrange the windows so you can see the two Digits displays.



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 C10: Determine R, the Gas Constant (Pressure Sensor, Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Gas laws	C10 Gas Constant.DS	C10 Determine R	C10_R.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Pressure Sensor (CI-6532A)	1	Tongs	1
Temperature Sensor (CI-6505A)	1	**Tubing, plastic (w/sensor)**	1
Balance (SE-8723)	1	Protective gear	PS
Connector, rubber stopper (w/sensor)	1		
Flask, Erlenmeyer, 250 mL	1	**Chemicals and Consumables**	**Qty**
Graduated cylinder	1	Dry ice, solid*	1 g
Rubber stopper, two-hole	1	Glycerin	1 mL

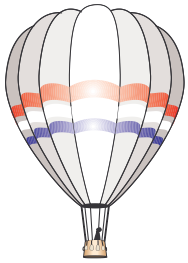
(*SAFETY CAUTION! Do not handle dry ice with bare hands!)

What Do You Think?

The Ideal Gas Law describes the behavior of the pressure, volume and temperature of a 'gas' that has ideal properties. Can you use measurements of pressure, volume, and temperature for a 'real' gas to determine the value of the Gas Constant, **R**?

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

Background



The Gas Constant relates the number of moles of a gas to the pressure, volume and absolute temperature of its surroundings.

The Ideal Gas Law states that pressure, volume, and temperature are related to the number of moles of gas as follows:

$$PV = nRT$$

where **P** is the pressure in atmospheres, **V** is the volume in liters, **n** is the number of moles of the gas, **R** is the gas constant and **T** is the absolute temperature.

If the equation is solved for R, the resulting relationship is:

$$R = \frac{PV}{nT}\left(\frac{atm \cdot Liter}{mole \cdot K}\right)$$

The units of the constant show its value. The accepted value for R is 0.082 atm • L / mole • K.

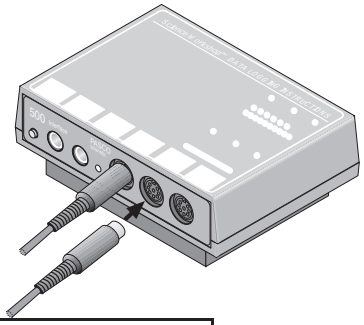
SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Do not handle dry ice with bare hands.

For You To Do

Use the Pressure and Temperature Sensors to measure the changes in pressure and temperature inside a container that has a small amount of 'dry ice' (frozen carbon dioxide). Use *DataStudio* or *ScienceWorkshop* to record and display the data. Determine the change in the mass of the dry ice due to sublimation (phase change from solid to gas). Use your data to calculate a value for R, the Gas Constant, and compare your results to the accepted value.

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)
C10 Gas Constant.DS	C10 Determine R	C10_R.SWS

- The *DataStudio* file has a Graph display. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display with a plot of the pressure versus time and a plot of temperature versus time.
- Data recording is set at ten measurements per second (10 Hz).

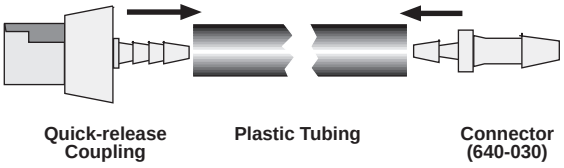
PART II: Sensor Calibration and Equipment Setup

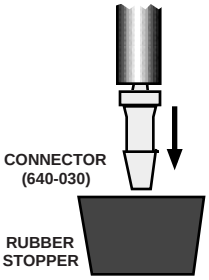
You do not need to calibrate the sensors.

Set Up the Equipment

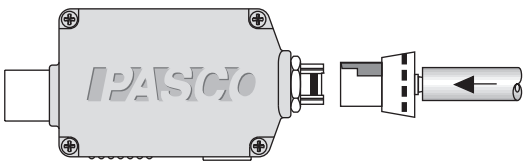
- For this part you will need the following: glycerin, quick-release coupling, connector, plastic tubing, two-hole rubber stopper, flask, Temperature Sensor, Pressure Sensor, dry ice, and balance (for measuring mass).

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.

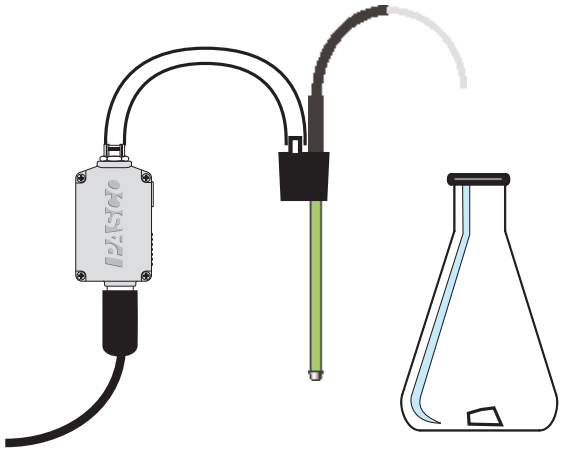




2. Put a drop of glycerin on the barb end of the connector. Push the barb end of the connector into the other end of the plastic tubing.
3. Fit the end of the connector into one of the holes in the rubber stopper.
4. Put a drop of glycerin into the other hole of the stopper and slide the Temperature Sensor through the hole.
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).



Name _____ Class _____ Date _____



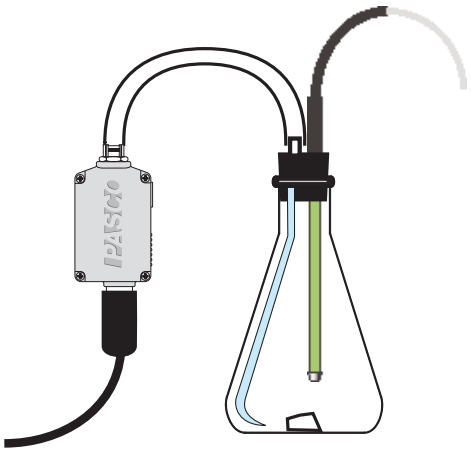
PART III: Data Recording

Measure the Initial Mass

1. Put a 1-g piece of dry ice into a flask. Carefully measure the mass of the flask plus dry ice. Record the mass in the Lab Report section.

Measure the Pressure and Temperature

2. Wait about 20 seconds and then start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.
3. CAREFULLY force the rubber stopper with sensors attached into the top of the flask.



- CAUTION! The pressure inside the flask may become high enough to blow the rubber stopper out of the flask. Try to hold the stopper in place, but don't put your hands on the flask (because your hands might warm the flask too much).

4. When the pressure has reached a maximum (or the rubber stopper blows off), stop recording data.
5. If the rubber stopper is still in place, slowly open the flask to allow carbon dioxide to escape. Blow air into the bottle to clear the inside of carbon dioxide gas.

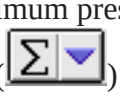
Measure the Final Mass

6. Measure and record the final mass of the flask (with any remaining dry ice).
7. After you have measured the flask and remaining dry ice, discard the dry ice according to instructions.

Measure the Volume

8. Use the large graduated cylinder to add water to the flask to determine the actual volume of the gas in the flask. (Hint: Be sure to account for the space occupied by the bottom of the rubber stopper when it was in the flask.) Record the volume in the Lab Report section.
9. Empty the bottle.

Analyzing the Data

1. Use the built-in statistics in the Graph display to find the minimum pressure and the maximum pressure. (Hint: Click the 'Statistics menu' button () in *DataStudio* or the 'Statistics button () in *ScienceWorkshop*.) Record the minimum and maximum pressure in the Lab Report section.
2. Use the statistics in the Graph display to find the average temperature ("mean"). Record the value in the Lab Report section as the Average temperature of the gas.
3. Use your data to calculate the pressure change in atmospheres, the temperature of the gas in Kelvin, the number of moles of carbon dioxide gas, and your experimental value for R
4. Compare your experimental value of R and the accepted value of R.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C10: Determine R, the Gas Constant

What Do You Think?

The Ideal Gas Law describes the behavior of the pressure, volume and temperature of a 'gas' that has ideal properties. Can you use measurements of pressure, volume, and temperature for a 'real' gas to determine the value of the Gas Constant, **R**?

Data Table

Data	Measurement	Value
1	Mass of dry ice and bottle (before)	g
2	Starting pressure of gas	kPa
3	Maximum pressure of gas	kPa
4	Change in pressure due to gas	kPa
5	Change in pressure in atmospheres (Data 4 x 1 atmosphere/101 kPa)	atm
6.	Average temperature of the gas	C
7	Average temperature in K (Data 6 + 273)	K
8	Volume of gas (bottle)	mL
9	Volume of gas in Liters (Data 8 x 1 Liter/1000 mL)	L
10	Mass of dry ice and bottle (after)	g
11	Mass of dry ice used (Data 1 - Data 10)	g
12	Moles of carbon dioxide used (Data 11 x 1 mole/44 g)	moles
13	Calculated value of R (See below)	
14	% difference (See below)	%

The calculation for the Gas Constant is $R = \frac{PV}{nT}\left(\frac{atm \cdot Liter}{mole \cdot K}\right)$, or $\frac{Data5 \times Data9}{Data12 \times Data7}$

The accepted value for the Gas Constant is $R = 0.082 \frac{atm \cdot L}{mole \cdot K}$.

Remember, percent difference is $\left|\frac{\text{experimental value} - \text{accepted value}}{\text{accepted value}}\right| \times 100\%$

Questions

1. How does your calculated value for R, the Gas Constant, compare to the accepted value?

2. 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 C11: Determine n for a Chemical Reaction (Pressure Sensor, Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Gas laws	C11 Determine n.DS	C11 Determine n	C11_N.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Pressure Sensor (CI-6532A)	1	Test tube, 16 by 125 mm	1
Temperature Sensor (CI-6505A)	1	**Tubing, plastic (w/sensor)**	1
Balance (SE-8723)	1	Protective gear	PS
Bottle, 2 L	1	**Chemicals and Consumables**	**Qty**
Connector, rubber stopper (w/sensor)	1	Glycerin	1 mL
Graduated cylinder	1	Nitric acid, 6 molar	10 mL
Rubber stopper, two-hole	1	Sodium bicarbonate (baking soda)	4 g

(*SAFETY CAUTION! Be very careful when handling acid!)

What Do You Think?

The Ideal Gas Law (PV = nRT) relates the pressure, volume and temperature of a gas to the number of moles of gas. Can you use measurements of pressure, volume, and temperature for a gas produced during a chemical reaction to determine the number of moles of gas?

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

Background

The Ideal Gas Law (PV = nRT) relates the pressure, volume and temperature of a gas to the number of moles of gas. The Gas Constant, R, is a proportionality constant in the Ideal Gas Law,

$$PV = nRT$$

where **P** is the pressure of the gas in atmospheres, **V** is the volume in liters, **n** is the number of moles of the gaseous compound, **R** is the gas constant (0.082 atm • liters / mole • K) and **T** is the absolute temperature in Kelvins.

By rearranging the variables in this equation, the number of moles of a chemical compound can be calculated.

$$n = \frac{PV}{RT}$$

The reaction in this activity is the decomposition of sodium bicarbonate by nitric acid. The equation for the reaction is shown below:

$$NaHCO_3 + HNO_3 \Longrightarrow NaNO_3 + CO_2 + H_2O$$

Since the equation is balanced, the number of moles of sodium bicarbonate used in the reaction is equal to the number of moles of carbon dioxide formed. It is a one-to-one stoichiometric relationship.

An excess of acid is used to insure the complete reaction of sodium bicarbonate to form carbon dioxide. Sodium bicarbonate is the limiting reagent. Sodium nitrate and water are the other products. Since sodium nitrate and water are condensed phases of matter the volumes of the sodium nitrate and water are minimal and do not effect your results.

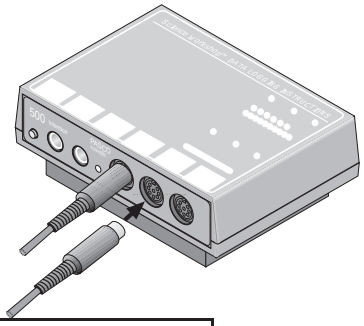
SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

For You To Do

Use the sensors to measure the changes in pressure and temperature inside a container during a chemical reaction. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use your data and the Ideal Gas Law to calculate the number of moles of gas produced during the reaction and compare your results to the accepted value.

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)
C11 Determine n.DS	C11 Determine n	C11_N.SWS

- The *DataStudio* file has a Graph display. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display with a plot of the pressure versus time and a plot of temperature versus time.
- Data recording is set at ten measurements per second (10 Hz).

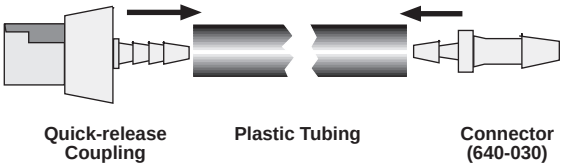
PART II: Sensor Calibration and Equipment Setup

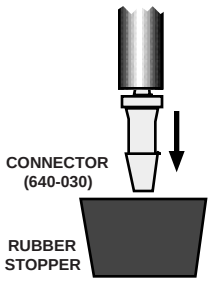
You do not need to calibrate the sensors.

Set Up the Equipment

- For this part you will need the following: glycerin, quick-release coupling, connector, plastic tubing, two-hole rubber stopper, Temperature Sensor, Pressure Sensor.

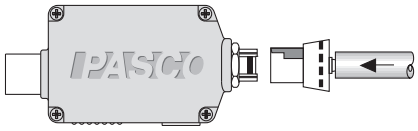
1. Put a drop of glycerin on the barb end of a quick release coupling. Put the end of the quick release coupling into one end of a piece of plastic tubing (about 15 cm) that comes with the Pressure Sensor.



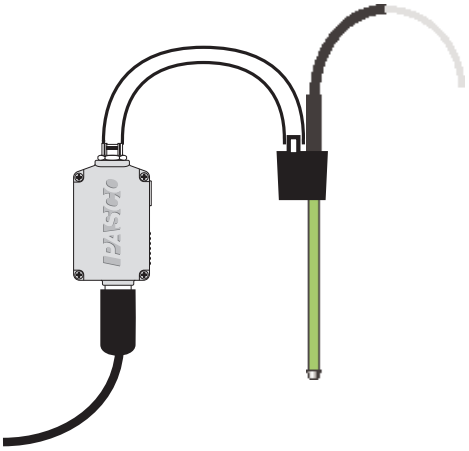


2. Put a drop of glycerin on the barb end of the connector. Push the barb end of the connector into the other end of the plastic tubing.
3. Fit the end of the connector into one of the holes in the rubber stopper.
4. Put a drop of glycerin into the other hole of the stopper and slide the Temperature Sensor through the hole.

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).

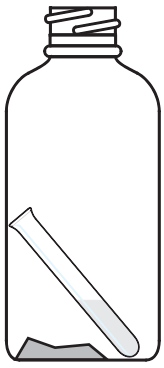


- Pressure Sensor and Temperature Sensor with two-hole rubber stopper.



Prepare the Chemicals

- For this part you will need the following: balance, sodium bicarbonate, graduated cylinder, nitric acid, test tube, bottle.

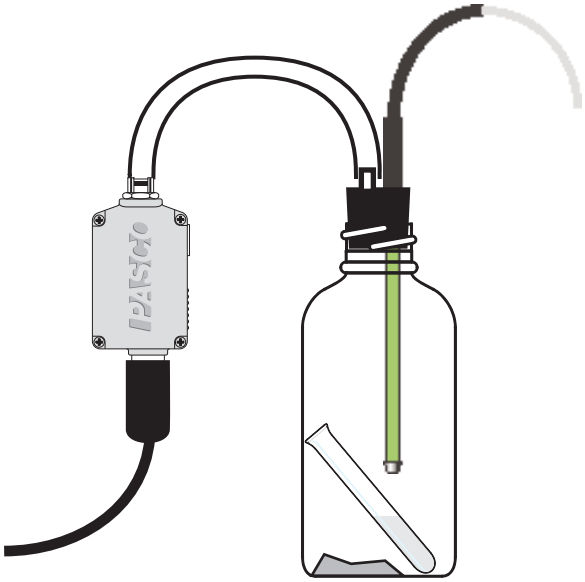


1. Put 4 grams of sodium bicarbonate in the 2-liter bottle.
2. Put 10 mL of 6 molar nitric acid in the test tube. CAREFULLY slip the test tube into the bottle with the sodium bicarbonate. Don't let the acid spill out of the tube yet.

- When you are ready to record data, you will place the two-hole rubber stopper with sensors into the top of the bottle, and then add the acid to the sodium bicarbonate by tilting the bottle and spilling the acid out of the test tube.

PART III: Data Recording

Measure the Pressure and Temperature



1. When you are ready, start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
2. CAREFULLY force the rubber stopper with sensors attached into the top of the bottle.
3. Tilt the bottle so the contents of the test tube spill out. Swirl the nitric acid/sodium bicarbonate mixture in the bottle.

- CAUTION! The pressure inside the bottle may become high enough to blow the rubber stopper out of the bottle. Try to hold the stopper in place, but don't put your hands on the bottle (because your hands might warm it too much).

4. When the bubbling stops (or the rubber stopper blows off), stop recording data.
5. If the rubber stopper is still in place, slowly open the flask to allow carbon dioxide to escape.
6. Slowly remove the stopper from the bottle to allow carbon dioxide to escape.
7. Dispose of the mixture by pouring the solution down the drain with a large volume of water following. Rinse the bottle and test tube.
8. Use the graduated cylinder to add water to the bottle to determine the actual volume of the bottle. Record the volume in the Lab Report section. (Hint: Remember to account for the space occupied by the bottom of the rubber stopper when it was in the bottle. Should you also account for the space taken up by the test tube? Disregard the volume of the nitric acid from the total volume.)

Analyzing the Data

1. Use the built-in statistics in the Graph display to find the minimum pressure and the maximum pressure. (Hint: Click the 'Statistics menu' button () in *DataStudio* or the 'Statistics button () in *ScienceWorkshop*.) Record the minimum and maximum pressure in the Lab Report section.
2. Use the statistics in the Graph display to find the maximum temperature. Record the value in the Lab Report section.
3. Use your data and the Gas Constant, R, to calculate the pressure change in atmospheres, the maximum temperature of the gas in Kelvin, the volume of gas in liters, and **n**, the moles of carbon dioxide gas produced.
4. Calculate the moles of sodium bicarbonate. Compare your experimental value of moles of carbon dioxide gas to the moles of sodium bicarbonate.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C11: Determine n for a Chemical Reaction

What Do You Think?

The Ideal Gas Law (PV = nRT) relates the pressure, volume and temperature of a gas to the number of moles of gas. Can you use measurements of pressure, volume, and temperature for a gas produced during a chemical reaction to determine the number of moles of gas?

Data Table

Data	Measurement	Value
1	Minimum pressure	kPa
2	Maximum pressure	kPa
3	Change in pressure (Data 2 - Data 1)	kPa
4	Change in pressure in atmospheres (Data 3 x 1 atm/101 kPa)	atm
5	Maximum temperature	°C
6	Maximum temperature in K (Data 5 + 273)	K
7	Volume of gas in mL	mL
8	Volume of gas in L (Data 7 x 1 Liter/1000 mL)	L
9	Gas Constant, R	0.082 atm L/mole K
10	Moles of carbon dioxide formed ($\mathbf{n = \frac{PV}{RT}}$)	moles
11	Mass of sodium bicarbonate used	g
12	Moles of sodium bicarbonate used (Data 11 x 1 mole/84 g)	moles
13	Moles of carbon dioxide formed (same as Data 12)	moles
14	% difference (See below)	%

Remember, percent difference is $\left|\frac{\text{experimental value} - \text{accepted value}}{\text{accepted value}}\right| \times 100\%$

Questions

1. How does your calculated value for **n** compare to the accepted value?

2. 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 C12: Dalton's Law of Partial Pressure (Pressure Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Gas laws	C12 Partial Pressure.DS	C12 Dalton's Law	C12_DALT.SWS

Equipment Needed	**Qty**	**Chemicals and Consumables**	**Qty**
Pressure Sensor (CI-6532A)	1	Calcium hydroxide solution	15 mL
Bottle (or flask), 250 mL	1	Candle	1
Connector, rubber stopper (w/sensor)	1	Clay, modeling	10 g
Graduated cylinder	1	Matches	1 bk
Rubber stopper, two-hole	1	Tape	1 roll
Tubing, plastic (w/sensor)	1		
Protective gear	PS		

(*SAFETY CAUTION! Be very careful around any flame!)

What Do You Think?

How can you use Dalton's Law of Partial Pressure to determine the approximate percentage of oxygen and nitrogen in the air?

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

Background

Dalton's Law of Partial Pressure states that the total pressure of a gas is equal to the sum of the pressure of each individual gas at a specific temperature.

$$P_t = \Sigma P_i$$

Where P_t is the total pressure of the gas and P_i is the pressure of each individual gas.

The combination of all the partial pressures of the gases that make up the atmosphere gives the total pressure of the atmosphere. The average pressure of the atmosphere is 101 kilopascals (kPa). Most of the pressure of the atmosphere results from nitrogen. Oxygen is the second most common gas in the atmosphere. The concentrations of carbon dioxide, argon, helium and xenon are so minor that they contribute very little to the overall pressure of the atmosphere.

Remove the oxygen in the atmospheric mixture in order to determine the amount of nitrogen in the atmosphere.

Be careful with matches and be careful with the burning candle.

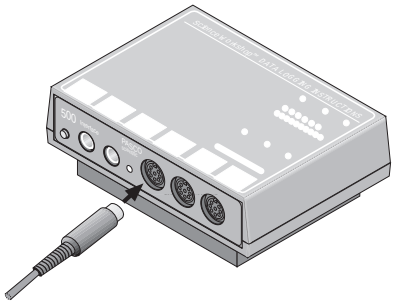
SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

For You To Do

A burning candle consumes oxygen. If the candle burns in a closed container and you use a chemical to remove the carbon dioxide produced, the pressure in the container should decrease due to the removal of oxygen. The remainder of the partial pressure will be assumed to be due to nitrogen.

Use the Pressure Sensor to measure the change in pressure as a candle burns inside a container. Use calcium hydroxide to absorb carbon dioxide gas released during combustion. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use your data to determine the approximate percentage of oxygen 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 the DIN plug of the Pressure Sensor to Analog Channel A on the interface.
3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C12 Partial Pressure.DS	C12 Dalton's Law	C12_DALT.SWS

- The *DataStudio* file has a Graph display. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display with a plot of the pressure versus time.
- Data recording is set at two measurements per second (2 Hz).

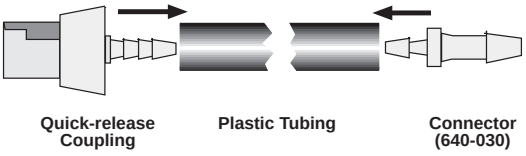
PART II: Sensor Calibration and Equipment Setup

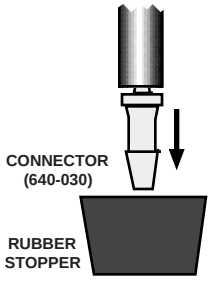
You do not need to calibrate the sensor.

Set Up the Equipment

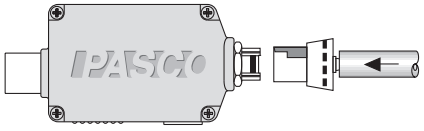
- For this part you will need the following: glycerin, quick-release coupling, connector, plastic tubing, one-hole rubber stopper, Pressure Sensor, clay, straw, tape, candle.

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.

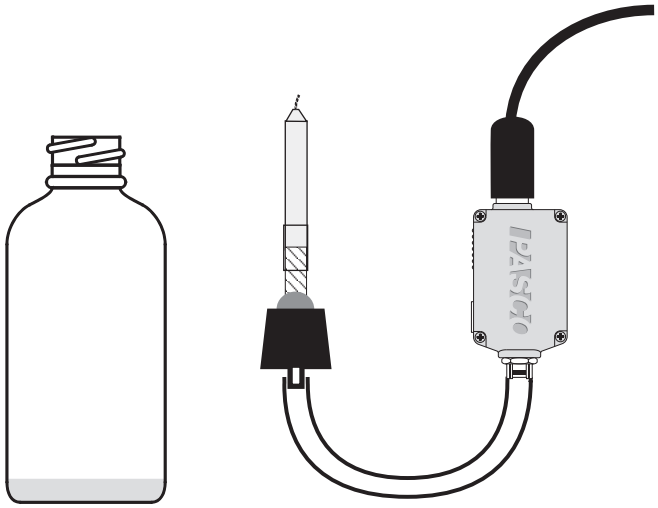




2. Put a drop of glycerin on the barb end of the connector. Push the barb end of the connector into the other end of the plastic tubing.
3. Fit the end of the connector into the hole in the rubber stopper.
4. Align the quick-release coupling on the end of the plastic tubing with the pressure port of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



5. Use a piece of clay to attach the candle to bottom of the rubber stopper. (Note: Do not let the clay cover the hole.) Make sure that when the rubber stopper is put into the bottle (or flask), the tip of the candle is at least halfway into the bottle. (Note: Use a straw and tape to extend the distance of the candle into the bottle if needed.)



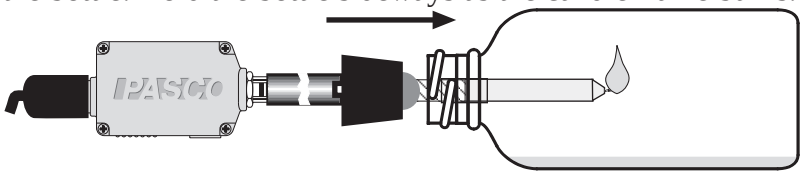
Set Up the Bottle

6. Put 15 mL of saturated calcium hydroxide solution into the bottle.

- When you are ready to record data you will hold the bottle sideways. Then you will light the candle and put the candle/rubber stopper into the bottle.

PART III: Data Recording

1. When you are ready, light the candle. Start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
2. Tilt the bottle sideways. Insert the burning candle and then CAREFULLY but quickly force the rubber stopper into the top of the bottle. Be sure there is a tight seal between the rubber stopper and the bottle. Hold the bottle sideways as the candle flame burns.

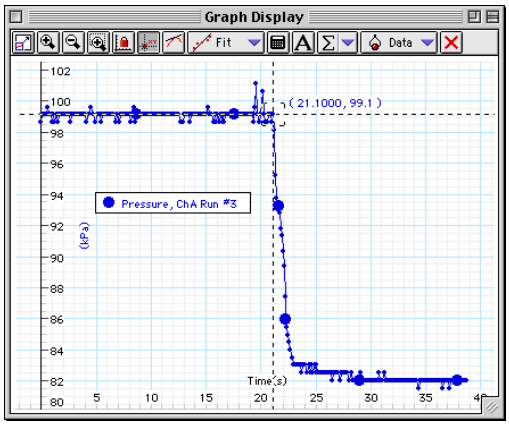


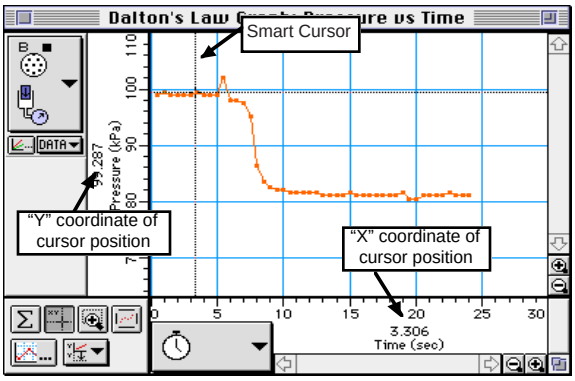
3. When the candle flame is completely extinguished, stop recording data.
4. Remove the candle/rubber stopper from the bottle. Fill the bottle with water to rinse out the products of combustion.
5. Dispose of the water as instructed.

Analyzing the Data

1. Use the Graph display to find the initial pressure inside the bottle and the final pressure after the candle flame went out.

- (Hint: Use the 'Smart Tool' () in *DataStudio* or the 'Smart Cursor' () in *ScienceWorkshop*.)





2. Record the initial and final pressures in the Lab Report section.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C12: Dalton's Law of Partial Pressure

What Do You Think?

How can you use Dalton's Law of Partial Pressure to determine the approximate percentage of oxygen and nitrogen in the air?

Data Table

Data	Measurement	Value
1	Starting pressure (O_2 + N_2)	kPa
2	Ending pressure (N_2 alone)	kPa
3	Change in pressure (O_2 alone)	kPa
4	Percentage of O_2 in air (Data 3 ÷ Data 1)	%
5	Percentage of N_2 in air (Data 2 ÷ Data 1)	%

Questions

1. How does your calculated value for the percentage of oxygen in air compare to the accepted value?

2. How does your calculated value for the percentage of nitrogen in air compare to the accepted value?

3. What are possible sources for error in this experiment?

Name _____ Class _____ Date _____

Activity C13: Raoult's Law
(Pressure Sensor, Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Gas laws	C13 Raoult's Law.DS	C13 Raoult's Law	C13_RAOU.SWS

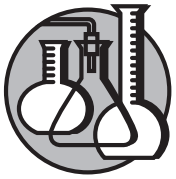
Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Pressure Sensor (CI-6532A)	1	Stirring rod	1
Temperature Sensor (CI-6505A)	1	**Thermometer (SE-9084)**	1
Balance (SE-8723)	1	**Tubing, plastic (w/sensor)**	1
Beaker, 150 mL	2	Protective gear	PS
Beaker, 1 L	1		
Bottle (or flask), 250 mL	3	**Chemicals and Consumables**	**Qty**
Connector, rubber stopper (w/sensor)	1	Acetone	100 mL
Coupling, quick-release (w/sensor)	1	Glycerin	1 mL
Graduated cylinder	1	Label	5
Hot plate	1	Para-dichlorobenzene	6 g
Rubber stopper, two-hole	1	Water	1 L

What Do You Think?

How will the vapor pressure of a pure solvent change when an unknown amount of solute is dissolved in the solvent?

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

Background



The vapor pressure of a liquid in a closed system depends on molecules of a liquid that have sufficient energy to overcome the intermolecular attractive forces and escape from the surface of the liquid as gas molecules. When a nonionic solute is added to the liquid the intermolecular attractive forces between the solvent and the solute molecules are different than the forces between molecules in a pure solvent.

Raoult's Law describes the relationship between the vapor pressure of a solution and the amount of nonionic solute in the solution. For a solvent and a non-volatile solute the relationship is based on the mole fraction, **X**, of the solvent in the solution. The mole fraction is the number of moles of the solvent divided by the total moles (both solvent and solute) in the solution.

Raoult's Law is as follows:

$$\mathbf{P_t} = \Sigma X_\mathbf{i} \mathbf{P_i}$$

where $\mathbf{P_t}$ is the total vapor pressure, Σ means "the sum of", $X_\mathbf{i}$ is the mole fraction, and $\mathbf{P_i}$ is the individual vapor pressure of the pure solvent at that temperature.

For example, pure toluene has a vapor pressure of 2.93 kPa at 25 °C. If 0.2 mole of naphthalene (a non-volatile solid) is added to one mole of toluene, the vapor pressure of the toluene will **decrease**. In fact, the more solute added to the solvent, the lower the vapor pressure of the solvent.

$$\mathbf{P_t} = \Sigma X_\mathbf{i} \mathbf{P_i} = 1.0 \text{ mole toluene}/1.2 \text{ total moles} \times 2.93 \text{kPa}$$

$$\mathbf{P_t} = 2.44 \text{ kPa}$$

SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

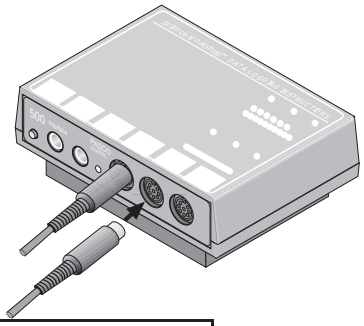
For You To Do

Prepare the Water Bath

- Make a water bath of about 600 mL of water in a 1 liter beaker. Heat the water bath to 60 ˚C and maintain this temperature. Use a thermometer to check the progress of the water bath as you set up the rest of the lab materials.

Use the Pressure Sensor to measure the change in vapor pressure in a rigid container containing a liquid. Use the Temperature Sensor to measure the change of temperature inside the container. Measure the pressure and temperature for a pure solvent first, and then measure the pressure and temperature for a solution with different amounts of a solute added to the solvent. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use the data to determine the relationship between the change in vapor pressure and the amount of the solute for a given temperature.

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)
C13 Raoult's Law.DS	C13 Raoult's Law	C13_RAOU.SWS

- The *DataStudio* file has a Graph display. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display with a plot of the pressure versus temperature.
- Data recording is set at one measurement per second (1 Hz).

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensors.

Prepare the Solutions

- For this part you need the following: balance, graduated cylinder, beakers (150 mL), stirring rod, labels, para-dichlorobenzene, acetone

1. In the first beaker, dissolve 2 g of para-dichlorobenzene (PDCB) in 20 mL of acetone. Label this as solution as "Solution #1".
2. In the second beaker, dissolve 4 g of para-dichlorobenzene in 20 mL of acetone. Label this solution as "Solution #2".

3. Label each bottle:

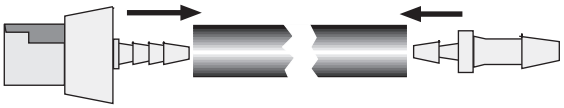
Bottle	Label	Contents
1	Solvent	3 mL of acetone
2	Solution #1	3 mL of Solution #1 (acetone + 2-g PDCB)
3	Solution #2	3 mL of Solution #2 (acetone + 4-g PDCB)

4. Put 3 mL of acetone in the first bottle. Put 3 mL of Solution #1 in the second bottle. Put 3 mL of Solution #2 in the third bottle.

Set Up the Equipment

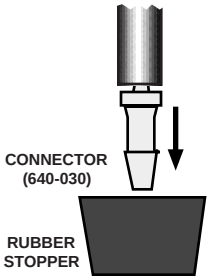
- For this part you will need the following: glycerin, quick-release coupling, connector, plastic tubing, two-hole rubber stopper, Temperature Sensor, Pressure Sensor.

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.



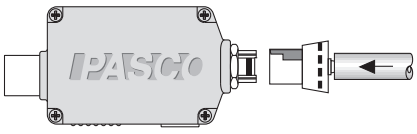
2. Put a drop of glycerin on the barb end of the connector. Push the barb end of the connector into the other end of the plastic tubing.

3. Fit the end of the connector into one of the holes in the rubber stopper.

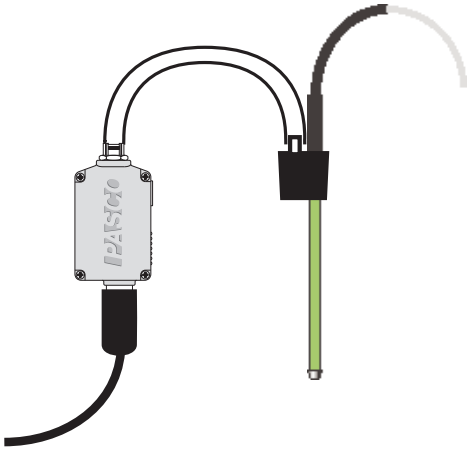


4. Put a drop of glycerin into the other hole of the stopper and slide the Temperature Sensor through the hole.

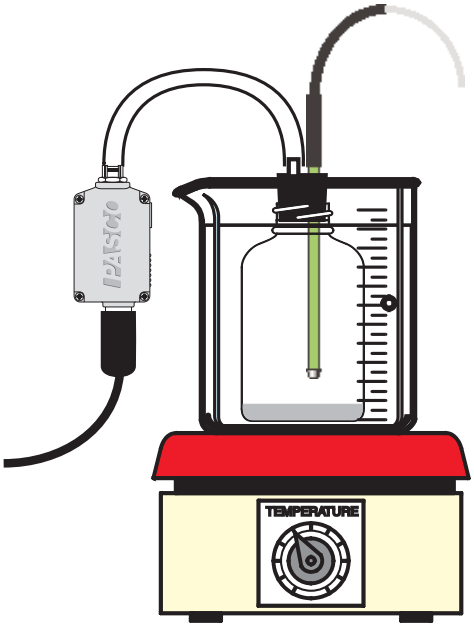
5. Align the quick-release coupling on the end of the plastic tubing with the pressure port of the Pressure Sensor. Push the coupling onto the port, and then turn the coupling clockwise until it clicks (about one-eighth turn).



- Pressure Sensor and Temperature Sensor with two-hole rubber stopper.



PART IIIA: Data Recording - Solvent



1. When you are ready to begin, place the two-hole rubber stopper with sensors into the top of Bottle 1. Place Bottle 1 in the hot water bath.

- **Predict how the pressure - temperature graph will look for the solvent.**

2. Start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
3. Allow the heating to continue for only 60 seconds. Stop recording data.
4. Remove Bottle 1 from the hot water bath.
5. Slowly open the bottle to allow the vapors to escape. Remove the rubber stopper from Bottle 1 and place it in the top of Bottle 2.

PART IIIB: Data Recording – Solution #1

1. Place Bottle 2 in the hot water bath. Begin recording data.

- **Predict how the pressure – temperature graph for solution #1 will differ from the graph for the solvent.**

2. Allow the heating to continue for only 60 seconds. Stop recording data.
3. Remove Bottle 2 from the hot water bath.
4. Slowly open the bottle to allow the vapors to escape. Remove the rubber stopper from Bottle 2 and place it in the top of Bottle 3.

PART IIIC: Data Recording – Solution #2

1. Place Bottle 3 in the hot water bath. Begin recording data.

- **Predict how the pressure - temperature graph for solution #2 will differ from the graph for solution #1.**

The third curve will have vapor pressures that are lower than the other samples at the same temperature.

2. Allow the heating to continue for only 60 seconds. Stop recording data.
3. Remove Bottle 3 from the hot water bath. Turn off the heat source for the hot water bath.
4. Slowly open the bottle to allow the vapors to escape. Remove the rubber stopper from Bottle 3.
5. Dispose of the remaining liquid in each bottle by pouring the liquid into a beaker labeled **waste solution**. Rinse the bottles.

Analyzing the Data

- Use the data in the Graph display and your observations to answer the questions in the Lab Report section.

Record your predictions and results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C13: Raoult's Law

What Do You Think?

How will the vapor pressure of a pure solvent change when an unknown amount of solute is dissolved in the solvent?

Predictions

- **Predict how the pressure - temperature graph will look for the solvent.**

- **Predict how the pressure - temperature graph for solution #1 will differ from the graph for the solvent.**

- **Predict how the pressure - temperature graph for solution #2 will differ from the graph for solution #1.**

Questions

1. What is the general relationship between the vapor pressure of acetone and the amount of solid dissolved?

2. What do you think are the limitations of Raoult's Law?

3. Think about an automobile. Where is Raoult's Law an important consideration in the design of a car?

4. You made two solutions of acetone and p - dichlorobenzene.

   Solution #1 = 2 g of p - dichlorobenzene in 20 mL of acetone.

   Solution #2 = 4 g of p - dichlorobenzene in 20 mL of acetone.

• Acetone has a density of 0.80 g/mL. What is the mole fraction of acetone in each solution?

Solution #1

The mole fraction of acetone for Solution #1 is

Solution #2

The mole fraction of acetone for Solution #2 is

5. Pick a temperature that is in the range of your data (e.g., 35 ˚C). Use the 'Smart Tool' in *DataStudio* or the 'Smart Cursor' in *ScienceWorkshop* to measure the pressure at that temperature. Use the mole fraction of acetone for Solution #1 to calculate the theoretical vapor pressure of Solution #1 and the mole fraction of acetone for Solution #2 to calculate theoretical vapor pressure of Solution #2 for that temperature.

Solution	Actual Pressure	Theoretical Pressure	% difference
Acetone	kPa		
Acetone + 2 g PDCB	kPa	kPa	
Acetone + 4 g PDCB	kPa	kPa	

6. How do your experimental results compare with your calculations?

Name _____ Class _____ Date _____

Activity C14: Rate of a Chemical Reaction 1 (Colorimeter)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Rate of reactions	C14 Reaction Rate 1.DS	C14 Reaction Rate 1	C14_REA1.SWS

Equipment Needed	**Qty**	**Chemicals and Consumables**	**Qty**
Colorimeter (CI-6747)	1	Hydrochloric acid, 6 molar	10 mL
Cuvette (w/sensor)	1	Sodium thiosulfate, 0.2 molar	10 mL
Graduated cylinder, 10 mL	2	Water, distilled	100 mL
Protective gear	PS		

What Do You Think?

How will changing the concentrations of the reactants in a chemical reaction affect the rate of the reaction?

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

Background

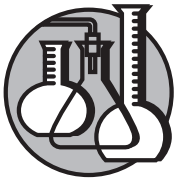
All chemical reactions occur at specific rates. The rate of a chemical reaction depends on several physical and chemical factors. These factors include:

- The concentration of the reactants
- The pressure on the reaction
- The temperature of the reaction
- The presence of a catalyst

In this activity you will determine the effect of changes in concentration of the reactants on the rate of the chemical reaction. The reaction for this activity is the acidic reduction of the thiosulfate ion to sulfur and sulfur dioxide.

The equation for the reaction is:

$$S_2O_3^{2-}(aq) + 2\ H^+(aq) \text{ =========> } SO_2(g) + S\ (s) + H_2O$$



One way to determine the effect of concentration on the rate of the reaction is to use a Colorimeter to measure the formation of the solid sulfur generated. The solid sulfur will block the light in the Colorimeter and the amount of blockage is directly proportional to the amount of sulfur in suspension.

The rate of this chemical reaction is given by the equation:

$$\text{Rate} = k\ [\text{thiosulfate}]^a\ [\text{acid}]^b$$

The letters a and b seen as exponents are numerals which can only be determined experimentally. Each reactant must be varied separately while the other is kept constant. The effect on the rate of the reaction is noted and the value of the exponent is determined in this way:

- If a change in concentration of one of the reactants has no effect, the exponent is 0.
- If doubling the concentration doubles the rate, the exponent is 1.
- If doubling the concentration quadruples the rate, the exponent is 2.

The over all order of the reaction is determined by adding a + b.

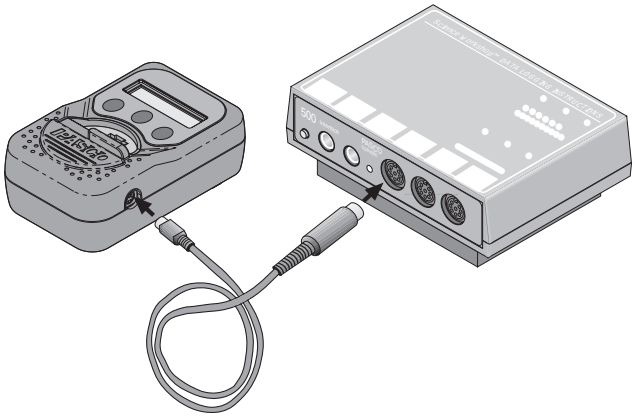
SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

For You To Do

Use the Colorimeter to measure the change in absorbance of light by a solution of sodium thiosulfate and hydrochloric acid as the two components react. Begin with a mixture with specific concentrations of the two components, and then test mixtures with different concentrations of one component or the other. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use the data to determine the overall order of the rate of reaction.

PART I: Computer Setup



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

- The sensor's connector cable has a mini-DIN plug at one end and a regular DIN plug at the other.

2. Plug the mini-DIN end of the cable into the sensor and then connect the other end of the cable into Analog Channel A on the interface.

- The Colorimeter will automatically turn itself on when it is connected to the *ScienceWorkshop* interface.

3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C14 Reaction Rate 1.DS	C14 Reaction Rate 1	C14_REA1.SWS

- The *DataStudio* file has a Graph display. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display with absorbance of light versus time.
- Data recording is set at ten measurements per second (10 Hz).

PART II: Sensor Calibration and Equipment Setup

About the Colorimeter

The Colorimeter analyzes colors of light that pass through a solution. The solution is put into a rectangular container called a cuvette, which is then placed inside the Colorimeter. The measure of the amount of light that passes through a solution is called "transmittance". Transmittance is a ratio of the intensity of the transmitted light to the intensity of the original light, and is usually expressed as a percentage.

Absorbance is related to transmittance. The light absorbed by a solution depends on the absorbing ability of the solution, the distance traveled by the light through the solution, and the concentration of the solution. The relationship of absorbance to transmittance is: $A = 2 - \log\%T$

Name _____ Class _____ Date _____

Calibration

The general method for calibrating the Colorimeter is as follows:

- **First**, calibrate the Colorimeter with a clear cuvette containing distilled water.
- **Second**, calibrate the software (either *DataStudio* or *ScienceWorkshop*) for one of the four colors of light that can be selected in the Colorimeter. (For this activity you will use the RED wavelength.)

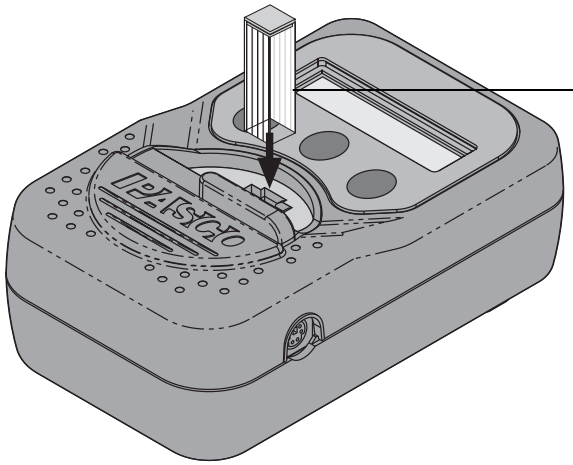
Note: The cuvette has two clear sides and two ridged sides.

- All cuvettes should be wiped clean and dry on the outside with a tissue.
- Handle cuvettes only by the top edge of the ridged sides.
- All solutions should be free of bubbles.
- Always position the cuvette so the light beam will pass through the clear sides.

Calibrate the Colorimeter

When the Colorimeter comes on, the liquid crystal display (LCD) should say "Please calibrate".

To calibrate the Colorimeter with a clear cuvette, fill a clean cuvette with distilled water and cap the cuvette. (The clear cuvette is a control or 'reference' that accounts for the small amount of light scattered or reflected by the walls of the cuvette.)



On the Colorimeter, press the 'Select' button (Select) and the 'Start/Stop' button (Start/Stop) at the same time.

The Colorimeter's LCD will say "Insert reference then push SELECT".

Place the closed cuvette inside the Colorimeter. Make sure that the clear sides of the cuvette (without ridges) are lined up with the light path in the Colorimeter. Close the lid on the Colorimeter.

On the Colorimeter, press the 'Select' button.

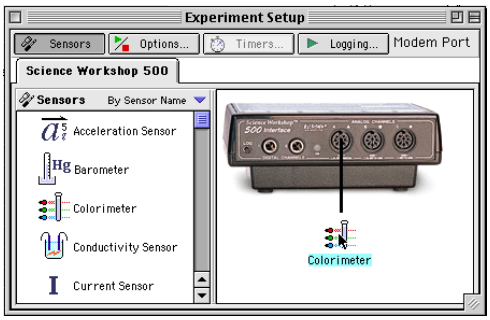
The Colorimeter will *automatically* calibrate itself for all four wavelengths assuming that the light passing through the clear cuvette represents "100% Transmittance". (The automatic calibration takes only a few seconds.)

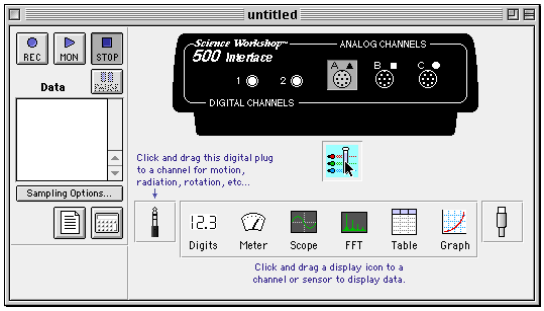
The Colorimeter's LCD will say "CAL done, push SELECT or START".

Calibrate the Software

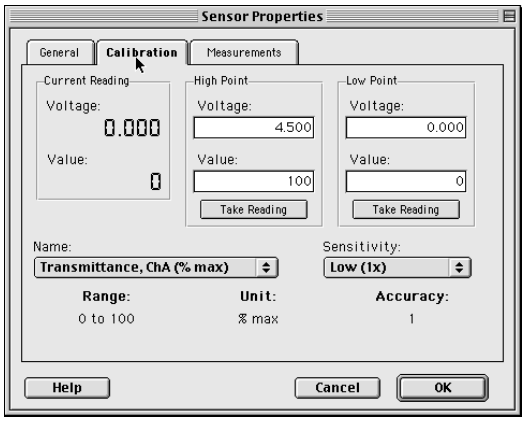
Follow these steps to calibrate the software for one of the four colors of light:

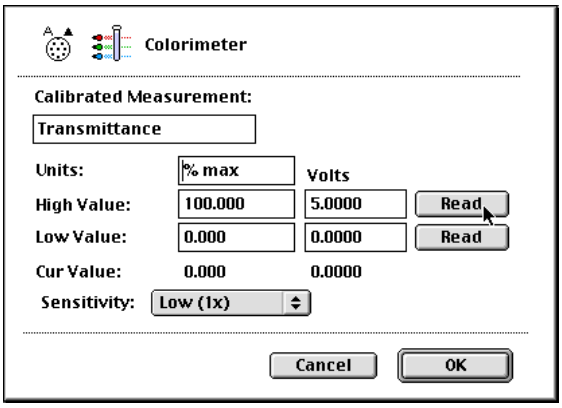
1. Leave the cuvette with distilled water inside the Colorimeter.
2. In the Experiment Setup window, double-click the Colorimeter icon.





- In *DataStudio*, the Sensor Properties window will open. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window will open.





3. Select the color of light.

• NOTE: The default color is RED, so you do not need to change the selection for this activity.

4. Calibrate the software.

- **First**, press the 'Start/Stop' button (Start Stop) to start the Colorimeter. (The LCD shows the color and wavelength, the percent transmittance, and "RUN".)
- **Second**, check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*.
- **Third**, 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*.
- **Fourth**, press the 'Start/Stop' button to stop the Colorimeter. (The LCD changes to "STOP".)

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

- The software is now calibrated for the Colorimeter.

Name _____ Class _____ Date _____

Equipment Setup

When sodium thiosulfate and hydrochloric acid are mixed, the solution gradually becomes darker. The solution absorbs more and more light (its absorbance increases).

You will test four solutions made up of different amounts of two reactants as follows:

Solution	Component A	Component B
#1	1.6 mL of 0.2 M sodium thiosulfate	1.6 mL of 6 M hydrochloric acid
#2	1.6 mL of 0.2 M sodium thiosulfate	0.8 mL of 6 M hydrochloric acid and 0.8 mL of distilled water
#3	0.8 mL of 0.2 M sodium thiosulfate and 0.8 mL of distilled water	1.6 mL of 6 M hydrochloric acid
#4	0.4 mL of 0.2 M sodium thiosulfate and 1.2 mL of distilled water	1.6 mL of 6 M hydrochloric acid

The general procedure is as follows:

1. Measure the liquids needed for Component A into one graduated cylinder.
2. Measure the liquids needed for Component B into a second graduated cylinder.
3. Put Component B into a cuvette.
4. Add Component A to the same cuvette and put a cap on the cuvette.
5. Quickly invert the cuvette to mix the components.
6. Quickly put the cuvette into the Colorimeter.
7. Start the Colorimeter. Record data. Stop the Colorimeter

PART III: Data Recording

1. When you are ready to begin data recording, place Component B for the first solution in the cuvette. Add Component A for the first solution to the cuvette. Cap the cuvette, invert it to mix the components, and *quickly* put the cuvette into the Colorimeter. Close the Colorimeter lid.
2. Press the 'Start/Stop' button (

) to start the Colorimeter.
3. Start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
4. Record data for 3 minutes and then stop the data recording.
5. Press the 'Start/Stop' button (

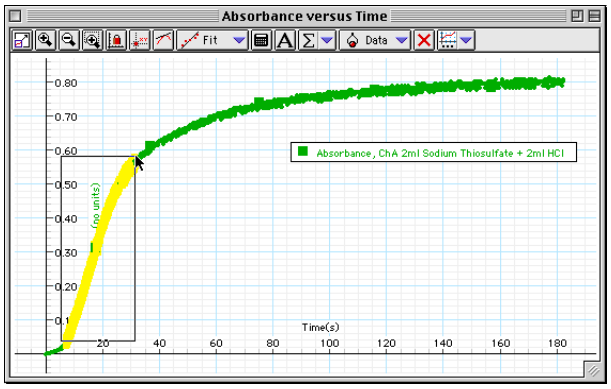
) to stop the Colorimeter.
6. Remove the cuvette from the Colorimeter and dispose of the solution as instructed.
7. Repeat the procedure for solutions 2, 3, and 4. There will be four runs of data at the end of the data recording.

Analyzing the Data in *DataStudio*

Use the analysis tools in the Graph display to determine the rate of reaction for each solution. A procedure for doing this is as follows:

1. Select the run to analyze.
2. Use the cursor to select a region near the beginning the plot where the absorbance is changing.
3. Select 'Linear' from the 'Fit' menu.
4. Record the value of the slope ('m') as the rate of the reaction.

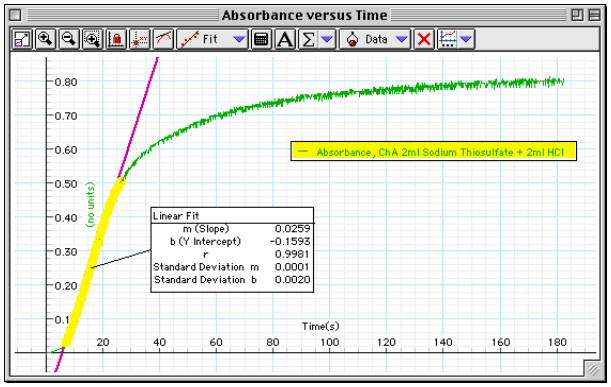
Repeat the process for each run of data.

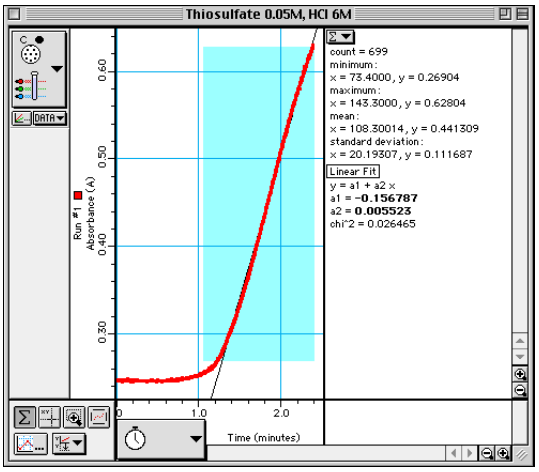


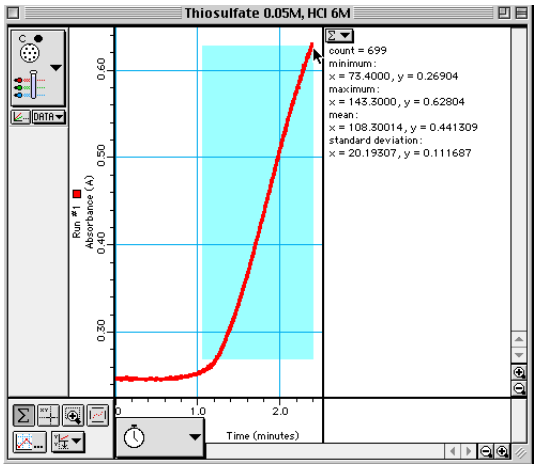
Analyzing the Data in *ScienceWorkshop*

Use the analysis tools in the Graph display to determine the rate of reaction for each solution. A procedure for doing this is as follows:

1. Select the run to analyze.
2. Click the 'Statistics' button ( ) to open the statistics area. Rescale the display to fit the data.
3. Use the cursor to select a region near the beginning the plot where the absorbance is changing.







4. Click the 'Statistics menu' button ( ) and select 'Curve Fit, Linear Fit' from the menu.
5. Record the value of **a2** as the rate of reaction.

Repeat the process for each run of data.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C14: Rate of a Chemical Reaction 1

What Do You Think?

How will changing the concentrations of the reactants affect the rate of a chemical reaction?

Data Table

Solution	Rate
#1 (1.6 mL thiosulfate, 1.6 mL HCl)	
#2 (1.6 mL thiosulfate, 0.8 mL HCl + 0.8 mL water)	
#3 (0.8 mL thiosulfate + 0.8 mL water, 1.6 mL HCl)	
#4 (0.4 mL thiosulfate + 1.2 mL water, 1.6 mL HCl)	

Questions

1. What is the effect on the rate of the reaction by halving the concentration of thiosulfate?

2. What is the order of the reaction due to thiosulfate?

3. What was the effect on the rate of reaction by halving the concentration of acid?

4. What is the order of the reaction due to acid?

5. What is the over all order of the reaction?

Name _____ Class _____ Date _____

Activity C15: Rate of a Chemical Reaction 2 (Colorimeter)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Rate of reactions	C15 Reaction Rate 2.DS	C15 Reaction Rate 1	C15_REA2.SWS

Equipment Needed	**Qty**	**Chemicals and Consumables**	**Qty**
Colorimeter (CI-6747)	1	2-butanol, 2 molar	10 mL
Cuvette (w/sensor)	1	Potassium permanganate, 0.2 molar	10 mL
Pipette, 1 mL	4	Sulfuric acid, 1 molar	10 mL
Protective gear	PS	Water, distilled	10 mL

What Do You Think?

How will changing the concentration of the reactants affect the rate of a chemical reaction?

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

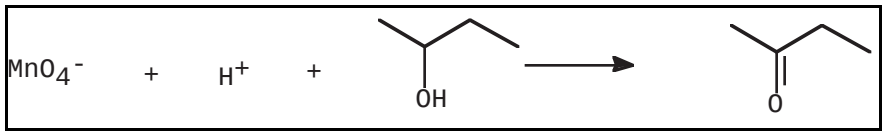
Background

All chemical reactions occur at specific rates. The rate of a chemical reaction depends on several physical and chemical factors. These factors include:

- The concentration of the reactants
- The pressure on the reaction
- The temperature of the reaction
- The presence of a catalyst

In this activity you will determine the effect of changes in concentration on the rate of a chemical reaction. The chemical reaction under investigation is the conversion of 2-butanol to methyl ethyl ketone or 2-butanone. The reaction will be monitored by using a Colorimeter to measure the change in optical density (absorbance) at 635 nm (wavelength of red light).

The equation for the reaction is:



or

permanganate ion + hydrogen ion + 2 butanol ==> 2 butanone

or

$$2\ MnO_4^- + 6\ H^+ + 5\ C_4H_{10}O \Longrightarrow 5\ C_4H_8O + 8\ H_2O + 2\ Mn^{2+}$$

In order to determine the effect of concentration on the rate of the reaction, you will follow the reaction by using the Colorimeter to monitor the absorption of the manganese ion. As the reaction produces the Mn^{2+} the light from the Colorimeter will be absorbed. The amount of absorption is directly related to the concentration of the manganous ion in the solution.

The rate of this chemical reaction is given by the equation:

$$\text{Rate} = k\,[\text{reactant}]^a\,[\text{reactant}]^b\,[\text{reactant}]^c$$

The letters a, b and c seen as exponents are numerals which can only be determined experimentally. Each reactant must be varied separately while the other is kept constant. The effect on the rate of the reaction is noted and the value of the exponent is determined in this way:

- If a change in concentration of one of the reactants has no effect, the exponent is 0.
- If doubling the concentration doubles the rate, the exponent is 1.
- If doubling the concentration quadruples the rate, the exponent is 2.

The over all order of the reaction is determined by adding a + b + c.

SAFETY REMINDERS

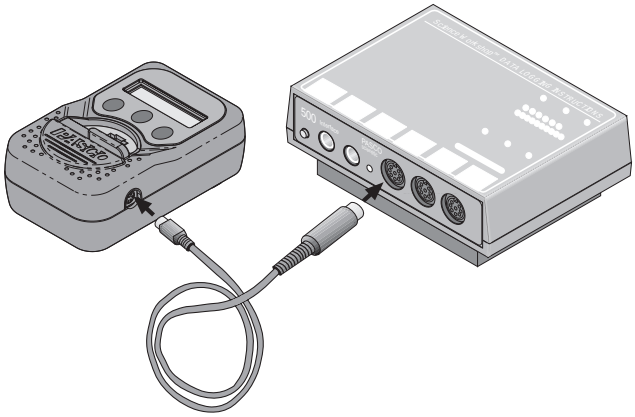
- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

CAUTION: Never pipette by mouth. Always use a pipette bulb or a pipette pump. Be careful when handling any acid or base solutions.

For You To Do

Use the Colorimeter to measure the change in absorbance of light by a solution of 2-butanol, potassium permangante, and sulfuric acid as the three components react. Begin with a mixture with specific concentrations of the three components, and then test mixtures with different concentrations of one component or the other. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use the data to determine the overall order of the rate of reaction.

PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
   - The sensor's connector cable has a mini-DIN plug at one end and a regular DIN plug at the other.
2. Plug the mini-DIN end of the cable into the sensor and then connect the other end of the cable into Analog Channel A on the interface.
   - The Colorimeter will automatically turn itself on when it is connected to the *ScienceWorkshop* interface.
3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C15 Reaction Rate 2.DS	C15 Reaction Rate 1	C15_REA2.SWS

- The *DataStudio* file has a Graph display. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display with absorbance of light versus time.
- Data recording is set at ten measurements per second (10 Hz).

Name _____ Class _____ Date _____

PART II: Sensor Calibration and Equipment Setup

About the Colorimeter

The Colorimeter analyzes colors of light that pass through a solution. The solution is put into a rectangular container called a cuvette, which is then placed inside the Colorimeter. The measure of the amount of light that passes through a solution is called "transmittance". Transmittance is a ratio of the intensity of the transmitted light to the intensity of the original light, and is usually expressed as a percentage.

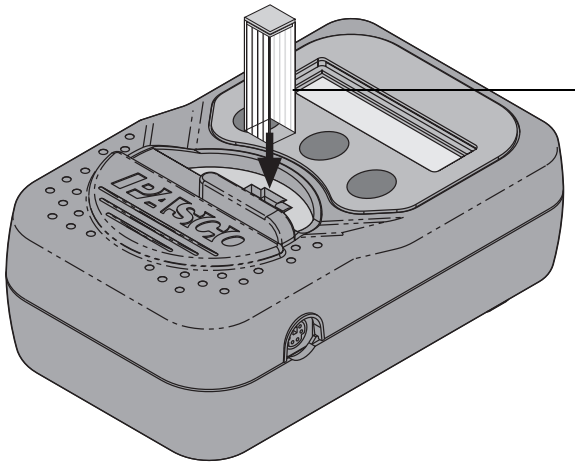
Absorbance is related to transmittance. The light absorbed by a solution depends on the absorbing ability of the solution, the distance traveled by the light through the solution, and the concentration of the solution. The relationship of absorbance to transmittance is: $A = 2 - \log\%T$

Calibration

The general method for calibrating the Colorimeter is as follows:

- **First**, calibrate the Colorimeter with a clear cuvette containing distilled water.
- **Second**, calibrate the software (either *DataStudio* or *ScienceWorkshop*) for one of the four colors of light that can be selected in the Colorimeter. (For this activity you will use the RED wavelength.)

Note: The cuvette has two clear sides and two ridged sides.



- All cuvettes should be wiped clean and dry on the outside with a tissue.
- Handle cuvettes only by the top edge of the ridged sides.
- All solutions should be free of bubbles.
- Always position the cuvette so the light beam will pass through the clear sides.

Calibrate the Colorimeter

When the Colorimeter comes on, the liquid crystal display (LCD) should say "Please calibrate".

To calibrate the Colorimeter with a clear cuvette, fill a clean cuvette with distilled water and cap the cuvette. (The clear cuvette is a control or 'reference' that accounts for the small amount of light scattered or reflected by the walls of the cuvette.)

On the Colorimeter, press the 'Select' button (Select) and the 'Start/Stop' button (Start Stop) at the same time.

The Colorimeter's LCD will say "Insert reference then push SELECT".

Place the closed cuvette inside the Colorimeter. Make sure that the clear sides of the cuvette (without ridges) are lined up with the light path in the Colorimeter. Close the lid on the Colorimeter.

On the Colorimeter, press the 'Select' button.

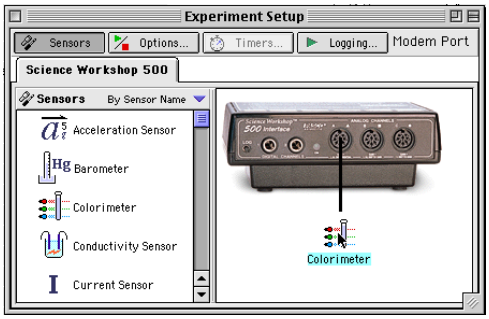
The Colorimeter will *automatically* calibrate itself for all four wavelengths assuming that the light passing through the clear cuvette represents "100% Transmittance". (The automatic calibration takes only a few seconds.)

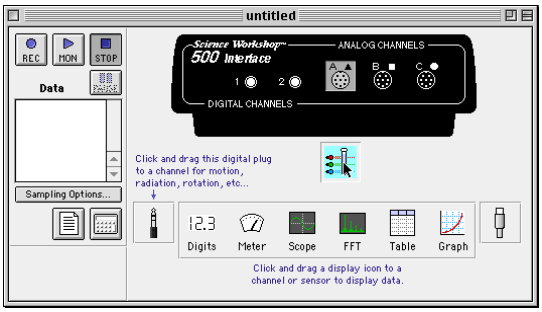
The Colorimeter's LCD will say "CAL done, push SELECT or START".

Calibrate the Software

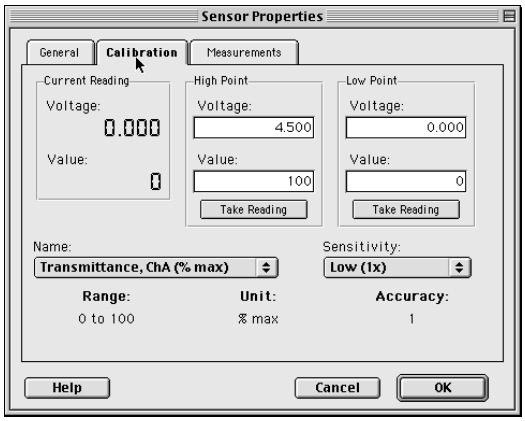
Follow these steps to calibrate the software for one of the four colors of light:

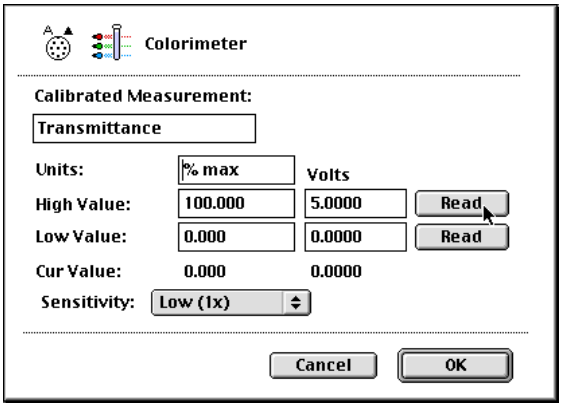
1. Leave the cuvette with distilled water inside the Colorimeter.
2. In the Experiment Setup window, double-click the Colorimeter icon.





- In *DataStudio*, the Sensor Properties window will open. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window will open.





3. Select the color of light.

• NOTE: The default color is RED, so you do not need to change the selection for this activity.

4. Calibrate the software.

- **First**, press the 'Start/Stop' button (

) to start the Colorimeter. (The LCD shows the color and wavelength, the percent transmittance, and "RUN".)
- **Second**, check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*.
- **Third**, 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*.
- **Fourth**, press the 'Start/Stop' button to stop the Colorimeter. (The LCD changes to "STOP".)

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

- The software is now calibrated for the Colorimeter.

Equipment Setup

When the reactants are mixed, the solution gradually becomes darker. In other words, the solution absorbs more and more light (absorbance goes up).

You will test how each of the three substances (sulfuric acid (2 Molar), 2-butanol (1 Molar), and potassium permanganate (0.02 Molar)) effect the rate of reaction. You will vary the concentration of one reactant at a time by diluting it with distilled water.

Use the following protocol in each test:

1. Add the specified amount of distilled water to the cuvette.
2. Add the specified amount of 2-butanol to the cuvette.
3. Add the specified amount of sulfuric acid to the cuvette.
4. Add the specified amount of potassium permanganate to the cuvette LAST and quickly cap the cuvette.
5. Quickly invert the cuvette to mix the components.
6. Quickly put the cuvette into the Colorimeter.
7. Start the Colorimeter, record data, then stop the Colorimeter
8. Remove the cuvette, discard the solution, and rinse the cuvette thoroughly.

PART IIIA: Data Recording - Vary the Concentration of Permanganate Ion

You will test three solutions made up of different amounts of the reactants as follows:

Table IIIA: Vary the Concentration of Permanganate Ion

Trial#	Water	2-butanol, 2 M	Sulfuric acid, 1 M	Potassium permanganate, 0.2 M
1	0.8 mL	0.8 mL	0.8 mL	0.8 mL
2	1.2 mL	0.8 mL	0.8 mL	0.4 mL
3	1.4 mL	0.8 mL	0.8 mL	0.2 mL

1. When you are ready to begin data recording, place distilled water, 2-butanol, and sulfuric acid in the cuvette in the amounts specified.
2. Add the specified amount of potassium permanganate LAST. Quickly cap the cuvette, mix, and put the cuvette into the Colorimeter. Close the Colorimeter lid.
3. Press the 'Start/Stop' button (

) to start the Colorimeter.
4. Start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
5. Record data for about 135 seconds and then stop recording data.
6. Press the 'Start/Stop' button (

) to stop the Colorimeter. Empty and rinse the cuvette with distilled water.
7. Repeat the procedure for trials 2 and 3 using the amounts of reactants shown above. Remember to add the $KMnO_4$ last.

- You will have <u>three</u> runs of data at the end of the data recording for Part IIIA.

PART IIIB: Data Recording - Vary the Concentration of 2-Butanol

You will test three solutions made up of different amounts of the reactants as follows:

Table IIIB: Vary the Concentration of 2-Butanol

Trial#	Water	2-butanol, 2 M	Sulfuric acid, 1 M	Potassium permanganate, 0.2 M
4	0.8 mL	0.8 mL	0.8 mL	0.8 mL
5	1.2 mL	0.4 mL	0.8 mL	0.8 mL
6	1.4 mL	0.2 mL	0.8 mL	0.8 mL

1. When you are ready to begin data recording, place distilled water, 2-butanol, and sulfuric acid in the cuvette in the amounts specified.
2. Add the specified amount of potassium permanganate LAST. Quickly cap the cuvette, mix, and put the cuvette into the Colorimeter. Close the Colorimeter lid.
3. Press the 'Start/Stop' button (

) to start the Colorimeter.

4. Start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
5. Record data for about 135 seconds and then stop recording data.
6. Press the 'Start/Stop' button (

) to stop the Colorimeter. Empty and rinse the cuvette with distilled water.
7. Repeat the procedure for trials 5 and 6 using the amounts of reactants shown above. Remember to add the $KMnO_4$ last.

- You will have <u>three</u> more runs of data at the end of the data recording for Part IIIB.

PART IIIC: Data Recording - Vary the Concentration of Sulfuric Acid

You will test three solutions made up of different amounts of the reactants as follows:

Table IIIC: Vary the Concentration of Sulfuric Acid

Trial#	Water	2-butanol, 2 M	Sulfuric acid, 1 M	Potassium permanganate, 0.2 M
4	0.8 mL	0.8 mL	0.8 mL	0.8 mL
5	1.2 mL	0.8 mL	0.4 mL	0.8 mL
6	1.4 mL	0.8 mL	0.2 mL	0.8 mL

1. When you are ready to begin data recording, place distilled water, 2-butanol, and sulfuric acid in the cuvette in the amounts specified.
2. Add the specified amount of potassium permanganate LAST. Quickly cap the cuvette, mix, and put the cuvette into the Colorimeter. Close the Colorimeter lid.
3. Press the 'Start/Stop' button (

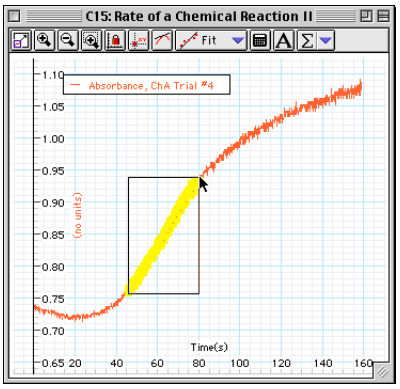
) to start the Colorimeter.
4. Start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
5. Record data for about 135 seconds and then stop recording data.
6. Press the 'Start/Stop' button (

) to stop the Colorimeter. Empty and rinse the cuvette with distilled water.
7. Repeat the procedure for trials 5 and 6 using the amounts of reactants shown above. Remember to add the $KMnO_4$ last.

- You will have <u>three</u> more runs of data at the end of the data recording for Part IIIB.

Analyzing the Data in *DataStudio*

Use the analysis tools in the Graph display to determine the rate of reaction for each solution. A procedure for doing this is as follows:

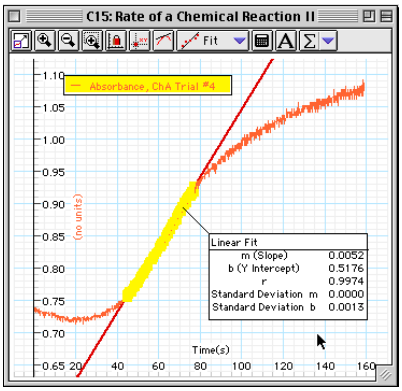


1. Select the run to analyze.
2. Use the cursor to select a region near the beginning the plot where the absorbance is changing.
3. Select 'Linear' from the 'Fit' menu.
4. Record the value of the slope ('m') as the rate of the reaction.

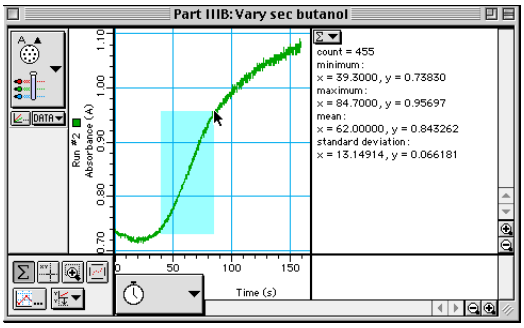
Repeat the process for each run of data.

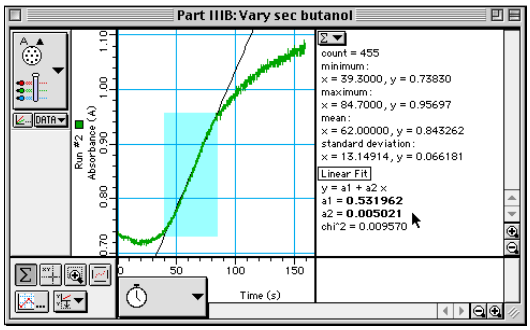
Analyzing the Data in *ScienceWorkshop*

Use the analysis tools in the Graph display to determine the rate of reaction for each solution. A procedure for doing this is as follows:



1. Select the run to analyze.
2. Click the 'Statistics' button () to open the statistics area. Rescale the display to fit the data.
3. Use the cursor to select a region near the beginning the plot where the absorbance is changing.
4. Click the 'Statistics menu' button () and select 'Curve Fit, Linear Fit' from the menu.





5. Record the value of **a2** as the rate of reaction.

Repeat the process for each run of data.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C15: Rate of a Chemical Reaction 2

What Do You Think?

How will changing the concentrations of the reactants affect the rate of a chemical reaction?

Data Table

Trial #	Variable	Amount (mL)	Rate
1	Potassium permanganate ($KmnO_4$)	0.8	
2	Potassium permanganate ($KmnO_4$)	0.4	
3	Potassium permanganate ($KmnO_4$)	0.2	
4	2-butanol	0.8	
5	2-butanol	0.4	
6	2-butanol	0.2	
7	Sulfuric acid (H_2SO_4)	0.8	
8	Sulfuric acid (H_2SO_4)	0.4	
9	Sulfuric acid (H_2SO_4)	0.2	

Questions

1. What is the effect of varying the concentration of each of the reactants?

2. Which of the reactants effected the rate of reaction the most?

3. Use the information in the Data Table to determine the order of each reactant and then determine the overall rate of the reaction.

Name _____ Class _____ Date _____

Activity C16: A Pseudo First Order Reaction (Colorimeter)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Rate of reactions	C16 Pseudo 1.DS	C17 Pseudo 1	C17_PSE1.SWS

Equipment Needed	**Qty**	**Chemicals and Consumables**	**Qty**
Colorimeter (CI-6747)	1	Ethanol	20 mL
Cuvette (w/sensor)	1	Hydrochloric acid, 1 molar	20 mL
Pipette, 1 mL	4	Potassium permanganate, 0.02 molar	20 mL
Protective gear	PS	Water, distilled	20 mL

What Do You Think?

How will changing the concentrations of the reactants affect the rate of a chemical reaction?

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

Background

The rate of a chemical reaction depends on the temperature, pressure and other physical characteristics of the reaction surroundings. The first consideration a chemist gives to a chemical reaction however, is the concentration of the reactants. High concentrations of chemical reactants insure that molecules have the greatest opportunity to for successful collisions.

Chemists often change the concentration of reactants so that they can study the effect the change has on the rate of the reaction. For example, consider the reaction of permanganate ion (MnO_4^-), in an acidic solution with ethyl alcohol (C_2H_6O) to form the acetate ion ($C_2H_3O_2^-$). The balanced equation for this reaction is given below.

$$5\ C_2H_6O + 4\ MnO_4^- + 7\ H^+ \Longrightarrow 5\ C_2H_3O_2^- + 4\ Mn^{2+} + 11\ H_2O$$

Five moles of ethyl alcohol are needed to react with four moles of permanganate ion to form five moles of acetate ion and four moles of the manganous (Mn^{2+}) ion. If the concentration of ethyl alcohol and acid are raised to a high level relative to the permanganate concentration, the kinetics of the appearance of the Mn^{2+} ion can be studied. In a similar manner, if the concentration of the hydrogen ion is raised above the stoichiometric requirement of the reaction, then the interaction of the other two reactants can be studied. Each participant in the reaction can be studied in turn using this technique. The method is a pseudo first order reaction because the kinetics of the single reactant can be studied as if the concentration were first order while the other reactants are held almost constant because their concentration is so large relative to the species being studied.

Remember that the Colorimeter measures the change in absorbance due to the manganous ion in the reaction solution.

SAFETY REMINDERS

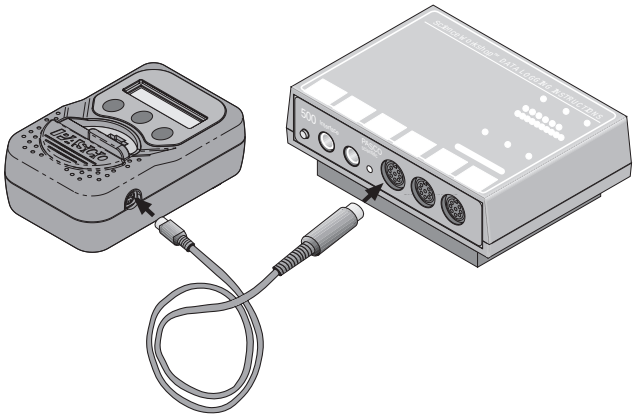
- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

CAUTION: Never pipette by mouth. Always use a pipette bulb or a pipette pump. Be careful when handling any acid or base solutions.

For You To Do

Use the Colorimeter to measure the change in absorbance of light by a solution of ethanol, hydrochloric acid and potassium permangante as the three components react. Begin with a mixture with specific concentrations of the three components, and then test mixtures with different concentrations of one component or the other. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use the data to determine the overall order of the rate of reaction.

PART I: Computer Setup



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

- The sensor's connector cable has a mini-DIN plug at one end and a regular DIN plug at the other.

2. Plug the mini-DIN end of the cable into the sensor and then connect the other end of the cable into Analog Channel A on the interface.

- The Colorimeter will automatically turn itself on when it is connected to the *ScienceWorkshop* interface.

3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C16 Pseudo 1.DS	C17 Pseudo 1	C17_PSE1.SWS

- The *DataStudio* file has a Graph display. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display with absorbance of light versus time.
- Data recording is set at two measurements per second (2 Hz).

PART II: Sensor Calibration and Equipment Setup

About the Colorimeter

The Colorimeter analyzes colors of light that pass through a solution. The solution is put into a rectangular container called a cuvette, which is then placed inside the Colorimeter. The measure of the amount of light that passes through a solution is called "transmittance". Transmittance is a ratio of the intensity of the transmitted light to the intensity of the original light, and is usually expressed as a percentage.

Absorbance is related to transmittance. The light absorbed by a solution depends on the absorbing ability of the solution, the distance traveled by the light through the solution, and the concentration of the solution. The relationship of absorbance to transmittance is: $A = 2 - \log\%T$

Calibration

The general method for calibrating the Colorimeter is as follows:

- **First**, calibrate the Colorimeter with a clear cuvette containing distilled water.
- **Second**, calibrate the software (either *DataStudio* or *ScienceWorkshop*) for one of the four colors of light that can be selected in the Colorimeter. (For this activity you will use the RED wavelength.)

Name _____ Class _____ Date _____

Note: The cuvette has two clear sides and two ridged sides.

- All cuvettes should be wiped clean and dry on the outside with a tissue.
- Handle cuvettes only by the top edge of the ridged sides.
- All solutions should be free of bubbles.
- Always position the cuvette so the light beam will pass through the clear sides.

Calibrate the Colorimeter

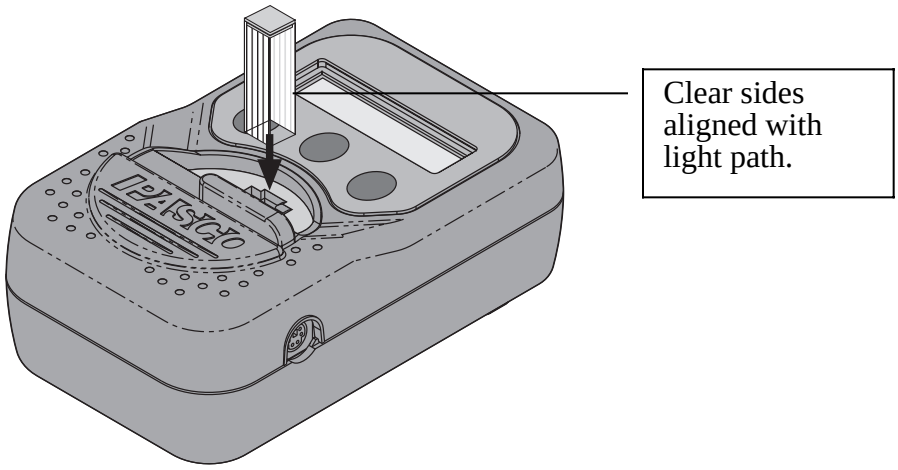
When the Colorimeter comes on, the liquid crystal display (LCD) should say "Please calibrate".

To calibrate the Colorimeter with a clear cuvette, fill a clean cuvette with distilled water and cap the cuvette. (The clear cuvette is a control or 'reference' that accounts for the small amount of light scattered or reflected by the walls of the cuvette.)

On the Colorimeter, press the 'Select' button (Select) and the 'Start/Stop' button (Start Stop) at the same time.

The Colorimeter's LCD will say "Insert reference then push SELECT".

Place the closed cuvette inside the Colorimeter. Make sure that the clear sides of the cuvette (without ridges) are lined up with the light path in the Colorimeter. Close the lid on the Colorimeter.



On the Colorimeter, press the 'Select' button.

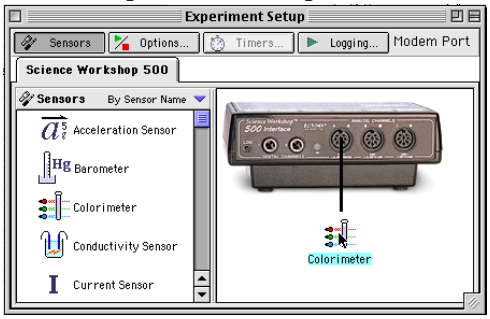
The Colorimeter will *automatically* calibrate itself for all four wavelengths assuming that the light passing through the clear cuvette represents "100% Transmittance". (The automatic calibration takes only a few seconds.)

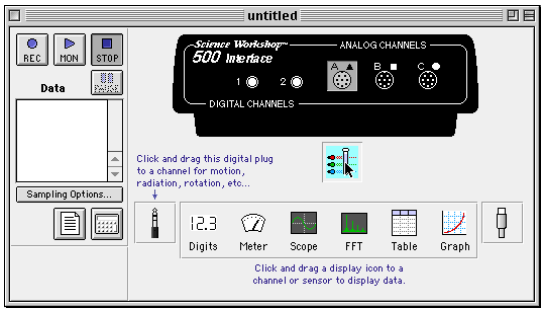
The Colorimeter's LCD will say "CAL done, push SELECT or START".

Calibrate the Software

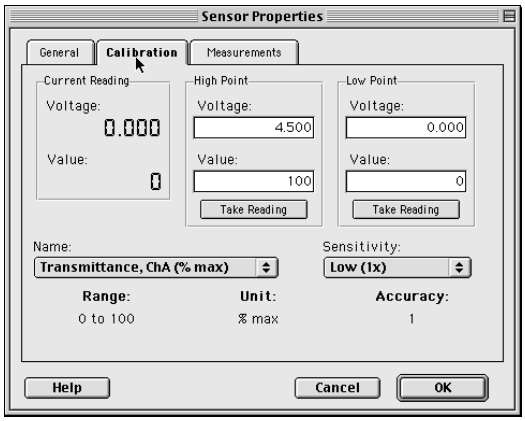
Follow these steps to calibrate the software for one of the four colors of light:

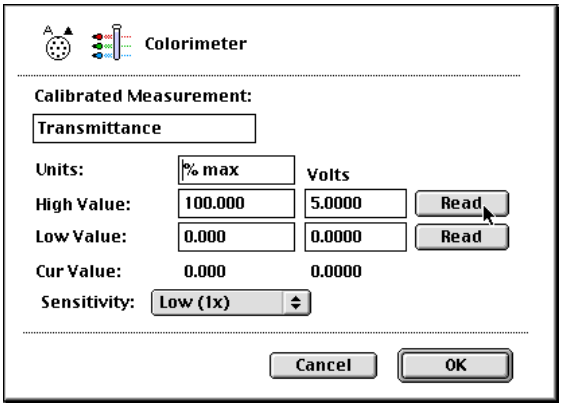
1. Leave the cuvette with distilled water inside the Colorimeter.
2. In the Experiment Setup window, double-click the Colorimeter icon.





- In *DataStudio*, the Sensor Properties window will open. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window will open.





3. Select the color of light.

• NOTE: The default color is RED, so you do not need to change the selection for this activity.

4. Calibrate the software.

- **First**, press the 'Start/Stop' button (Start/Stop) to start the Colorimeter. (The LCD shows the color and wavelength, the percent transmittance, and "RUN".)
- **Second**, check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*.
- **Third**, 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*.
- **Fourth**, press the 'Start/Stop' button to stop the Colorimeter. (The LCD changes to "STOP".)

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

- The software is now calibrated for the Colorimeter.

Equipment Setup

When the reactants are mixed, the solution gradually becomes darker. In other words, the solution absorbs more and more light (absorbance goes up).

You will test how each of the three substances (hydrochloric acid (1 Molar), ethyl alcohol, and potassium permanganate (0.02 Molar)) effect the rate of reaction. You will vary the concentration of one reactant at a time by diluting it with distilled water.

Use the following protocol in each test:

1. Add the specified amount of distilled water to the cuvette.
2. Add the specified amount of 2-butanol to the cuvette.
3. Add the specified amount of sulfuric acid to the cuvette.
4. Add the specified amount of potassium permanganate to the cuvette LAST and quickly cap the cuvette.
5. Quickly invert the cuvette to mix the components.
6. Quickly put the cuvette into the Colorimeter.
7. Start the Colorimeter, record data, then stop the Colorimeter
8. Remove the cuvette, discard the solution, and rinse the cuvette thoroughly.

PART IIIA: Data Recording - Vary the Concentration of Permanganate Ion

You will test three solutions made up of different amounts of the reactants as follows:

Table IIIA: Vary the Concentration of Permanganate Ion

Trial #	Water	Ethanol	Hydrochloric acid,1 M	Potassium permanganate, 0.02 M
1	0.8 mL	0.8 mL	0.8 mL	0.8 mL
2	1.2 mL	0.8 mL	0.8 mL	0.4 mL
3	1.4 mL	0.8 mL	0.8 mL	0.2 mL

1. When you are ready to begin data recording, place distilled water, ethanol, and hydrochloric acid in the cuvette in the amounts specified.
2. Add the specified amount of potassium permanganate LAST. Quickly cap the cuvette, mix, and put the cuvette into the Colorimeter. Close the Colorimeter lid.
3. Press the 'Start/Stop' button (

) to start the Colorimeter.
4. Start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
5. Record data for about 120 seconds and then stop recording data.
6. Press the 'Start/Stop' button (

) to stop the Colorimeter. Empty and rinse the cuvette with distilled water.
7. Repeat the procedure for trials 2 and 3 using the amounts of reactants shown above. Remember to add the $KMnO_4$ last.

- You will have <u>three</u> runs of data at the end of the data recording for Part IIIA.

PART IIIB: Data Recording - Vary the Concentration of Ethyl Alcohol

You will test three solutions made up of different amounts of the reactants as follows:

Table IIIB: Vary the Concentration of Ethanol

Trial #	Water	Ethanol	Hydrochloric acid, 1 M	Potassium permanganate, 0.02 M
4	0.8 mL	0.8 mL	0.8 mL	0.8 mL
5	1.2 mL	0.4 mL	0.8 mL	0.8 mL
6	1.4 mL	0.2 mL	0.8 mL	0.8 mL

1. When you are ready to begin data recording, place distilled water, ethanol, and hydrochloric acid in the cuvette in the amounts specified.
2. Add the specified amount of potassium permanganate LAST. Quickly cap the cuvette, mix, and put the cuvette into the Colorimeter. Close the Colorimeter lid.
3. Press the 'Start/Stop' button (

) to start the Colorimeter.
4. Start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
5. Record data for about 120 seconds and then stop recording data.
6. Press the 'Start/Stop' button (

) to stop the Colorimeter. Empty and rinse the cuvette with distilled water.
7. Repeat the procedure for trials 5 and 6 using the amounts of reactants shown above. Remember to add the $KMnO_4$ last.

- You will have <u>three</u> more runs of data at the end of the data recording for Part IIIB.

PART IIIC: Data Recording - Vary the Concentration of Hydrochloric Acid

You will test three solutions made up of different amounts of the reactants as follows:

Table IIIC: Vary the Concentration of Hydrochloric Acid

Trial #	Water	Ethanol	Hydrochloric acid, 1 M	Potassium permanganate, 0.02 M
4	0.8 mL	0.8 mL	0.8 mL	0.8 mL
5	1.2 mL	0.8 mL	0.4 mL	0.8 mL
6	1.4 mL	0.8 mL	0.2 mL	0.8 mL

1. When you are ready to begin data recording, place distilled water, ethanol, and hydrochloric acid in the cuvette in the amounts specified.
2. Add the specified amount of potassium permanganate LAST. Quickly cap the cuvette, mix, and put the cuvette into the Colorimeter. Close the Colorimeter lid.
3. Press the 'Start/Stop' button (

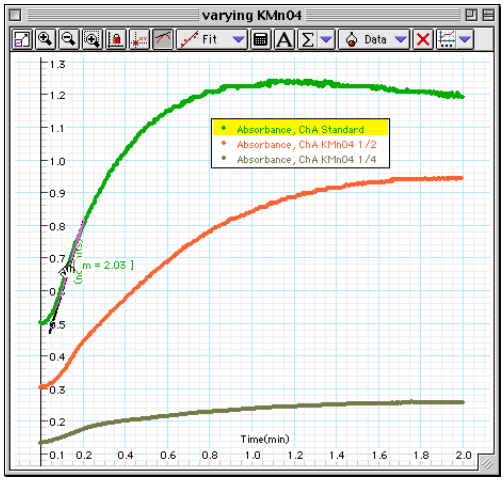
) to start the Colorimeter.
4. Start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
5. Record data for about 135 seconds and then stop recording data.
6. Press the 'Start/Stop' button (

) to stop the Colorimeter. Empty and rinse the cuvette with distilled water.
7. Repeat the procedure for trials 5 and 6 using the amounts of reactants shown above. Remember to add the $KMnO_4$ last.

- You will have <u>three</u> more runs of data at the end of the data recording for Part IIIB.

Analyzing the Data in *DataStudio*

Use the analysis tools in the Graph display to determine the rate of reaction for each solution. A procedure for doing this is as follows:



1. Select the run to analyze.
2. Click the 'Slope Tool' button ().

- The 'Slope Tool' shows the slope of a line tangent to any point on the plot of data.

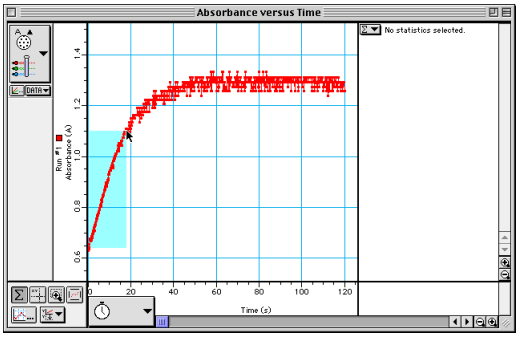
3. Use the cursor to move the tool to a point near the beginning the plot where the absorbance is changing.
4. Record the value of the slope ('m') as the rate of the reaction.

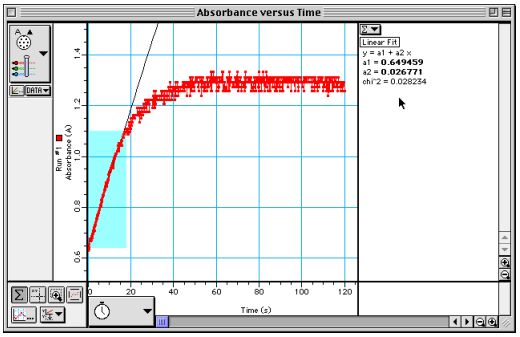
Repeat the process for each run of data.

Analyzing the Data in *ScienceWorkshop*

Use the analysis tools in the Graph display to determine the rate of reaction for each solution. A procedure for doing this is as follows:

1. Select the run to analyze.
2. Click the 'Statistics' button () to open the statistics area. Rescale the display to fit the data.
3. Use the cursor to select a region near the beginning the plot where the absorbance is changing.
4. Click the 'Statistics menu' button () and select 'Curve Fit, Linear Fit' from the menu.





5. Record the value of **a2** as the rate of reaction.

Repeat the process for each run of data.

Record your results in the Lab Report section.

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Lab Report - Activity C16: A Pseudo First Order Reaction

What Do You Think?

How will changing the concentrations of the reactants affect the rate of a chemical reaction?

Data Table

Trial #	Variable	Amount (mL)	Rate (slope)
1	Potassium permanganate ($KmnO_4$)	0.8	
2	Potassium permanganate ($KmnO_4$)	0.4	
3	Potassium permanganate ($KmnO_4$)	0.2	
4	Ethanol	0.8	
5	Ethanol	0.4	
6	Ethanol	0.2	
7	Hydrochloric acid (HCl)	0.8	
8	Hydrochloric acid (HCl)	0.4	
9	Hydrochloric acid (HCl)	0.2	

Questions

1. What is the effect of varying the concentration of each of the reactants?

2. Which of the reactants effected the rate of reaction the most?

3. Using the information in the Data Table determine the order of each reactant and then determine the overall rate of the reaction.

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Activity C17: Another Pseudo First Order Reaction (Colorimeter)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Rate of reactions	C17 Pseudo 2.DS	C18 Pseudo 2	C18_PSE2.SWS

Equipment Needed	**Qty**	**Chemicals and Consumables**	**Qty**
Colorimeter (CI-6747)	1	Hydrochloric acid, 3 molar	20 mL
Cuvette (w/sensor)	1	Potassium permanganate, 0.001 molar	20 mL
Graduated cylinder	1	Sodium oxalate, 0.1 molar	20 mL
Pipette, 1 mL	4	Water, distilled	200 mL
Protective gear	PS		

What Do You Think?

How will changing the concentrations of the reactants affect the rate of a chemical reaction?

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

Background

The rate of a chemical reaction depends on the temperature, pressure and other physical characteristics of the reaction surroundings. The first consideration a chemist gives to a chemical reaction however, is the concentration of the reactants. High concentrations of chemical reactants insure that molecules have the greatest opportunity to for successful collisions.

Chemists often change the concentration of reactants so that they can study the effect the change has on the rate of the reaction. For example, consider the reaction of permanganate ion (MnO_4^-), in an acidic solution with oxalate ion to form carbon dioxide. The balanced equation for this reaction is given below.

$$5\ C_2O_4^{2-} + 2\ MnO_4^- + 16\ H^+ \Longrightarrow 10\ CO_2 + 2\ Mn^{2+} + 8\ H_2O$$

Five moles of oxalate ion are needed to react with two moles of permanganate ion to form ten moles of carbon dioxide and two moles of the manganous ion (Mn^{2+}). If the concentration of oxalate ion and acid are raised to a high level relative to the permanganate concentration, the kinetics of the disappearance of the permanganate ion can be studied. In a similar manner, if the concentration of the hydrogen ion is raised above the stoichiometric requirement of the reaction, then the interaction of the other two reactants can be studied. Each participant in the reaction can be studied in turn using this technique. The method is a pseudo first order reaction because the kinetics of the single reactant can be studied as if the concentration were first order while the other reactants are held almost constant because their concentration is so large relative to the species being studied.

The Colorimeter measures the change in absorbance of light caused by the disappearance of the permanganate ion as it is consumed by the reaction.

SAFETY REMINDERS

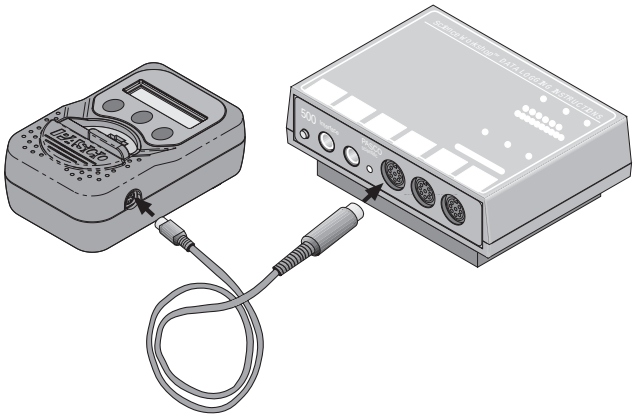
- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

CAUTION: Never pipette by mouth. Always use a pipette bulb or a pipette pump. Be careful when handling any acid or base solutions.

For You To Do

Use the Colorimeter to measure the change in absorbance of light by a solution of hydrochloric acid, sodium oxalate, and potassium permangante as the three components react. Begin with a mixture with specific concentrations of the three components, and then test mixtures with different concentrations of one component or the other. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use the data to determine the overall order of the rate of reaction.

PART I: Computer Setup



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

- The sensor's connector cable has a mini-DIN plug at one end and a regular DIN plug at the other.

2. Plug the mini-DIN end of the cable into the sensor and then connect the other end of the cable into Analog Channel A on the interface.

- The Colorimeter will automatically turn itself on when it is connected to the *ScienceWorkshop* interface.

3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C17 Pseudo 2.DS	C18 Pseudo 2	C18_PSE2.SWS

- The *DataStudio* file has a Graph display. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display with absorbance of light versus time.
- Data recording is set at ten measurements per second (10 Hz).

PART II: Sensor Calibration and Equipment Setup

About the Colorimeter

The Colorimeter analyzes colors of light that pass through a solution. The solution is put into a rectangular container called a cuvette, which is then placed inside the Colorimeter. The measure of the amount of light that passes through a solution is called "transmittance". Transmittance is a ratio of the intensity of the transmitted light to the intensity of the original light, and is usually expressed as a percentage.

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Absorbance is related to transmittance. The light absorbed by a solution depends on the absorbing ability of the solution, the distance traveled by the light through the solution, and the concentration of the solution. The relationship of absorbance to transmittance is: $A = 2 - \log\%T$

Calibration

The general method for calibrating the Colorimeter is as follows:

- **First**, calibrate the Colorimeter with a clear cuvette containing distilled water.
- **Second**, calibrate the software (either *DataStudio* or *ScienceWorkshop*) for one of the four colors of light that can be selected in the Colorimeter. (For this activity you will use the RED wavelength.)

Note: The cuvette has two clear sides and two ridged sides.

- All cuvettes should be wiped clean and dry on the outside with a tissue.
- Handle cuvettes only by the top edge of the ridged sides.
- All solutions should be free of bubbles.
- Always position the cuvette so the light beam will pass through the clear sides.

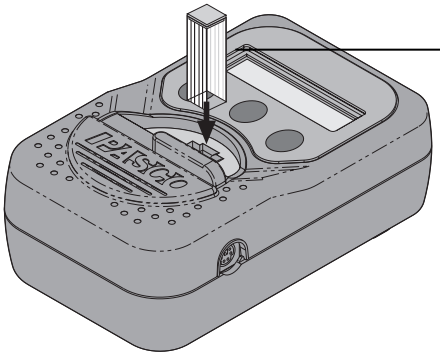
Calibrate the Colorimeter

When the Colorimeter comes on, the liquid crystal display (LCD) should say "Please calibrate".

To calibrate the Colorimeter with a clear cuvette, fill a clean cuvette with distilled water and cap the cuvette. (The clear cuvette is a control or 'reference' that accounts for the small amount of light scattered or reflected by the walls of the cuvette.)

On the Colorimeter, press the 'Select' button (Select) and the 'Start/Stop' button (Start/Stop) at the same time.

The Colorimeter's LCD will say "Insert reference then push SELECT".



Clear sides aligned with light path.

Place the closed cuvette inside the Colorimeter. Make sure that the clear sides of the cuvette (without ridges) are lined up with the light path in the Colorimeter. Close the lid on the Colorimeter.

On the Colorimeter, press the 'Select' button.

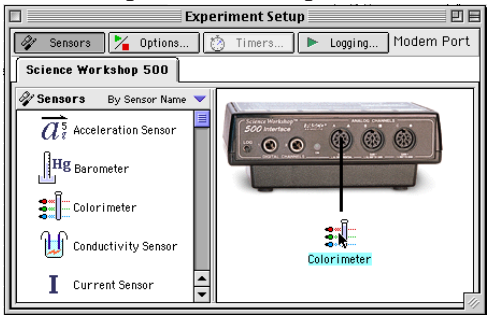
The Colorimeter will *automatically* calibrate itself for all four wavelengths assuming that the light passing through the clear cuvette represents "100% Transmittance". (The automatic calibration takes only a few seconds.)

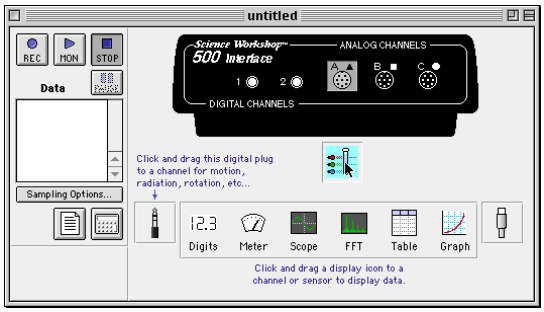
The Colorimeter's LCD will say "CAL done, push SELECT or START".

Calibrate the Software

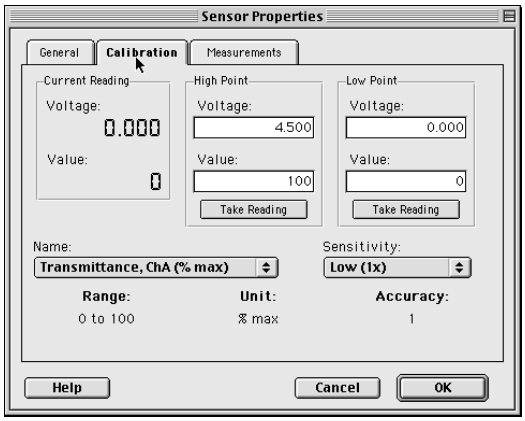
Follow these steps to calibrate the software for one of the four colors of light:

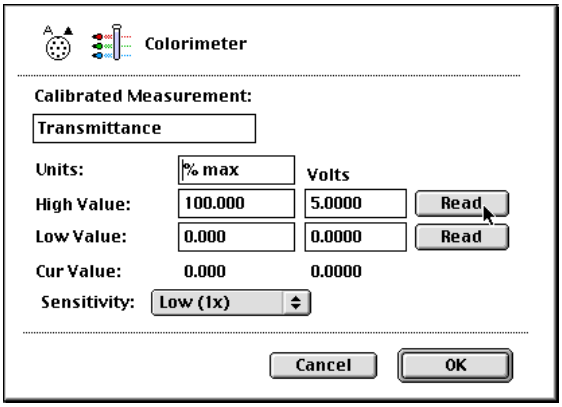
1. Leave the cuvette with distilled water inside the Colorimeter.
2. In the Experiment Setup window, double-click the Colorimeter icon.





- In *DataStudio*, the Sensor Properties window will open. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window will open.





3. Select the color of light.

• NOTE: The default color is RED, so you do not need to change the selection for this activity.

4. Calibrate the software.

- **First**, press the 'Start/Stop' button (Start/Stop) to start the Colorimeter. (The LCD shows the color and wavelength, the percent transmittance, and "RUN".)
- **Second**, check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*.
- **Third**, 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*.
- **Fourth**, press the 'Start/Stop' button to stop the Colorimeter. (The LCD changes to "STOP".)

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

- The software is now calibrated for the Colorimeter.

Equipment Setup

When the reactants are mixed, the solution gradually becomes light. In other words, the solution absorbs less and less light so absorbance goes down.

You will test how each of the three substances effects the rate of reaction. You will vary the concentration of one reactant at a time by diluting it with distilled water.

Use the following protocol in each test:

1. Add the specified amount of distilled water to the cuvette.
2. Add the specified amount of sodium oxalate to the cuvette.
3. Add the specified amount of hydrochloric acid to the cuvette.
4. Add the specified amount of potassium permanganate to the cuvette LAST and quickly cap the cuvette.
5. Quickly invert the cuvette to mix the components.
6. Quickly put the cuvette into the Colorimeter.
7. Start the Colorimeter, record data, and then stop the Colorimeter
8. Remove the cuvette, discard the solution, and rinse the cuvette thoroughly.

PART IIIA: Data Recording - Vary the Concentration of Permanganate Ion

You will test three solutions made up of different amounts of the reactants as follows:

Table IIIA: Vary the Concentration of Permanganate Ion

Trial #	Water	Sodium oxalate, 0.1 M	HCl, 3 M	Potassium permanganate, 0.001 M
1	1.0 mL	1.0 mL	1.0 mL	1.0 mL
2	1.5 mL	1.0 mL	1.0 mL	0.5 mL

1. When you are ready to begin data recording, place distilled water, sodium oxalate, and hydrochloric acid in the cuvette in the amounts specified.
2. Add the specified amount of potassium permanganate LAST. Quickly cap the cuvette, mix, and put the cuvette into the Colorimeter. Close the Colorimeter lid.
3. Press the 'Start/Stop' button (

) to start the Colorimeter.
4. Start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
5. Record data for about 4 minutes (240 seconds) and then stop recording data.
6. Press the 'Start/Stop' button (

) to stop the Colorimeter. Empty and rinse the cuvette with distilled water.
7. Repeat the procedure for trial 2 using the amounts of reactants shown above. Remember to add the $KMnO_4$ last.

- You will have <u>two</u> runs of data at the end of the data recording for Part IIIA.

PART IIIB: Data Recording - Vary the Concentration of Oxalate Ion

Dilute a small amount of the sodium oxalate from 0.1 molar to 0.001 molar. Use the pipette to put 1 mL of 0.1 M sodium oxalate into a 100-mL graduated cylinder. Add distilled water to the cylinder until the volume is 100 mL.

Table IIIB: Vary the Concentration of Oxalate Ion

Trial #	Water	Sodium oxalate, 0.001 M	HCl, 3 M	Potassium permanganate, 0.001 M
3	None	2.0 mL	1.0 mL	1.0 mL
4	1.0 mL	1.0 mL	1.0 mL	1.0 mL

1. When you are ready to begin data recording for Part IIIB, place distilled water, sodium oxalate (0.001 M), and hydrochloric acid in the cuvette in the amounts specified.
2. Add the specified amount of potassium permanganate LAST. Quickly cap the cuvette, mix, and put the cuvette into the Colorimeter. Close the Colorimeter lid.
3. Press the 'Start/Stop' button (

) to start the Colorimeter.
4. Start recording data.
5. Record data for about 4 minutes (240 seconds) and then stop recording data.
6. Press the 'Start/Stop' button (

) to stop the Colorimeter. Empty and rinse the cuvette with distilled water.
7. Repeat the procedure for trial 4 using the amounts of reactants shown above. Remember to add the $KMnO_4$ last.

- You will have four runs of data at the end of the data recording for Part IIIA.

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PART IIIC: Data Recording - Vary the Concentration of Hydrochloric Acid

Dilute a small amount of the hydrochloric acid from 3 molar to 0.3 molar. Put 9 mL of distilled water into a graduated cylinder. Use a pipette to add 1 mL of 3 M hydrochloric acid into the water. Add distilled water to bring the total volume to 10 mL.

Table IIIB: Vary the Concentration of Oxalate Ion

Trial #	Water	Sodium oxalate, 0.1 M	HCl, 0.3 M	Potassium permanganate, 0.001 M
3	None	1.0 mL	2.0 mL	1.0 mL
4	1.0 mL	1.0 mL	1.0 mL	1.0 mL

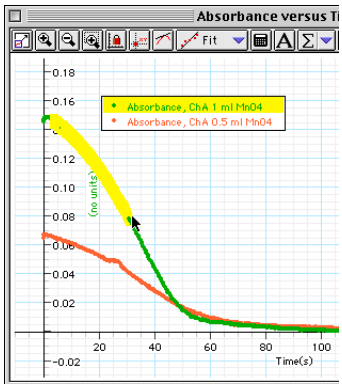
1. When you are ready to begin data recording for Part IIIB, place distilled water, sodium oxalate (0.1 M), and hydrochloric acid (0.3 M) in the cuvette in the amounts specified.
2. Add the specified amount of potassium permanganate LAST. Quickly cap the cuvette, mix, and put the cuvette into the Colorimeter. Close the Colorimeter lid.
3. Press the 'Start/Stop' button (

) to start the Colorimeter.
4. Start recording data.
5. Record data for about 4 minutes (240 seconds) and then stop recording data.
6. Press the 'Start/Stop' button (

) to stop the Colorimeter. Empty and rinse the cuvette with distilled water.
7. Repeat the procedure for trial 6 using the amounts of reactants shown above. Remember to add the $KMnO_4$ last.

Analyzing the Data in *DataStudio*

Use the analysis tools in the Graph display to determine the rate of reaction for each solution. A procedure for doing this is as follows:

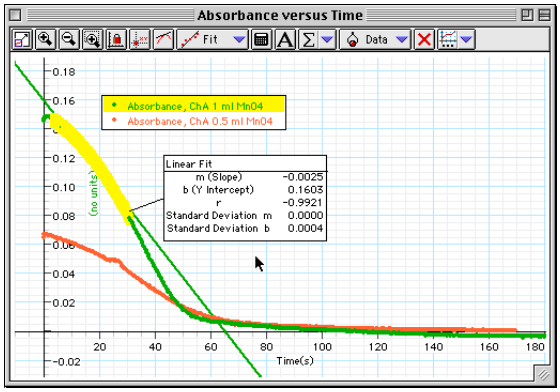


1. Select the run to analyze.
2. Use the cursor to select a region near the beginning the plot where the absorbance is changing.
3. Select 'Linear' from the 'Fit' menu.
4. Record the value of the slope ('m') as the rate of the reaction.

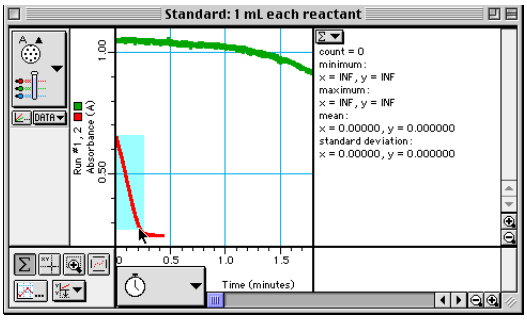
Repeat the process for each run of data.

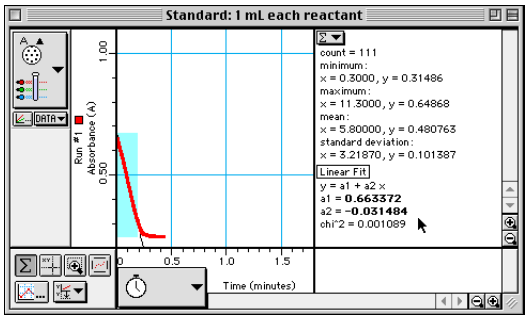
Analyzing the Data in *ScienceWorkshop*

Use the analysis tools in the Graph display to determine the rate of reaction for each solution. A procedure for doing this is as follows:



1. Select the run to analyze.
2. Click the 'Statistics' button (Σ) to open the statistics area. Rescale the display to fit the data.
3. Use the cursor to select a region near the beginning the plot where the absorbance is changing.
4. Click the 'Statistics menu' button (Σ▼) and select 'Curve Fit, Linear Fit' from the menu.
5. Record the value of **a2** as the rate of reaction.





Repeat the process for each run of data.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C17: Another Pseudo First Order Reaction

What Do You Think?

How will changing the concentrations of the reactants affect the rate of a chemical reaction?

Data Table

Trial #	Variable	Amount (mL)	Rate (slope)
1	Potassium permanganate (0.001 M)	1.0	
2	Potassium permanganate (0.001 M)	0.5	
3	Sodium oxalate (0.001 M)	2.0	
4	Sodium oxalate (0.001 M)	1.0	
5	Hydrochloric acid (0.3 M)	2.0	
6	Hydrochloric acid (0.3 M)	1.0	

Questions

1. What is the effect of varying the concentration of each of the reactants?

2. Which of the reactants effected the rate of reaction the most?

3. Using the information in the Data Table determine the order of each reactant and then determine the overall rate of the reaction.

Name _____ Class _____ Date _____

Activity C18: Chemical Equilibrium (Pressure Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Rate of reactions	C18 Equilibrium.DS	C19 Chemical Equilibrium	C19_CHEM.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Pressure Sensor (CI-6532A)	1	**Tubing (w/sensor)**	1
Connector, rubber stopper (w/sensor)	1	Protective gear	PS
Coupling, quick release (w/sensor)	1	**Chemicals and Consumables**	**Qty**
Flask, 250 mL	1	Glycerin	1 mL
Graduated cylinder	1	Soda water, cold	100 mL
Rubber stopper, one-hole	1	Soda water, warm	100 mL

What Do You Think?

How will the temperature of club soda affect the rate at which equilibrium is established?

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

Background

The process of chemical equilibrium is dynamic. The term dynamic means that even though no macroscopic chemical changes are noticeable, microscopic chemical changes are occurring constantly.

For any chemical reaction, the reactants combine with each other to form products. A general reaction could be written:

A + B ======> C

The equation states that chemical A reacts with chemical B at a set rate to produce C. This is a kinetic reaction which proceeds in only one direction. This is not a system in equilibrium.

But chemical C decomposes at another rate to reform chemicals A and B. This is also not a system in equilibrium.

C ======> B + A

When the two reactions are combined and the rate of the forward reaction equals the rate of the reverse reaction the two opposing reactions are said to be at equilibrium.

A <======> B + C

Carbonic acid decomposes to form carbon dioxide and water in the following equilibrium system:

$$H_2CO_{3(aq)} \;<=======>\; CO_{2(g)} + H_2O_{(aq)}$$

carbonic acid carbon dioxide water

The carbon dioxide then reacts with water to reform carbonic acid. The forward reaction occurs every time you open a soda bottle or pour soda into a glass. The carbonic acid decomposes to form the fizz that we associate with most soft drinks.

When you cap the bottle, the carbon dioxide gas begins to re-dissolve in the soda water to reform carbonic acid. Once the rate of the forward decomposition equals the rate of reformation of carbonic acid, the system has reached chemical and physical equilibrium. The reactions still occur at the microscopic level but there is no evidence of any macroscopic change. You will know when the carbonic acid/carbon dioxide system has reached equilibrium when there is no further change in the pressure in the soda bottle.

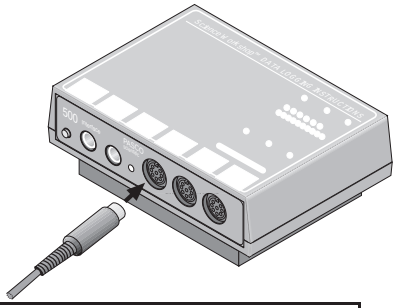
SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

For You To Do

Use the Pressure Sensor to measure the change in pressure inside a rigid container as a small amount of soda water decomposes. Use DataStudio or ScienceWorkshop to record and display the data. Compare the data collected for cold soda water to the data collected for warm soda 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 Pressure Sensor's DIN plug into Analog Channel A on the interface.
3. Open the file titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C18 Equilibrium.DS	C19 Chemical Equilibrium	C19_CHEM.SWS

- The *DataStudio* file has a Graph display of pressure versus time. Read the instructions in the Workbook display.
- The *ScienceWorkshop* document has a Graph display of pressure versus time.
- Data recording is set for one measurement per second.

Name _____ Class _____ Date _____

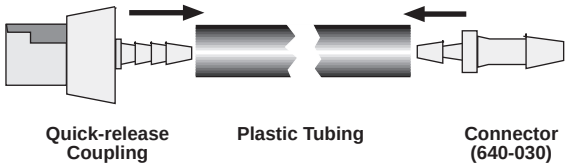
PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensor.

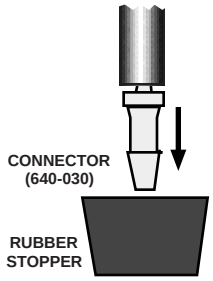
Set Up the Equipment

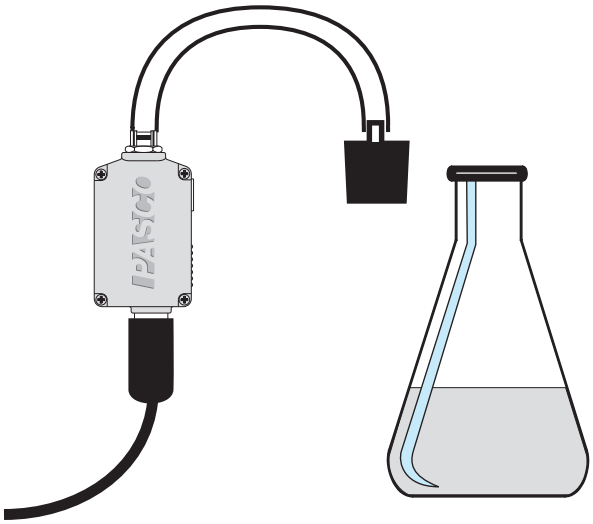
- For this part you will need the following: glycerin, quick-release coupling, connector, plastic tubing, rubber stopper, flask, graduated cylinder, and warm (room temperature) soda water.

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.



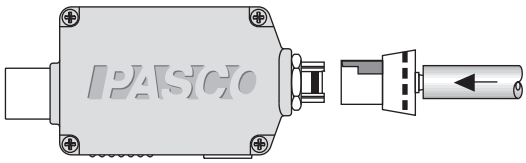
2. Put a drop of glycerin on the barb end of the connector. Push the barb end of the connector into the other end of the plastic tubing.
3. Fit the end of the connector into the one-hole rubber stopper.
4. Put 100 mL of warm (room temperature) soda water in the flask.





PART IIIA: Data Recording – Warm Soda Water

1. Put the rubber stopper firmly into the top of the flask.
2. 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).



3. When everything is ready, begin data recording. (Hint: Click 'Start' in *DataStudio* or 'REC' in *ScienceWorkshop*.)

What do you predict the graph of pressure versus time will look like?

- Observe the change in pressure as the carbonic acid decomposes in the flask.

4. Continue collecting data for about 6 minutes and then stop recording data.
5. Slowly remove the rubber stopper from the bottle. Disconnect the quick-release coupling from the Pressure Sensor.
6. Dispose of the soda water. Rinse the flask with cold water.

PART IIIB: Data Recording – Cold Soda Water

1. Put 100 mL of cold soda water in the flask. Put the rubber stopper firmly into the top of the flask.
2. 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).
3. When everything is ready, begin data recording.

How will the graph of the cold soda water differ from the graph of the room temperature soda water?

4. Continue collecting data for about 6 minutes and then stop recording data.
5. Slowly remove the rubber stopper from the bottle. Disconnect the quick-release coupling from the Pressure Sensor.
6. Dispose of the soda water. Rinse the flask.

Name _____ Class _____ Date _____

Analyzing the Data

1. Use the built-in statistics tools in the Graph display to find the minimum and maximum values for pressure for each run of data.

- Hint: In *DataStudio*, click the 'Statistics menu' button () in the display toolbar. The legend in the Graph display will show the minimum and maximum pressure.

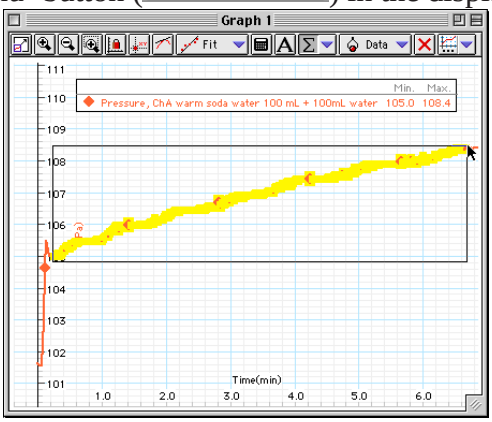
- Hint: In *ScienceWorkshop*, click the 'Statistics' button () to open the statistics area. Click the 'Statistics menu' button () in the statistics area and select Minimum and Maximum from the menu.

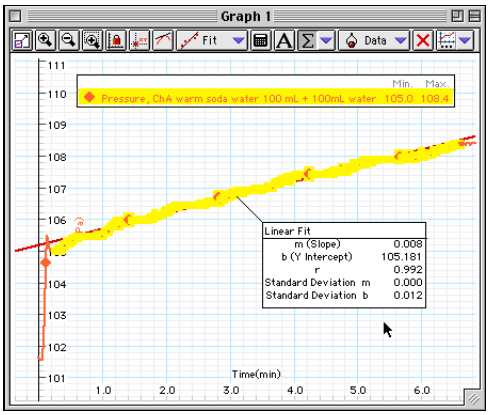
2. Record the values in the Lab Report section.

3. Use the built-in analysis tools in the Graph display to find the slope of the pressure versus time.

- Hint: In *DataStudio*, use the cursor to select a region of the plot of pressure. Click the 'Fit menu' button (

) in the display toolbar and select 'Linear' from the menu.





- Hint: In *ScienceWorkshop*, use the cursor to select a region of the plot of pressure. Click the 'Statistics menu' button in the statistics area and select 'Curve Fit, Linear Fit' from the menu.

4. Record the slope of each run of data as the rate of decomposition.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C18: Chemical Equilibrium

What Do You Think?

How will the temperature of club soda affect the rate at which equilibrium is established?

Data Table

Trial	Pressure (maximum)	Pressure (minimum)	Slope
Warm soda water	kPa	kPa	
Cold soda water	kPa	kPa	

Questions

1. Is there a difference in the rate to reach equilibrium?

2. What is the relationship of temperature to the rate to reach equilibrium?

3. Explain what is happening on a molecular level.

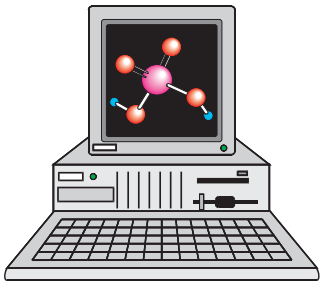
Name _____ Class _____ Date _____

Activity C19: Determine the Equilibrium Constant, K_c, of a Reaction (Colorimeter)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Rates of reaction	C19 Kc Constant.DS	See appendix.	See appendix.

Equipment Needed	**Qty**	**Chemicals and Consumables**	**Qty**
Colorimeter (CI-6747)	1	Iron nitrate, $Fe(NO_3)_3$, 0.200 molar	20 mL
Beaker, 100-mL	3	Iron nitrate, $Fe(NO_3)_3$, 0.002molar	30 mL
Cuvette (w/sensor)	1	Label	5
Pipette, 10 mL, with pipette bulb or pump	4	Potassium thiocyanate, KSCN, 0.002 M	25 mL
Stirring rod	1	Tissue	4
Test tube, 20 by 150 mm	5	Water, distilled	30 mL
Test tube rack	1		
Thermometer (SE-9084)	1		
Protective gear	PS		

What Do You Think?



In some chemical reactions the amounts of products formed can be calculated when the amounts of reactants are known, assuming that the reaction goes to completion so that one of the reactants is used up. However, many reactions to not go to completion. Instead, they reach an equilibrium state in which both reactants and products are present. The ratio of the concentrations of reactants to products at a given temperature is the equilibrium constant, K_c. The equilibrium constant allows the calculation of amounts of substances present at equilibrium. How can a Colorimeter be used to determine the equilibrium constant of a chemical reaction?

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

Background

When iron ions (Fe^{3+}) and thiocyanate ions (SCN^-) are combined, equilibrium is established between these two ions and the thiocyanoiron ion ($FeSCN^{2+}$).

$$Fe^{3+}(aq) + SCN^-(aq) \Leftrightarrow FeSCN^{2+}(aq)$$

In order to calculate K_c for the reaction, you need to know the concentrations of all ions at equilibrium: $[FeSCN^{2+}]_{eq}$, $[SCN^-]_{eq}$, and $[Fe^{3+}]_{eq}$. (Note: The square brackets [] around a reactant or product indicates its concentration in moles per liter.)

The $FeSCN^{2+}$ ion in solution produces a red color. The red solutions absorb blue light very well. A Colorimeter can measure the amount of blue light absorbed by the colored solutions. By comparing the absorbance, A_{eq}, of different equilibrium systems with unknown concentrations of thiocyanoiron ions to the absorbance, A_{std}, of a *standard* solution, you can use Beer's Law to determine the concentration of the thiocyanoiron ion $[FeSCN^{2+}]_{eq}$. Beer's Law describes the linear relationship between the absorbance and concentration for a solution. The standard solution has a known $FeSCN^{2+}$ concentration.

Assuming that the concentration of the thiocyanoiron ion ($FeSCN^{2+}$) and the absorbance are directly related (Beer's Law), the concentration of $FeSCN^{2+}$ for any of the equilibrium systems can be found by:

$$[FeSCN^{2+}]_{eq} = \frac{A_{eq}}{A_{std}} x [FeSCN^{2+}]_{std}$$

Knowing the $[FeSCN^{2+}]_{eq}$ allows you to determine the concentrations of the other two ions at equilibrium. Because the ratio of coefficients in the reaction equation are one-to-one, for each mole of $FeSCN^{2+}$ ions produced, one less mole of Fe^{3+} ions remain in the solution.

The $[Fe^{3+}]$ can be determined by:

$$[Fe^{3+}]_{eq} = [Fe^{3+}]_i - [FeSCN^{2+}]_{eq}$$

Because one mole of SCN^- is used up for each mole of $FeSCN^{2+}$ ions produced, $[SCN^-]_{eq}$ can be determined by:

$$[SCN^-]_{eq} = [SCN^-]_i - [FeSCN^{2+}]_{eq}$$

You can calculate the value of K_c, the equilibrium constant from the values of $[Fe^{3+}]_{eq}$, $[SCN^-]_{eq}$, and $[FeSCN^{2+}]_{eq}$.

SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

CAUTION: Never pipette by mouth. Always use a pipette bulb or a pipette pump. Be careful when handling any acid or base solutions.

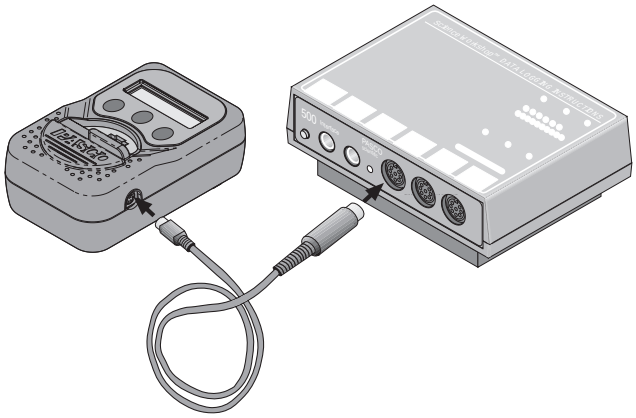
For You To Do

Prepare four solutions with different concentrations of the three ions (Fe^{3+}, SCN^- and $FeSCN^{2+}$). Also prepare a *standard* solution of thiocyanoiron ($FeSCN^{2+}$). Use the Colorimeter to measure the absorbance of each of the four solutions and also the absorbance of the standard solution. Use *DataStudio* or *ScienceWorkshop* to record and display the data.

Use the absorbance and concentration of the standard solution to calculate the equilibrium concentrations of the other four solutions. Calculate the equilibrium concentrations of each of the ions. Use these values concentration values and the ratio for the equilibrium constant expression to calculate K_c.

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 Colorimeter cable to Analog Channel A on the interface.

- The Colorimeter will automatically turn itself on when it is connected to the *ScienceWorkshop* interface.

3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C19 Kc Constant.DS	See appendix.	See appendix.

- The *DataStudio* file has a Digits display and a Table display of absorbance. Read the Workbook display for more information.
- See the appendix for instructions on creating a *ScienceWorkshop* document for this activity.
- Data recording is set at ten measurements per second (10 Hz). Data recording is also set so that you can manually enter the number of each solution.

PART II: Sensor Calibration and Equipment Setup

About the Colorimeter

The Colorimeter analyzes colors of light that pass through a solution. The solution is put into a rectangular container called a cuvette, which is then placed inside the Colorimeter. The measure of the amount of light that passes through a solution is called “transmittance”. Transmittance is a ratio of the intensity of the transmitted light to the intensity of the original light, and is usually expressed as a percentage.

Absorbance is related to transmittance. The light absorbed by a solution depends on the absorbing ability of the solution, the distance traveled by the light through the solution, and the concentration of the solution. The relationship of absorbance to transmittance is: $A = 2 - \log \%T$

Calibration

The general method for calibrating the Colorimeter is as follows:

- First, calibrate the Colorimeter with a clear cuvette containing distilled water.
- Second, calibrate the software (either *DataStudio* or *ScienceWorkshop*) for one of the four colors of light that can be selected in the Colorimeter. (For this activity you will use the BLUE wavelength.)

Note: The cuvette has two clear sides and two ridged sides.

- All cuvettes should be wiped clean and dry on the outside with a tissue.
- Handle cuvettes only by the top edge of the ridged sides.
- All solutions should be free of bubbles.
- Always position the cuvette so the light beam will pass through the clear sides.

Calibrate the Colorimeter

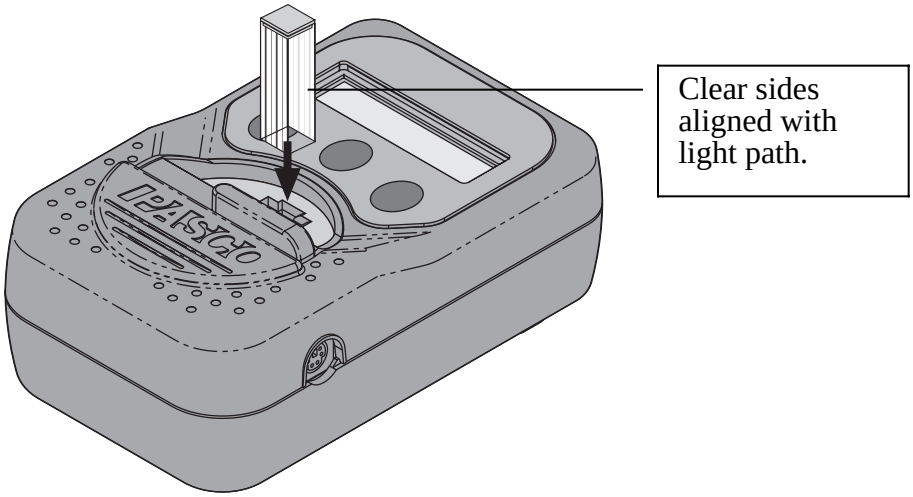
When the Colorimeter comes on, the liquid crystal display (LCD) should say "Please calibrate".

To calibrate the Colorimeter with a clear cuvette, fill a clean cuvette with distilled water and cap the cuvette. (The clear cuvette is a control or 'reference' that accounts for the small amount of light scattered or reflected by the walls of the cuvette.)

On the Colorimeter, press the 'Select' button (Select) and the 'Start/Stop' button (Start Stop) at the same time.

The Colorimeter's LCD will say "Insert reference then push SELECT".

Place the closed cuvette inside the Colorimeter. Make sure that the clear sides of the cuvette (without ridges) are lined up with the light path in the Colorimeter. Close the lid on the Colorimeter.



On the Colorimeter, press the 'Select' button.

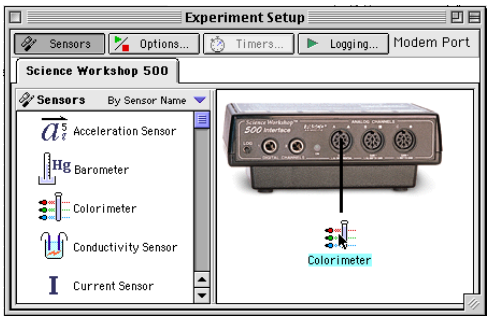
The Colorimeter will *automatically* calibrate itself for all four wavelengths assuming that the light passing through the clear cuvette represents "100% Transmittance". (The automatic calibration takes only a few seconds.)

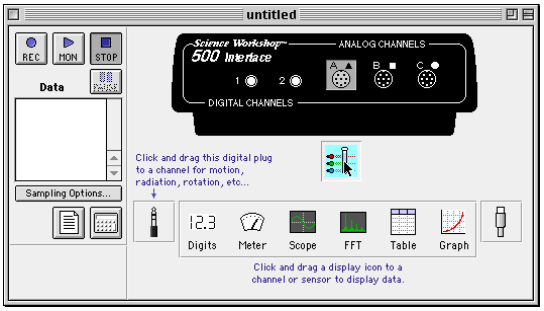
The Colorimeter's LCD will say "CAL done, push SELECT or START".

Calibrate the Software

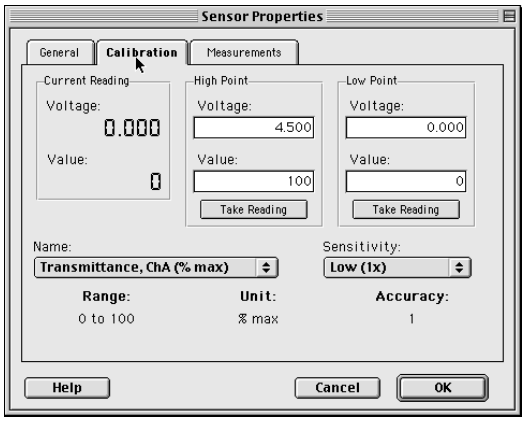
Follow these steps to calibrate the software for one of the four colors of light:

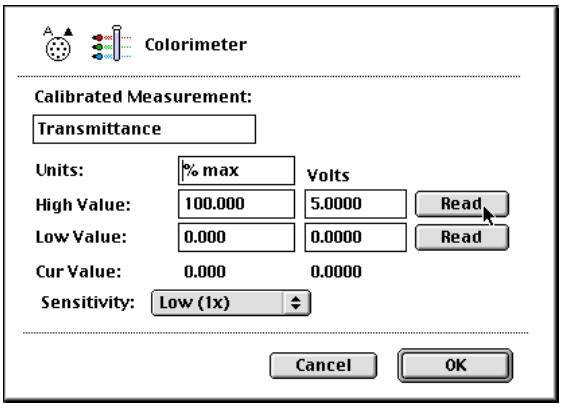
1. Leave the cuvette with distilled water inside the Colorimeter.
2. In the Experiment Setup window, double-click the Colorimeter icon.





- In *DataStudio*, the Sensor Properties window will open. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window will open.





3. Select the color of light. Use BLUE light for this activity.

Press the 'Select' button until the LCD shows "Blue 460 nm".

4. Calibrate the software.

- **First**, press the 'Start/Stop' button (Start Stop) to start the Colorimeter. (The LCD shows the color and wavelength, the percent transmittance, and "RUN".)
- **Second**, check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*.
- **Third**, 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*.
- **Fourth**, press the 'Start/Stop' button to stop the Colorimeter. (The LCD changes to "STOP".)

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

- The software is now calibrated for the Colorimeter.

Equipment Setup

SAFETY CAUTION! Be sure to wear protective gear (splash shield, gloves, apron or lab coat). The iron nitrate solutions used in this activity were prepared in 1 molar nitric acid. Handle these and all chemicals with extreme care. Use a pipette with a pipette bulb or a pipette pump to pipette the chemicals. *Do Not Pipette By Mouth!*

Prepare the Solutions

- For this part you need the following: test tubes (4), labels (4), 100-mL beakers (3), pipettes (4), stir rod, 25 mL of 0.002 M iron nitrate ($Fe(NO_3)_3$), 30 mL of 0.002 M potassium thiocyanate (KSCN), 30 mL of distilled water.

1. Put labels on four clean, dry test tubes and mark them #1 through #4.
2. Put 30 mL of 0.002 iron nitrate ($Fe(NO_3)_3$ into a beaker. Use a pipette to put 5.0 mL of the solution into each of the four test tubes.
3. Put 30 mL of 0.002 potassium thiocyanate (KSCN) into a second beaker. Use a pipette to put 2 mL into Test Tube #1, 3 mL into Test Tube #2, 4 mL into Test Tube #3, and 5 mL into Test Tube #4.
4. Put about 25 mL of distilled water into a third beaker. Use a pipette to put 3 mL into Test Tube #1, 2 mL into Test Tube #2, and 1 mL into Test Tube #3. (Note: Don't add any distilled water to Test Tube #4.)

- The summary of components in the test tubes is as follows:

Test Tube	$Fe(NO_3)_3$ mL	KSCN mL	H_2O mL
1	5	2	3
2	5	3	2
3	5	4	1
4	5	5	none

5. Use a stir rod to mix the contents of each test tube thoroughly. Note: Be sure to rinse and dry the stir rod after you stir each test tube.
6. Use the thermometer to measure the temperature of one of the solutions. Record the temperature in the Lab Report section.

Prepare the Standard Thiocyanoiron Solution

To prepare the standard $FeSCN^{2+}$ solution, add a large concentration of Fe^{3+} ions to a relatively small concentration of SCN^- ions. The concentration of Fe^{3+} ions is so large that nearly all the SCN^- ions will be used up. Therefore, for every mole of SCN^- ions reacted, one mole of $FeSCN^{2+}$ is produced. The concentration of the standard thiocyanoiron solution will be the same as the initial concentration of the SCN^- ions.

- For this part you need a test tube, a label, a pipette, 18 mL of 0.200 M $Fe(NO_3)_3$, 2 mL of 0.002 M KSCN, and a stir rod.

1. Put the label on the test tube and mark it #5
2. Use the pipette to put 18 mL of 0.200 M $Fe(NO_3)_3$ into the test tube.
3. Add 2 mL of 0.002 M KSCN to the same test tube and use the stir rod to mix thoroughly.

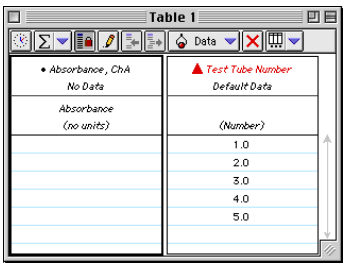
Name _____ Class _____ Date _____

PART III: Data Recording - *DataStudio*

- (Note: See the appendix for data recording using *ScienceWorkshop*.)

1. Empty the water from the cuvette used during calibration. Using the solution in Test Tube #1, rinse the cuvette twice with approximately 1 mL amounts of solution from the test tube, and then fill the cuvette with solution. Cap the cuvette.
2. Wipe the outside of the cuvette with a tissue and place the cuvette in the Colorimeter. Close the lid.
3. Arrange the Table display so you can see it clearly.
4. When everything is ready, press the 'Start/Stop' button (

) on the Colorimeter and then start recording data.



- The 'Start' button changes to a 'Keep' button (

). The Table display shows a column for Absorbance and a column for the numbers of each test tube.

5. When the Absorbance value stabilizes, click 'Keep' to record the Absorbance value for the sample from Test Tube #1.
6. Press the 'Start/Stop' button to stop the Colorimeter. Remove the cuvette from the Colorimeter and empty the cuvette. Rinse the cuvette carefully with distilled water. Empty the water from the cuvette.
7. Using the solution in Test Tube #2, rinse the cuvette twice with approximately 1 mL amounts and then fill the cuvette with solution from Test Tube #2. Cap the cuvette. Wipe the outside with a tissue and place the cuvette in the Colorimeter. Close the Colorimeter lid.
8. Press the 'Start/Stop' button to start the Colorimeter. When the Absorbance value stabilizes, click 'Keep' to record the new Absorbance value. Press the 'Start/Stop' button again to stop the Colorimeter.
9. Repeat the process to find the absorbance of the samples from Test Tubes #3, #4, and #5.
10. After you record the Absorbance for the last solution, stop recording data. Press the 'Start/Stop' button to stop the Colorimeter. Rinse the cuvette with distilled water.
11. Dispose of the solutions as directed.

Analyzing the Data – *DataStudio* and *ScienceWorkshop*

1. Record the absorbance data from the Table display into the Lab Report section.
2. Calculate the *initial* concentration of Fe^{3+}. The initial concentration, $[Fe^{3+}]_i$, is the amount of iron nitrate, $Fe(NO_3)_3$, in each test tube compared to the total volume in the test tube, multiplied by the concentration of the $Fe(NO_3)_3$.

$$[Fe^{3+}]_i = \frac{Fe(NO_3)_3\ mL}{total\ mL} \times (0.002\ M)$$

- Note: The initial concentration is the same for all four test tubes.

3. Calculate the *initial* concentration of SCN^- for each of the four samples. The initial concentration, $[SCN^-]$, is the amount of potassium thiocyanate, KSCN, in each test tube compared to the total volume in the test tube, multiplied by the concentration of the KSCN.

$$[SCN^-]_i = \frac{KSCN\ mL}{total\ mL} \times (0.002\ M)$$

For example, in Test Tube #1 the amount of KSCN is 2 ml and the total volume is 10 mL. The concentration of KSCN is 0.002 M.

$$[SCN^-]_i = \frac{2\ mL}{10\ mL} \times (0.002\ M) = 0.004\ M$$

4. Calculate the *equilibrium* concentration of $FeSCN^{2+}$ for each of the four samples. The equilibrium concentration is the ratio of the equilibrium absorbance to the standard absorbance multiplied by the concentration of the $FeSCN^{2+}$ in the standard solution.

$$[FeSCN^{2+}]_{eq} = \frac{A_{eq}}{A_{std}} \times [FeSCN^{2+}]_{std}$$

- Note: Remember that the concentration of the $FeSCN^{2+}$ in the standard solution is the same as the concentration of the SCN^- in the standard solution. Therefore, the concentration of the $FeSCN^{2+}$ standard is as follows:

$$[FeSCN^{2+}]_{std} = \frac{2\ ml}{20\ ml} \times (0.002) = 0.0002\ M$$

5. Calculate the *equilibrium* concentration of Fe^{3+} for each of the four samples. The equilibrium concentration is the initial concentration of Fe^{3+} minus the equilibrium concentration of $FeSCN^{2+}$.

$$[Fe^{3+}]_{eq} = [Fe^{3+}]_i - [FeSCN^{2+}]_{eq}$$

6. Calculate the *equilibrium* concentration of SCN^- for each of the four samples. The equilibrium concentration is the initial concentration of SCN^- minus the equilibrium concentration of $FeSCN^{2+}$.

$$[SCN^-]_{eq} = [SCN^-]_i - [FeSCN^{2+}]_{eq}$$

7. Calculate the equilibrium constant, Kc, for each of the four samples.

$$K_c = \frac{[FeSCN^{2+}]}{[Fe^{3+}][SCN^-]}$$

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C19: Determine the Equilibrium Constant, K_c, of a Reaction

What Do You Think?

In some chemical reactions the amounts of products formed can be calculated when the amounts of reactants are known, assuming that the reaction goes to completion so that one of the reactants is used up. However, many reactions to not go to completion. Instead, they reach an equilibrium state in which both reactants and products are present. The ratio of the concentrations of reactants to products at a given temperature is the equilibrium constant, Kc. The equilibrium constant allows the calculation of amounts of substances present at equilibrium. How can a Colorimeter be used to determine the equilibrium constant of a chemical reaction?

Data Table

Test Tube	#1	#2	#3	#4
Absorbance				

Absorbance of standard (Test Tube #5)	
Temperature	

Test Tube	#1	#2	#3	#4
$[Fe^{3+}]_i$				
$[SCN^-]_i$				
$[FeSCN^{2+}]_{eq}$				
$[Fe^{3+}]_{eq}$				
$[SCN^-]_{eq}$				
K_c				

Average K_c value	

Questions

1. What is the average value of the equilibrium constant, K_c, for the four samples?

2. How constant is the value of K_c for the four samples?

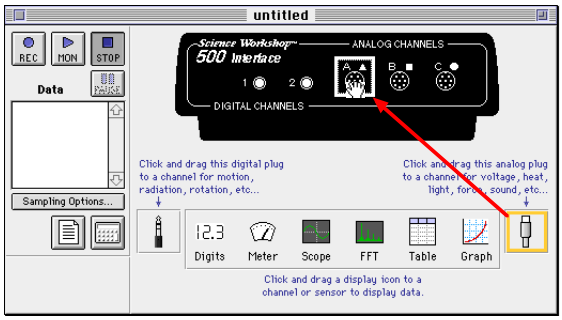
Name _____ Class _____ Date _____

Appendix: Set Up *ScienceWorkshop*

Create a *ScienceWorkshop* file to measure and display absorbance.

Set Up the Sensors

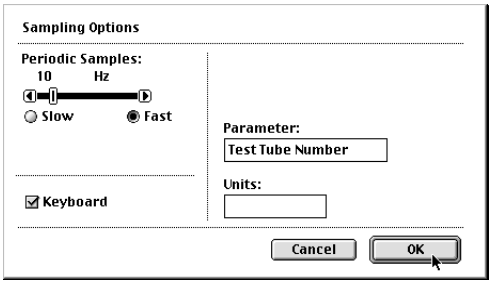
1. In the Experiment Setup window, click and drag the analog sensor plug to Channel A.



2. Select 'Colorimeter' from the list of sensors. Click 'OK' to return to the Experiment Setup window.

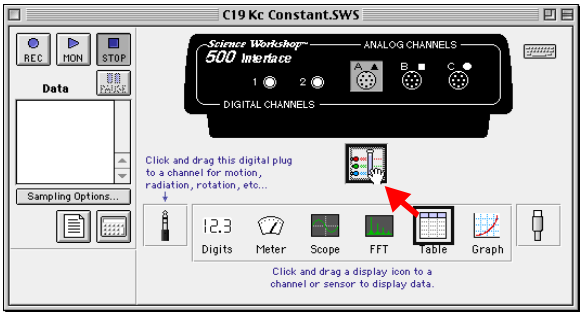
Set Up the Sampling Options

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 'Test Tube Number' as the Parameter. Leave 'Units' blank. Click 'OK' to return to the Experiment Setup window.

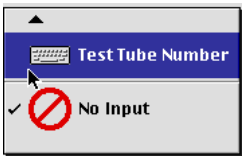


Set Up the Displays

1. In the Experiment Setup window, click and drag the Table display icon to the Colorimeter icon.



2. In the Table display, add a column for 'Test Tube Number'. Click the Add-a-Column menu button () and select 'Test Tube Number' from the list.
3. In the Experiment Setup window, click and drag the Digits display icon to the Colorimeter icon.

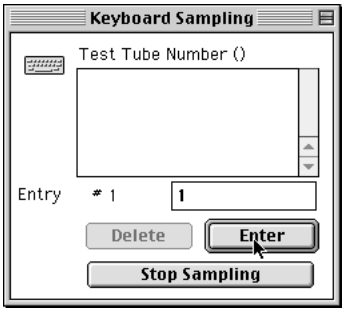


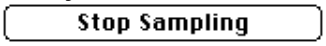
Record Data

1. Empty the water from the cuvette used during calibration. Using the solution in Test Tube #1, rinse the cuvette twice with approximately 1 mL amounts of solution from the test tube, and then fill the cuvette with solution. Cap the cuvette.
2. Wipe the outside of the cuvette with a tissue and place the cuvette in the Colorimeter. Close the lid.
3. When you are ready, press the 'Start/Stop' button (

) to start the Colorimeter. Click 'REC' to start recording data.

- The 'Keyboard Sampling' window will open. Arrange the windows so you can see the Digits display.



4. When the readings for Absorbance stabilize, type '1' in the Keyboard Sampling window and click 'Enter' to record the Absorbance for the first sample. Press the 'Start/Stop' button to stop the Colorimeter.
5. Remove the cuvette from the Colorimeter and empty the cuvette. Rinse the cuvette carefully with distilled water. Empty the water from the cuvette.
6. Using the solution in Test Tube #2, rinse the cuvette twice with approximately 1 mL amounts and then fill the cuvette with solution from Test Tube #2. Cap the cuvette. Wipe the outside with a tissue and place the cuvette in the Colorimeter. Close the Colorimeter lid.
7. Press the 'Start/Stop' button to start the Colorimeter. When the Absorbance value stabilizes, type '2' in the Keyboard Sampling window and click 'Enter' to record the new Absorbance value. Press the 'Start/Stop' button again to stop the Colorimeter.
8. Repeat the process to find the absorbance of the samples from Test Tubes #3, #4, and #5.
9. After you record the Absorbance for the last solution, click 'Stop Sampling' (

) to stop recording data. The Keyboard Sampling window will automatically close. Press the 'Start/Stop' button to stop the Colorimeter. Rinse the cuvette with distilled water.
10. Dispose of the solutions as directed.

Analyze the Data

See the 'Analyzing the Data' section.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Activity C20: Endothermic and Exothermic Reactions (Temperature Sensor)

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

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

What Do You Think?

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

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

Background

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

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

$$H_3C_6H_5O_7(aq) + 3\ NaHCO_3(s) \rightarrow 3\ CO_2(g) + 3\ H_2O(l) + Na_3C_6H_5O_7(aq)$$

Next, you will study the reaction between magnesium metal and hydrochloric acid. An equation for this reaction is:

$$Mg(s) + 2\ HCl(aq) \rightarrow H_2(g) + Mg\ Cl_2\ (aq)$$

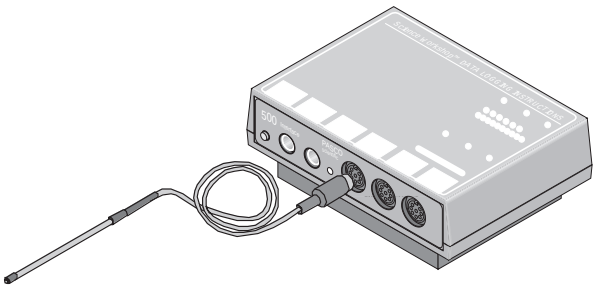
SAFETY REMINDERS

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

For You To Do

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

PART I: Computer Setup



1. Connect the *ScienceWorkshop* interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Temperature sensor's DIN plug into Analog Channel A on the interface.
3. Open the file titled as shown:

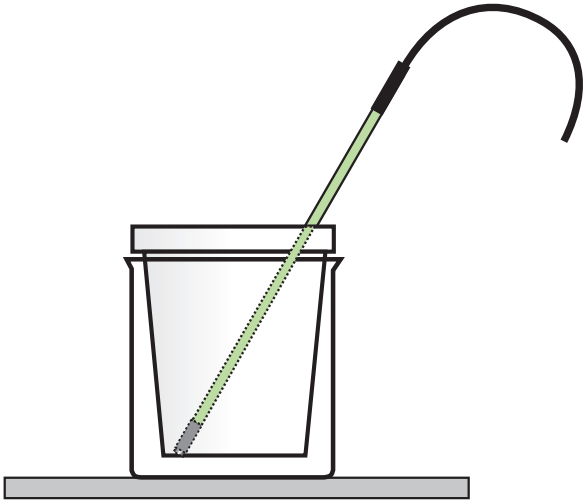
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C20 Endo and Exo React.DS	C20 Endo-Exo Reactions	C20_ENDO.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display of Temperature versus Time.
- Data recording is set for one measurement per second. Data recording stops automatically at 250 seconds (about 4 minutes).

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensor.

1. Place a Styrofoam cup into the 250 mL beaker as shown in the diagram. Put 30 mL of 1.5 Molar citric acid into the cup. Place the Temperature Sensor into the citric acid solution.
2. Weigh out 10.0 g of solid baking soda on a piece of weighing paper.



PART IIIA: Data Recording - Reacting Citric Acid and Baking Soda

1. Get ready to record data. The Temperature Sensor must be in the citric acid solution for a few seconds before you begin recording data.
2. When everything is ready, start recording data.
3. After about 20 seconds, add the baking soda to the citric acid solution.
4. Gently stir the solution with the Temperature Sensor to ensure good mixing.

Remember to stir for good mixing.

5. Record data until a minimum temperature has been reached and temperature readings begin to increase or let the computer automatically end it after 250 seconds.
6. Dispose of the reaction products as directed by your teacher. Rinse the cup.

PART IIIB: Data Recording - Reacting Magnesium and Hydrochloric Acid

1. Measure out 30 mL of HCl solution into the Styrofoam cup. Place the Temperature Sensor into the HCl solution.
2. Obtain a 20.0 cm piece of shiny magnesium metal from the teacher.
3. Get ready to record data. Note: The Temperature Sensor must be in the HCl solution for a few seconds before you begin recording data.
4. When everything is ready, begin data recording.
5. After about 20 seconds, add the magnesium ribbon to the acid solution.
6. Gently stir the solution with the Temperature Sensor to ensure good mixing.

Remember to stir for good mixing.

7. Record data until a maximum temperature has been reached and temperature readings begin to decrease or let the computer automatically end it after 250 seconds.
8. Dispose of the reaction products as directed by your teacher. Rinse the cup.

Analyzing the Data

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

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

1. Find the minimum and maximum values for temperature for Run #2. Look at the graph to determine if the minimum or maximum occurred first. Record this value as the initial temperature in the Data Table. Record the other as the final temperature.
2. Calculate the temperature change for each reaction by subtracting the initial temperature from the final temperature.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C20: Endothermic and Exothermic Reactions

What Do You Think?

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

Data Table

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

Questions

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

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

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

Name _____ Class _____ Date _____

Activity C21: Heat of Solution (Temperature Sensor)

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

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

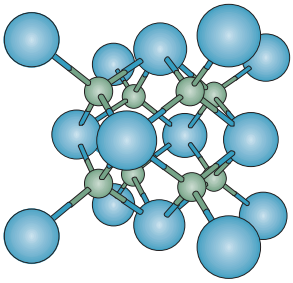
(*The calorimeter is made from two small plastic cups nested one inside the other. Please see the diagram.)

What Do You Think?

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

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

Background



When an ionic compound dissolves in water, the ions that make up the crystalline structure break into individual charged particles. Water molecules then surround these charged particles. In fact, the polar covalent water molecules are responsible for the crystal's breakdown. Dissolution requires an increase in entropy. Entropy, S, a measure of disorder, is positive. Crystals, which are orderly arrangement of molecules, break down to individual ions. The ions become scattered throughout the solution. The change in entropy (ΔS) is positive.

Beside the increase in disorder, the process of dissolving a solid may give off or require heat. If the solution of the solid crystal gets warm, the reaction is exothermic and the Heat of Solution (ΔH) is negative. If the solution of the solid crystal gets cool, the reaction is endothermic and the Heat of Solution (ΔH) is positive.

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

$$\mathbf{\Delta G = \Delta H - T\Delta S}$$

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

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

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

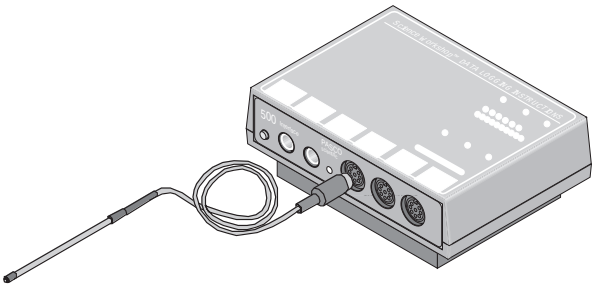
SAFETY REMINDERS

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

For You To Do

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

PART I: Computer Setup



1. Connect the *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.
3. Open the file titled as shown;

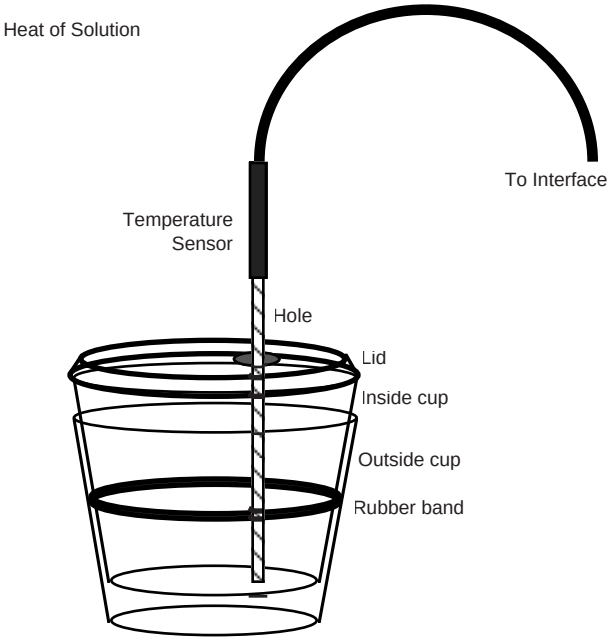
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C21 Heat of Solution.DS	C21 Heat of Solution	C21_HEAT.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook.
- The *ScienceWorkshop* document has a Graph display with a plot of the Temperature versus Time and a Table display of Temperature.

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensor.

1. Make a calorimeter by placing a rubber band about the middle of a plastic condiment cup. Nest this cup inside another cup of the same dimension.
2. Use a 1/4" paper punch to make a hole in the lid of the inside cup.
3. Put 20 mL of distilled water in the inside cup.
4. Measure 1.0 g of ammonium chloride on a piece of weighing paper. DON'T add the solid to the liquid yet.
5. Put the lid on the cup. Place the Temperature Sensor in the hole in the lid.



PART IIIA: Data Recording – Ammonium Chloride

1. When everything is ready, start recording data.
2. After about five seconds, remove the Temperature Sensor and add the ammonium chloride solid through the hole. QUICKLY put the sensor back into the cup.
3. Swirl the cup as you allow the reaction to continue until it is complete.
4. Continue until the temperature does not change any further, and then stop recording data.
5. Remove the Temperature Sensor from the cup and rinse the end of the sensor.
6. Discard the solution and rinse the cup.

PART IIIB: Data Recording – Sodium Carbonate

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

1. Put 20 mL of distilled water in the inside cup.
2. Measure 1.0 g of sodium carbonate on a piece of weighing paper. DON'T add the solid to the liquid yet.
3. Put the lid on the cup. Place the Temperature Sensor in the hole in the lid.
4. When everything is ready, start recording data.
5. After about five seconds, remove the Temperature Sensor and add the sodium carbonate solid through the hole. QUICKLY put the sensor back into the cup.
6. Swirl the cup as you allow the reaction to continue until it is complete.
7. Continue until the temperature does not change any further, and then stop recording data.
8. Remove the Temperature Sensor from the cup and rinse the end of the sensor.
9. Discard the solution and rinse the cup.

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

Analyzing the Data

1. Set up the Table so it has two columns: one for the first data run (ammonium chloride - Run #1) and one for the second data run (sodium carbonate - Run #2).
2. Use the Table or Graph display to find the starting and ending values for temperature for the solution of ammonium chloride (Run #1). Record these values.
3. Find the starting and ending values for temperature for the solution of sodium carbonate (Run #2). Record these values.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C21: Heat of Solution

What Do You Think?

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

Data Table: Ammonium Chloride

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

Data Table: Sodium Carbonate

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

Questions

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

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

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

Summary	Ammonium chloride	Sodium carbonate
ΔG		
ΔH		
ΔS		

Name _____ Class _____ Date _____

Activity C22: Hess' Law – Additivity of Heats of Reaction (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Reactions & energy	C22 Hess' Law.DS	C23 Hess's Law	C23_HESS.SWS

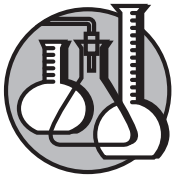
Equipment Needed	**Qty**	**Chemicals and Consumables**	**Qty**
Temperature Sensor (CI-6505A)	1	Hydrochloric acid (HCl), 1.00 Molar	50 mL
Balance (SE-8723)	1	Hydrochloric acid (HCl), 0.50 Molar	100 mL
Base and Support Rod (ME-9355)	1	Sodium hydroxide (NaOH), 1 Molar	50 mL
Beaker, 250 mL	1	Sodium hydroxide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

What Do You Think?

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

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

Background



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

$$\mathbf{A + B \rightarrow C} \qquad \mathbf{\Delta H_C = ?}$$

$$\mathbf{\Delta H_C = \Delta H_A + \Delta H_B}$$

The reactions you will use in this activity are:

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

I. $\mathbf{NaOH\ (s) \rightarrow Na^+\ (aq) + OH^-\ (aq)}$

Solid sodium hydroxide reacts with aqueous hydrochloric acid to form water and an aqueous solution of sodium chloride.

II. $\mathbf{NaOH\ (s) + H^+\ (aq) + Cl^-\ (aq) \rightarrow H_2O\ (l) + Na^+\ (aq) + Cl^-\ (aq)}$

Solutions of aqueous sodium hydroxide and hydrochloric acid react to form water and aqueous sodium chloride.

III. $\mathbf{Na^+\ (aq) + OH^-(aq) + H^+(aq) + Cl^-\ (aq) \rightarrow H_2O\ (l) + Na^+\ (aq) + Cl^-\ (aq)}$

SAFETY REMINDERS

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

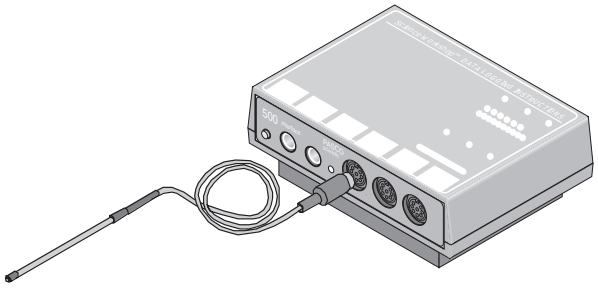
Pre-Lab

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

For You To Do

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

PART I: Computer Setup



1. Connect the *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.
3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C22 Hess' Law.DS	C23 Hess's Law	C23_HESS.SWS

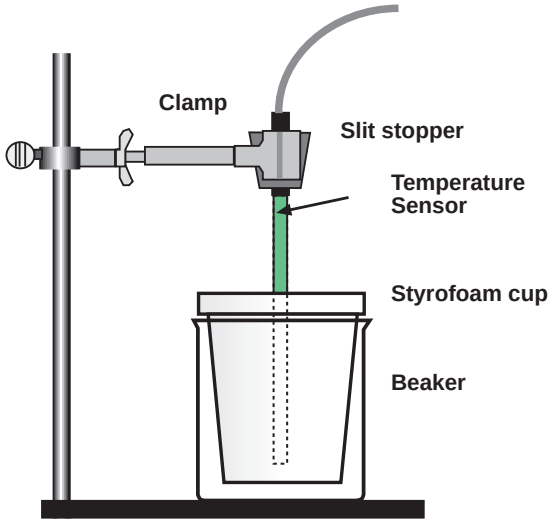
- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook
- The *ScienceWorkshop* document has a Digits display and a Table display of Temperature.
- Data recording is set so there is one measurement per second. Data recording stops automatically at 200 seconds.

Name _____ Class _____ Date _____

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensor.

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



2. Place a Styrofoam cup into a 250-mL beaker as shown in the diagram. Measure out 100.0 mL of water into the Styrofoam cup.
3. Tare the balance to the weight of the weighing paper. Weigh out about 2 grams of solid sodium hydroxide, NaOH, and record the mass to the nearest 0.01 g.

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

PART IIIA: Data Recording - Solid NaOH and Water

1. When everything is ready, start recording data.
2. After about two seconds, add the solid sodium hydroxide to the water.

- Observe the change in temperature on the Digits display.

3. Use the stirring rod to stir the contents continuously for 200 seconds or until a maximum temperature has been reached and the temperature starts to drop.
4. As soon as the temperature begins to drop after reaching a maximum, stop recording data.
5. Remove the Temperature Sensor from the cup and rinse and dry the sensor.
6. Dispose of the solution as directed. Rinse and dry the cup and stirring rod.

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

1. Put 100.0 mL of 0.50 Molar hydrochloric acid into the Styrofoam cup. Put the Temperature Sensor into the cup.
2. Weigh out about 2 grams of solid sodium hydroxide, and record the mass to the nearest 0.01.

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

3. Repeat the procedure described in Part IIIA to record the temperature as the solid sodium hydroxide reacts with the hydrochloric acid.
4. Remove the Temperature Sensor from the cup and rinse and dry the sensor.
5. Dispose of the solution as directed and rinse and dry the cup and stirring rod.

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

1. Put 50.0 mL of 1.00 Molar hydrochloric acid into the Styrofoam cup. Put the Temperature Sensor into the acid.
2. Measure out 50.0 mL of 1.00 Molar sodium hydroxide into a graduated cylinder.

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

3. When everything is ready, start recording data.
4. After about two seconds, add the sodium hydroxide solution to the acid.

- Observe the change in temperature on the Digits display.

5. Use the stirring rod to stir the contents continuously for 200 seconds or until a maximum temperature has been reached and the temperature starts to drop.
6. As soon as the temperature begins to drop after reaching a maximum, stop recording data.
7. Remove the Temperature Sensor from the cup and rinse and dry the sensor.
8. Dispose of the solution as directed and rinse and dry the cup and stirring rod.

Name _____ Class _____ Date _____

Analyzing the Data

1. Determine the mass of 100 mL of solution for each reaction (assume the density of each solution is 1.00 g/mL). Record the values in the Data Table.
2. Set up the Table display so there is one column for each run of data: one for Run #1 (solid NaOH and water), a second for Run #2 (solid NaOH and 0.5 Molar HCl), and a third for Run #3 (NaOH solution and 1 Molar HCl).
3. Use the Table to determine the initial temperature, T_1 for each reaction. Record the temperature, T_1.
4. Use the Tables data analysis tools to determine the maximum temperature, T_2, for each reaction. Record the temperatures.

Calculations

1. Determine the temperature change, ΔT, for each reaction.
2. Calculate the heat released by each reaction, q, by using the formula:

   $$q = Cp \cdot m \cdot \Delta T \quad (Cp = 4.18\ J/g°C)$$

   Convert joules to kiloJoules in your final answer.
3. Find the heat of reaction, ΔH ($\Delta H = -q$).
4. Calculate moles of NaOH used for reactions I, II, and III.
5. Use the heat of reaction and the number of moles to determine ΔH/mol NaOH in each of the three reactions.
6. To verify the results of the experiment, combine the heat of reaction (ΔH/mol) for Reaction I and Reaction III.

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

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

Formulas

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

$$\Delta T = T_2 - T_1$$

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

$$\Delta H = -q$$

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

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

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

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

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C22: Hess' Law – Additivity of Heats of Reaction

What Do You Think?

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

Pre-Lab

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

Data Table: Hess' Law

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

(*No solid NaOH mass.)

Heat of Reaction I plus Heat of Reaction III:

Heat of Reaction II:

Percent difference(%):

Question

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

Name _____ Class _____ Date _____

Activity C23: Heat of Combustion - Magnesium (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Reactions & energy	C23 Combustion.ds	C22 Heat of Combustion	C22_COMB.SWS

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

Purpose

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

Background - Calorimetry

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

What Do You Think?

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

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

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

Background – Heat of Reaction

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

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

IV. Mg (s) + 1/2 O_2 (g) -> MgO (s)

(Magnesium and oxygen form magnesium oxide.)

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

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

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

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

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

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

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

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

(Hydrogen and oxygen form water.)

Pre-Lab

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

SAFETY REMINDERS

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

For You To Do

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

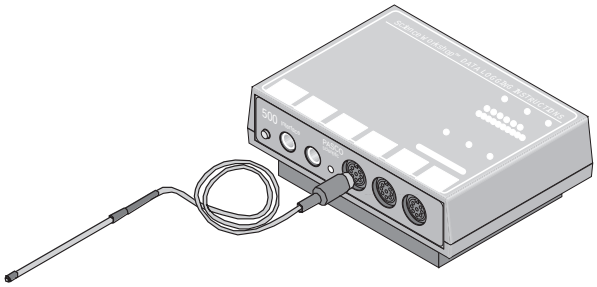
Use the data to calculate the heat of reaction for magnesium oxide and hydrochloric acid (equation **I**) and the heat of reaction for magnesium and hydrochloric acid (equation **II**).

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

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

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.
3. Open the file titled as shown:

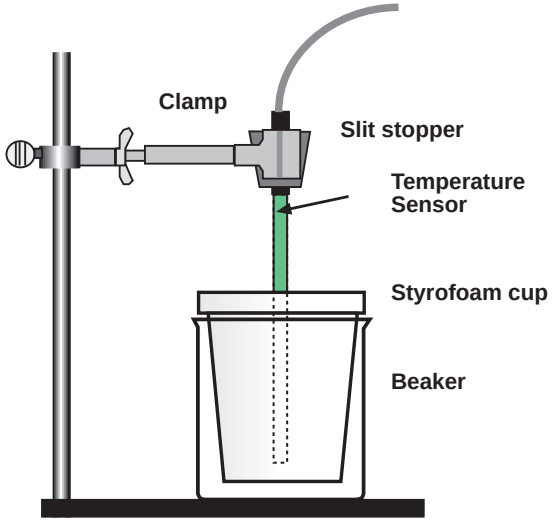
DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C23 Combustion.ds	C22 Heat of Combustion	C22_COMB.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook
- The *ScienceWorkshop* document has a Digits display and a Table display of Temperature.
- Data recording is set for one measurement per second.

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensor.

1. Use a base and support rod, a clamp, and a slit stopper to support a Temperature Sensor as shown.
2. Place a Styrofoam cup into a 250-mL beaker as shown in the diagram. Measure out 100.0 ml of 1.00 Molar HCl into the Styrofoam cup.
3. Lower the Temperature Sensor into the solution.



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

Safety Alert!

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

PART IIIA: Data Recording - Magnesium Oxide and Hydrochloric Acid

1. When everything is ready, start recording data.
2. After about five seconds, add the white magnesium oxide powder to the solution.

- Observe the change in temperature on the Digits display.

3. Use the stirring rod to stir the contents of the cup until a maximum temperature has been reached and the temperature starts to drop. Then stop recording data.
4. Remove the Temperature Sensor from the cup and rinse the end of the sensor.
5. Discard of the solution as directed and rinse the cup.

PART IIIB: Data Recording - Magnesium Ribbon and Hydrochloric Acid

6. Repeat the procedure with 0.50 g of magnesium ribbon rather than magnesium oxide powder. Be sure to measure and record the mass of the magnesium ribbon.
7. When everything is ready, start recording data.
8. After about five seconds, add the white magnesium oxide powder to the solution.

- Observe the change in temperature on the Digits display.

9. Use the stirring rod to stir the contents of the cup until a maximum temperature has been reached and the temperature starts to drop. Then stop recording data.
10. Remove the Temperature Sensor from the cup and rinse the end of the sensor.
11. Discard of the solution as directed and rinse the cup.

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

Analyzing the Data

1. Set up the Table display so it has two columns: one for the first run of data (magnesium oxide and hydrochloric acid) and one for the second run of data (magnesium ribbon and hydrochloric acid).
2. Use the Table data analysis tools to find the initial temperature T_1 and maximum temperature T_2 for Run #1 (magnesium oxide and hydrochloric acid). Record these values.
3. Find the initial temperature T_1 and maximum temperature T_2 for Run #2 (magnesium ribbon and hydrochloric acid). Record these values.

Calculations

1. Calculate the change in temperature, ΔT, for both reactions.
2. Calculate the energy released by both reactions, q, using the formula

$$\mathbf{q = C_p \cdot m \cdot \Delta T}$$

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

3. Determine the heat of reaction, ΔH, for both magnesium oxide and magnesium ribbon. (Remember, $\Delta H = -q$.)
4. Determine the moles of magnesium oxide (MgO) and magnesium ribbon (Mg) used.
5. Use your calculation of the heats of reaction and the number of moles to calculate ΔH/mol for magnesium oxide (MgO) and magnesium ribbon (Mg).

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

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

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

Formulas

$$\Delta T = T_f - T_i$$

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

$$\Delta H = -q$$

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

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

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

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

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C23: Heat of Combustion - Magnesium

What Do You Think?

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

Data Table

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

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

Eqn.	Reactants	Results	Heat of Reaction
I.	$MgCl_2$ (aq) + H_2O (l) ->	MgO (s) + 2 HCl (aq)	$\Delta \mathbf{H_1}$ =
II.	Mg (s) + 2 HCl (aq) ->	$MgCl_2$ (aq) + H_2 (g)	$\Delta \mathbf{H_2}$ =
III.	H_2 (g) + 1/2 O_2 (g) ->	H_2O (l)	$\Delta \mathbf{H_3}$ =
IV.	Mg (s) + 1/2 O_2 (g) ->	MgO (s)	$\Delta \mathbf{H_4}$ =

Determine the percent difference between your calculation and the accepted value (-602 kJ/mol).

Percent difference =

Optional – Calorimeter Method

In this method, use the heat given off by a piece of burning magnesium to heat up a known volume of water. Use the mass of water heated, its specific heat (the specific heat for water is c = 1.0 cal/g ˚C or 4.18 J/g˚C, and the change in the temperature of the water to calculate the heat of combustion of the magnesium.

This method is often used to calculate the caloric content of many foods such as peanuts or sugar. (Refer to the "Food Energy Content" activity.)

Follow the procedure in the "Food Energy Content" activity. Modify the equipment set-up so that a magnesium ribbon can be burned instead of a food sample. Use a crucible to hold the burning magnesium. Use extreme caution when working with burning magnesium.

Safety Alert!

Never look into the flame produced by the burning magnesium or directly at the light given off from the combustion. The light energy is very intense and contains UV radiation that could possibly damage your eyes and vision.

Follow the same calculation method as in the "Food Energy Content" activity. Note any and all possible sources of error that may result using this method.

Questions

1. What is the Heat of Combustion of magnesium based on your data from the calorimeter method?

2. What is the percent difference between your calculation and the accepted value?

3. Which method do you think was more reliable?

Name _____ Class _____ Date _____

Activity C24: Determine the Molecular Mass of a Compound – The Dumas Bulb Method (Pressure Sensor, Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
The Mole	C24 Molecular Mass.DS	C24 Dumas Bulb	C24_DUMA.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Pressure Sensor (CI-6532A)	1	Rubber stopper, two-hole	1
Temperature Sensor (CI-6505A)	1	**Thermometer (SE-9084)**	1
Beaker, 1 L	1	**Tubing, plastic (w/sensor)**	1
Bottle or flask, 250 mL	2	Protective gear	PS
Connector, rubber stopper (w/sensor)	1		
Coupling, quick-release (w/sensor)	1	**Chemicals and Consumables**	**Qty**
Graduated cylinder, 10 mL	1	Acetone	1 mL
Graduated cylinder, 100 mL	1	Glycerin	1 mL
Hot plate	1	Water	600 mL

What Do You Think?

In this activity, a known mass of a volatile liquid is placed in a sealed container. The liquid is then placed in a water bath of known temperature so that the liquid vaporizes and fills the container. Knowing the mass, the temperature, pressure and the value of R, the Gas Constant, can you use the Ideal Gas Law to determine the molecular mass of the liquid?

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

Background

The molecular mass (grams per mole) of a compound is one of the most important variables needed to identify and characterize a chemical. The molecular mass of an unknown compound allows a chemist to determine the molecular formula of the compound. The molecular formula can then be used to determine the structure and possible physical and chemical properties of the compound.

One of the earliest methods of determining the molecular mass of a compound is the Dumas Bulb method. This method uses a rigid container of known volume. The pressure and temperature of a volatile liquid are measured, and the Ideal Gas Law is used to determine the number of moles of the substance.

$$n = \frac{PV}{RT}$$

In this arrangement of the Ideal Gas Law, n is the number of moles, P is the pressure in atmospheres, V is the volume in liters, R is the Gas Constant, and T is the absolute temperature.

SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

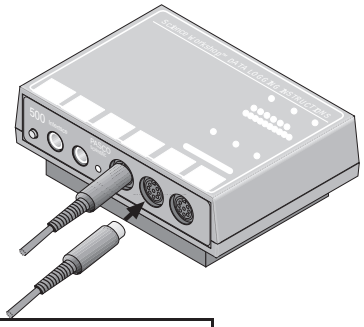
For You To Do

Prepare the Water Bath

- Make a water bath of about 600 mL of water in a 1 liter beaker. Heat the water bath to 65 ˚C and maintain this temperature. Use a thermometer to check the progress of the water bath as you set up the rest of the equipment.

Use the Pressure Sensor to measure the change in vapor pressure in a rigid container and use the Temperature Sensor to measure the change of temperature inside the container. First, measure the change for a sample of air when the container is immersed in hot water. Then measure the changes for a sample of air mixed with vaporized acetone. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use the data to determine the molecular mass of the liquid.

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)
C24 Molecular Mass.DS	C24 Dumas Bulb	C24_DUMA.SWS

- The *DataStudio* file has a Graph display. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display with a plot of the pressure versus time and a plot of the temperature versus time.
- Data recording is set at ten measurements per second (10 Hz). Data measurement is set to stop automatically at 120 seconds.

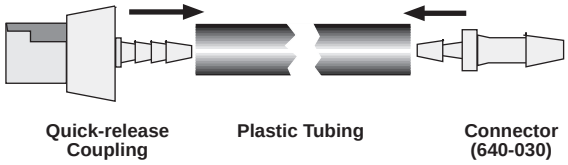
PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensors.

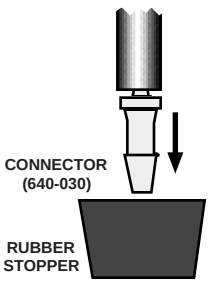
Set Up the Equipment

- For this part you will need the following: glycerin, quick-release coupling, connector, plastic tubing, two-hole rubber stopper, Temperature Sensor, Pressure Sensor.

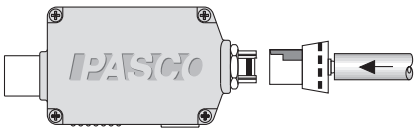
1. Put a drop of glycerin on the barb end of a quick release coupling. Put the end of the quick release coupling into one end of a piece of plastic tubing (about 15 cm) that comes with the Pressure Sensor.

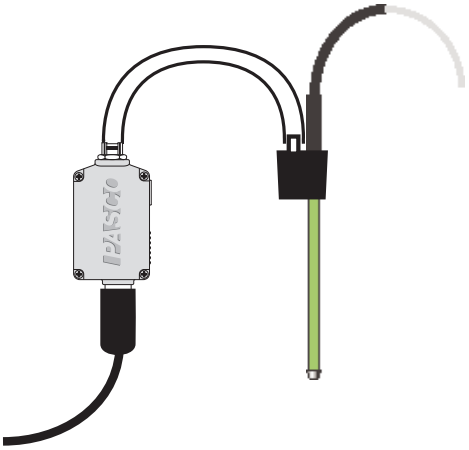


2. Put a drop of glycerin on the barb end of the connector. Push the barb end of the connector into the other end of the plastic tubing.
3. Fit the end of the connector into one of the holes in the rubber stopper.
4. Put a drop of glycerin into the other hole of the stopper and slide the Temperature Sensor through the hole.



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).





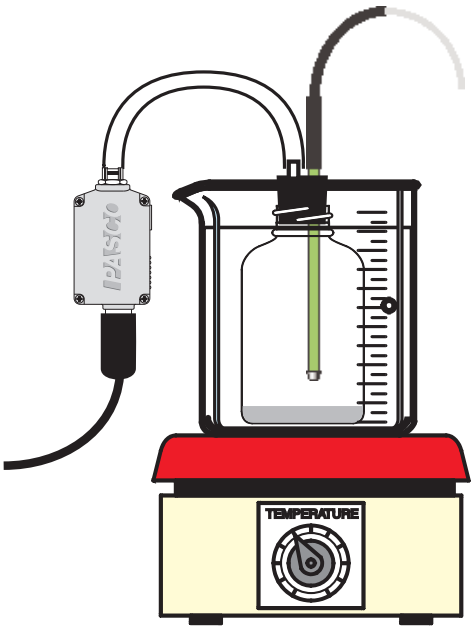
- Pressure Sensor and Temperature Sensor with two-hole rubber stopper.

PART IIIA: Data Recording – Air Only

1. When you are ready to begin, place the two-hole rubber stopper with sensors into the top of the first bottle and place the bottle in the hot water bath.
2. Start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
3. Allow the heating to continue for 120 seconds.
4. Remove the bottle from the hot water bath. Slowly open the bottle to allow the heated air to escape.
5. Remove the rubber stopper from the first bottle.

PART IIIB: Data Recording – Air and Acetone

1. Put 0.3 mL of acetone in the second bottle.
2. Place the two-hole rubber stopper with sensors into the top of the second bottle and place the bottle in the hot water bath.
3. Start recording data. Allow the heating to continue for 120 seconds.
4. Remove the bottle from the hot water bath. Slowly open the bottle to allow the vapors to escape.
5. Rinse the bottle.
6. Use the large graduated cylinder to add water to the bottle to determine the actual volume of the bottle. Record the volume in the Lab Report section. (Hint: Be sure to account for the space occupied by the bottom of the stopper and by the sensor.)



Analyzing the Data

- The Graph has two plots showing pressure and temperature data for air alone and pressure and temperature data for air and acetone.

1. Use the Graph's analysis tools to find the maximum pressure for the air alone, the maximum pressure for the air and acetone, and the final temperature of the air and acetone. (Hint: Use the 'Smart Tool' in *DataStudio* or the 'Smart Cursor' in *ScienceWorkshop*. Or, use the 'Statistics menu' to select 'Maximum'.)
2. Record the values for maximum pressure and temperature in the Lab Report section.
3. Convert the values of pressure from kilopascals to atmospheres (1 atm = 101 kPa). Convert the value of temperature from Celsius to Kelvin (K = 273 + C). Convert the volume of the container from milliliters to liters (1 L = 1000 mL).
4. Convert the volume of the acetone to a mass using the density of acetone (0.79 g/mL).
5. Use the data to determine the number of moles of acetone and then calculate the molecular mass of the acetone.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C24: Determine the Molecular Mass of a Compound – The Dumas Bulb Method

What Do You Think?

In this activity, a known mass of a volatile liquid is placed in a sealed container. The liquid is then placed in a water bath of known temperature so that the liquid vaporizes and fills the container. Knowing the mass, the temperature, pressure and the value of R, the Gas Constant, can you use the Ideal Gas Law to determine the molecular mass of the liquid?

Answers will vary.

Data and Calculations

Data	Measurement	Value
1	Maximum pressure of air alone	kPa
2	Maximum pressure of air and acetone	kPa
3	Change in pressure (Data 2 - Data 1)	kPa
4	Change in pressure in atmospheres (Data 3 x 1 atm/101 kPa)	atm
5	Final temperature of air and acetone	˚C
6	Final temperature in K (Data 5 + 273)	K
7	Volume of gas in mL	mL
8	Volume of gas in L (Data 7 x 1 Liter/1000 mL)	L
9	Gas Constant, R	0.082 atm L/mole K
10	Mass of acetone (0.3 mL x 0.79 g/mL)	g
11	Moles of acetone ($\mathbf{n = \frac{PV}{RT}}$)	moles
12	Molecular mass of acetone (g/mole)	g/mole
13	% difference (See below)	%

$$\%\ \text{difference} = \left| \frac{\text{observed } (Data12) \ - \ \text{expected}}{\text{expected}} \right| x100$$

Question

1. What is the percent difference between your measured value and the accepted value for the molecular mass of acetone?

Name _____ Class _____ Date _____

Activity C25: Molar Mass Determination by Freezing Point Depression (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Molar mass	C25 Molar Mass.DS	C25 Molar Mass	C25_MOLA.SWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
Temperature Sensor (CI-6505A)	1	Test tube, Pyrex, 25 x 150 mm	1
Balance (SE-8723)	1	Protective gear	PS
Base and Support Rod (ME-9355)	1	**Chemicals and Consumables**	**Qty**
Beaker, 250 mL (for water bath)	1	Para-dichlorobenzene (PDB)	15 g
Clamp, Buret (SE-9446)	1	"unknown"	2 g
Hot plate (for water bath)	1	Water	200 mL
Slit stopper	1	Weighing paper	3
Spatula	1		

What do you think?

The temperature of a mixture of pure water and pure ice is 0 ˚C. What happens to the temperature of the water/ice mixture if you add sodium chloride (table salt) to the mixture? Is the change in temperature determined by the amount of salt that you add? Are there any other substances that can have a similar effect on the freezing point of water? Will this change in the freezing point temperature happen for substances other than water?

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

Background

Freezing point depression is an example of a *colligative* property. Colligative properties depend on the concentration of solute particles (total number of moles per liter) and not on their size or specific properties. A pure substance has a specific freezing point temperature. The freezing point of the substance is lowered when another substance is dissolved in the pure substance. The freezing point *depression* (i.e., drop in freezing point temperature) depends on the total number of solute particles. For example, because sodium chloride molecules dissociate into Na^+ and Cl^- ions in solution, one mole of 'salt' becomes two moles of ions. The freezing point temperature drops twice as much as it would if the solute does not dissociate into ions. Using salt on icy roads during the winter in snowy areas is an example of freezing point depression.

Chemists use the following concept and equation. The freezing point depression, $\Delta \mathbf{T_f}$, of a solvent is given by:

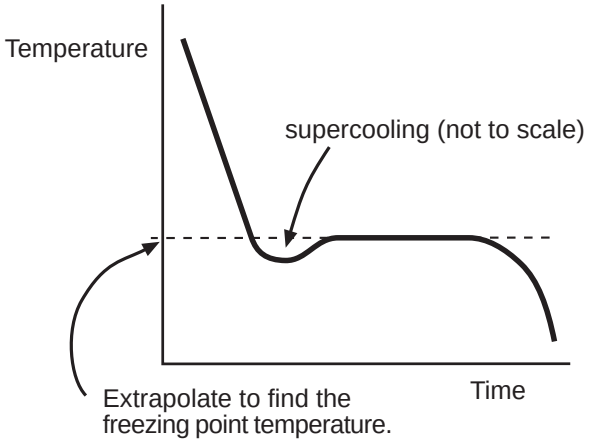
$$\Delta \mathbf{T_f} = -\mathbf{K_f}\ \mathbf{m}$$

where $\mathbf{K_f}$ is the molal freezing point depression constant for the solvent and **m** is the molality of the total solute particles.

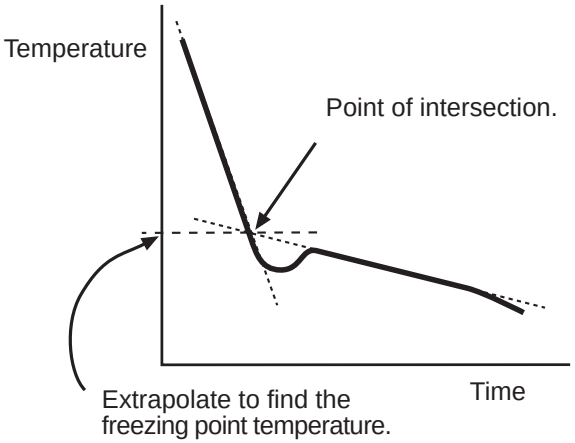
The *molality* is ratio of the number of moles per solute and the mass of the solvent. Therefore, you can determine the number of moles of the unknown solute from its molality, m, and the mass of the solute. Since the *molar mass* of the unknown is the ratio of the mass of the solute to the number of moles, you can determine the molar mass of an *unknown* compound by means of the freezing point depression of para-dichlorobenzene (PDB).

How to Determine the Freezing Point

As a pure substance cools in its liquid state, the temperature drops at a constant rate until it begins to solidify. While freezing, its temperature levels off at a temperature known as its freezing point. Occasionally the temperature drops a little below the actual freezing point before leveling off at the actual freezing point. This is known as super cooling. See the diagram below.



A solution may continue freezing over a broad temperature range. To get an good value for its freezing point draw a line through the original cooling curve of the liquid and a second through the area where it has tapered off slightly. The temperature at the point at which they intersect can be considered to be the freezing point. See the diagram below.



SAFETY REMINDERS

- Wear protective gear while handling chemicals.
- Follow directions for using the equipment.
- Make sure the room is well ventilated.
- Dispose of all chemicals and solutions properly.

Name _____ Class _____ Date _____

For You To Do

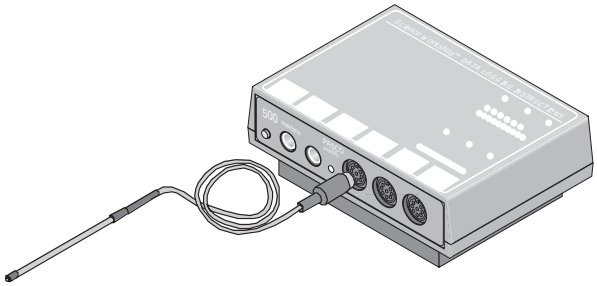
In this activity, measure the freezing point temperature of a pure organic substance, para-dichlorobenzene (PDB).Then measure the freezing point temperature of a solution of PDB and a measured amount of an unknown compound. The para-dichlorobenzene acts as the solvent and the unknown compound is the solute.

Use the Temperature Sensor to measure the change in temperature as melted PDB solidifies. Compare the freezing point temperature for pure PDB with the freezing point temperature of PDB mixed with an unknown substance. Use *DataStudio* or *ScienceWorkshop* to record, display, and analyze the data. Use the data to calculate the molar mass of the unknown compound.

Pre-Lab

Fill the 250 -mL beaker a little over half full with water. Begin to heat the water to 65 or 70 ˚C. As the water is heating, continue with the rest of the setup.

PART I: Computer Setup



1. Connect the *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.
3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C25 Molar Mass.DS	C25 Molar Mass	C25_MOLA.SWS

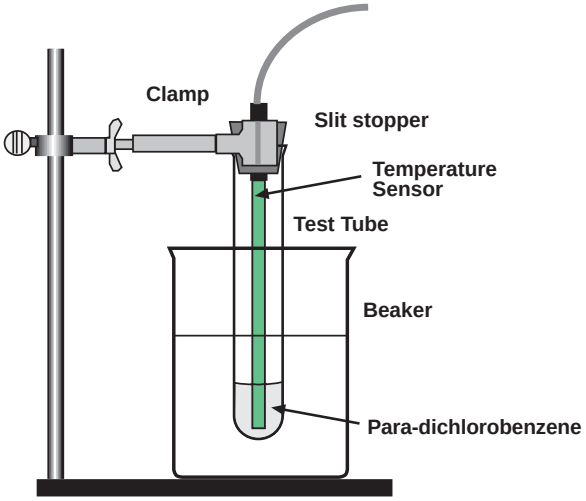
- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook
- The *ScienceWorkshop* document has a Digits display and a Table display of Temperature and a Graph display with a plot of the Temperature versus Time.

4. Data recording is set so there is one measurement per 15 seconds.

PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the Temperature Sensor.

1. Measure 15.00 gram of para-dichlorobenzene (p-dichlorobenzene or PDB). Record the exact mass to 0.01 g. Put the PDB into a clean dry 25 by 150-mm Pyrex test tube.
2. Use a base and support rod, clamp, and slit stopper to set up the test tube with the PDB as shown.



3. When the water bath is hot enough, turn off the heat source and lower the test tube and the Temperature Sensor into the hot water bath.

- NOTE: Never heat p-dichlorobenzene over an open flame.
- As the material melts, you can stir it gently with the Temperature Sensor.

4. Start to monitor the temperature of the PDB. Every fifteen seconds the Digits display will show the temperature.
5. When the melting is complete and the temperature is between 60 and 65 ˚C, stop monitoring the temperature (Hint: Click the STOP button.)

PART IIIA: Data Recording - Pure PDB

1. Raise the test tube. Immediately start recording data for determining the freezing point of the pure PDB.
2. Stir gently with the sensor throughout the entire run.
3. Continue recording data until all the material seems completely frozen.
4. Make a note of the apparent freezing point of the PDB.
5. When the PDB is solid, stop the data recording for Run #1.

PART IIIB: Data Recording - PDB and 1 gram Unknown

1. Again heat your hot water bath. Return the test tube with the PDB to the water bath. This time stop heating the test tube when the temperature is 10 degrees above the apparent freezing point of the pure PDB.
2. Carefully weigh out 1.00 g of unknown and pour it into the test tube with the PDB. Record the mass of unknown in your data table under Run #2.
3. Do Run #2 in the same manner as you did Run #1. The material may not get as hard this time.
4. Make a note of the apparent freezing point temperature of the PDB/unknown mixture.

PART IIIC: Data Recording - PDB and 1 gram Unknown

1. Again heat your hot water bath. Return the test tube with the mixture from Part IIIB to the water bath. This time stop heating the test tube when the temperature is 10 degrees above the apparent freezing point of the last mixture.
2. Carefully weigh out a second 1.00 g of unknown and pour it into the bottom of the test tube with the mixture. Record the combined mass of unknown in your data table under Run #3.

- Note: This should be about 2.00 g.

3. Do Run #3 in the same manner as you did the last two runs. The material may appear like a solid slush at the end.
4. Clean up and dispose of your chemicals as directed.

Analyzing the Data

1. Click the Graph display to make it active. The Graph display will show all three runs of data.
2. Rescale the graph to fit the data.

- NOTE: Drag-and-drop data runs from the Summary list to the Graph display in *DataStudio*. Select each run of data separately by clicking on the DATA menu button in the Graph display in *ScienceWorkshop*.

3. Use a printed copy of your Graph display to determine the freezing point for each run as discussed in the 'How to Determine the Freezing Point' section.
4. Use the Graph's data analysis tools to determine the freezing point depression, ΔT_f, for Run #2 (PDB plus 1 g of unknown) and Run #3 (PDB plus 2 g of unknown).

- Hint: Use the Smart Tool in *DataStudio* or the Smart Cursor in *ScienceWorkshop*.

Calculations

1. Use the freezing point depression and the value of $\mathbf{K_f}$ for PDB to calculate the molality, **m**, of the solutions for Run #2 and Run #3.
2. Use the molality and the mass of the unknown to calculate the number of moles of unknown ("solute") used in Run #2 and Run #3. (Remember that the molality of a solution equals the number of moles of solute per kilogram of solvent.)
3. Use the mass of the unknown and the number of moles of unknown ("solute") to determine the experimental value for the molar mass of the unknown for Run #2 and Run #3.
4. Calculate the average experimental molar mass for the unknown.
5. If your teacher gives you the actual value for the molar mass, then determine your percent difference.

Formulas

$$\Delta T_f = T_{pure} - T_{mixture}$$

$$Molality = \frac{\Delta T_f}{K_f} \quad \textbf{where } K_f \textbf{ = 7.10 °C kg/mol for PDB}$$

$$\#\,moles\,solute = molality\,x\,\#\,kg\,solute$$

$$Molar\,mass\,of\,solute = \frac{mass\,of\,solute}{\#\,moles\,solute}$$

$$Average\,molar\,mass = \frac{Molar\,mass\,1 + Molar\,mass\,2}{2}$$

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

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C25: Molar Mass Determination by Freezing Point Depression

What Do You Think?

The temperature of a mixture of pure water and pure ice is 0 ˚C. What happens to the temperature of the water/ice mixture if you add sodium chloride (table salt) to the mixture? Is the change in temperature determined by the amount of salt that you add? Are there any other substances that can have a similar effect on the freezing point of water? Will this change in the freezing point temperature happen for substances other than water?

Data Table and Calculations

	Run #1	Run #2	Run #
	PDB	1 g of unknown	2 g of unknown
Mass PDB (solvent)	kg	kg	kg
Mass unknown (solute)	--	g	kg
Freezing point, T	˚C	˚C	˚C
Freezing point depression, ΔT_f	--	˚C	˚C
Molality, m, of solute	--	mol/kg	mol/kg
Moles of unknown (solute)	--	mol	mol
Molar mass of unknown	--	kg/mol	kg/mod

Average molar mass	kg/mol
Actual molar mass of unknown	kg/mol
Percent difference	%

Question

1. What is the percent difference between your measured value and the accepted value for the molar mass of the unknown substance?

Name _____ Class _____ Date _____

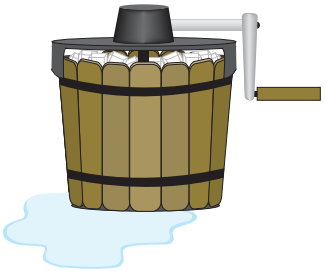
Activity C26: Molal Freezing Point Depression Constant, K_f (Temperature Sensor)

Concept	*DataStudio*	*ScienceWorkshop (Mac)*	*ScienceWorkshop* (Win)
Freezing point	C26 Freeze Point.DS	C26 Depression Constant	C26_DEPR.SWS

Equipment Needed	**Qty**	**Chemicals and Consumables**	**Qty**
Temperature Sensor (CI-6505A)	1	Ice, crushed (from deionized water)	150 g
Balance (SE-8723)	1	Lid (for Styrofoam cup)	1
Beaker, 500 mL	1	Rubber band	1
Calorimeter *	1	Sodium chloride, NaCl, solid	100 g
Graduated cylinder, 100 mL	1	Styrofoam cup	2
Stir rod	1	Water	100 mL
Test tube	1	Water, deionized	50 mL
Protective gear	PS	Weighing paper	1

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

What do you think?



Freezing a milk/cream mixture makes ice cream. The freezing usually takes place in an ice cream maker that has an inner and outer lining. The milk/cream mixture is placed into the inner container and ice, water and salt are placed in the outer container. The ice used in the outer container is initially at zero degrees Celsius. Water and salt are then added to this ice and the resulting mixture is used to "freeze" the milk/cream into ice cream. Milk and cream require a temperature colder than zero degrees Celsius to be turned into ice cream. Just how does this "freezing" temperature come about?

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

Background

Pure substances have characteristic boiling point temperatures and freezing point temperatures if the atmospheric pressure is constant. If a pure substance is contaminated with another, the boiling and freezing point temperatures are changed.

Changes in the physical properties of a substance are referred to as *colligative* properties. Each substance changes to a different degree. For every mole of contaminating substance, the dissolving substance's melting point will be depressed by a specific amount. This amount is known as the Molal Freezing Point Depression Constant or K_f. The presence of a non-volatile solute in a solution lowers the freezing point of a substance. A non-volatile substance is one, which is not boiled away when a solution is heated.

For example, when sodium chloride is dissolved in ice water, the molecule of the salt dissolves to form two ions for every molecule of salt.

$$NaCl_{(s)} \text{ ======> } Na^{+}_{(aq)} + Cl^{-}_{(aq)}$$

The effect on the freezing point of water with sodium chloride is double what it would be if the molecule stayed together and acted as a single unit. The number of particles influences the freezing point of a solid, not just the mass of material, dissolved.

SAFETY REMINDERS

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

For You To Do

This activity has two parts:

Part A - Observation

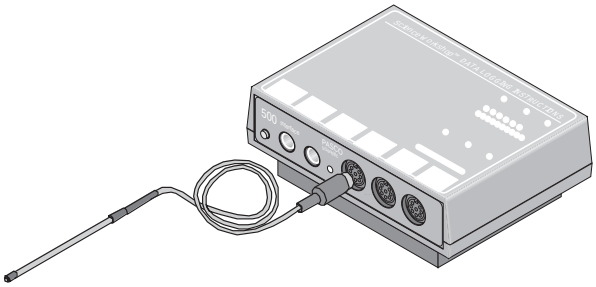
Place a test tube of water into a beaker containing ice, water and salt. Stir the ice/water/salt mixture and observe what happens to the ice in the test tube. Use a Temperature Sensor and either *DataStudio* or *ScienceWorkshop* to record the temperature of the water in the test tube.

Part B – Measurement

Use a Temperature Sensor to measure the change in the freezing point of a common substance, water, and to use these measurements to determine the value of the Molal Freezing Point Depression Constant K_f.

PART I: Computer Setup

1. Connect the *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.
3. Open the file titled as shown;



DataStudio	*ScienceWorkshop (Mac)*	*ScienceWorkshop* (Win)
C26 Freeze Point.DS	C26 Depression Constant	C26_DEPR.SWS

- The *DataStudio* file has a Workbook display. Read the instructions in the Workbook
- The *ScienceWorkshop* document has a Graph display of the Temperature versus Time.
- Data recording is set so there is one measurement per second.

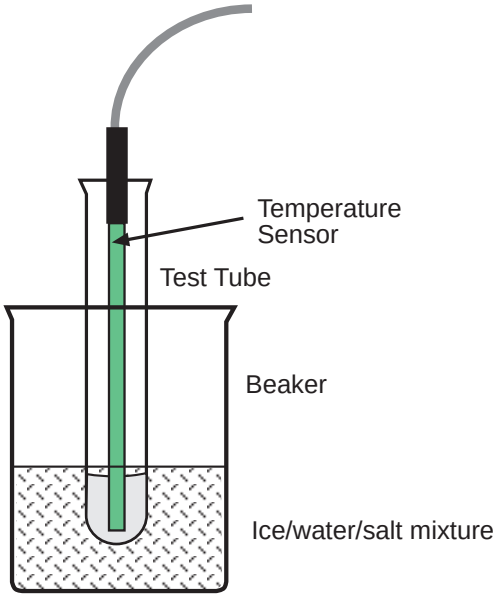
PART II: Sensor Calibration

This is an activity where it is good to calibrate the Temperature Sensor, since an actual freezing point is being measured and not just a change in temperature. The calibration procedure is simple. (Refer to the Temperature Sensor instruction sheet or the *DataStudio* On-Line Help file or the *ScienceWorkshop* User's Guide.)

Name _____ Class _____ Date _____

PART IIA: Equipment Setup - Observation

- Put about 100 grams of ice, 50 mL of water, and a couple of teaspoons of table salt into a beaker. Stir the mixture to dissolve the ice.



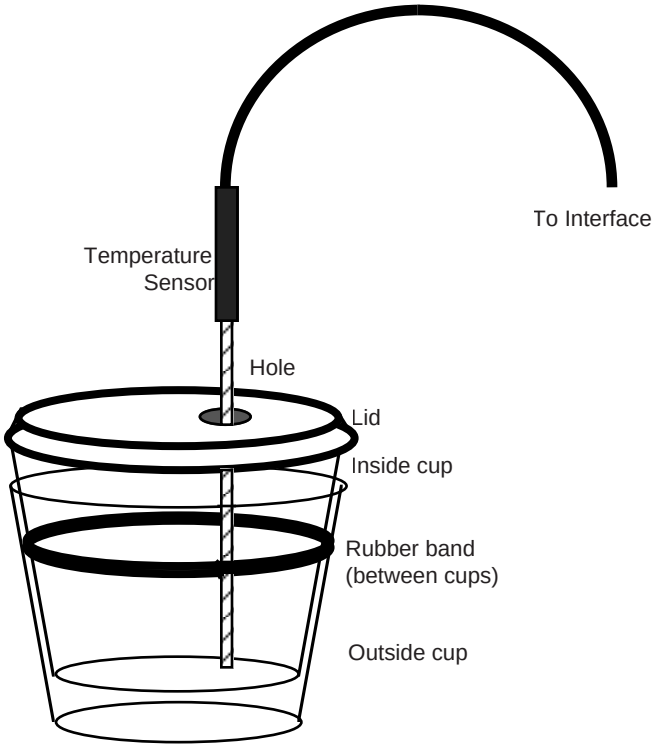
- Put water into a test tube. Place a Temperature Sensor into the water.
- Place the test tube into the ice/water/salt mixture in the beaker.
- Start recording the temperature of the water in the test tube.
- Continue to measure the temperature of the water in the test tube until it stops decreasing.
- Observe the contents of the test tube throughout the activity.

Questions About The Observation (Optional)

- Does a phase change occur for the water in the test tube?
- Can you determine the freezing point of water in this activity?
- Can ice be colder than zero degrees Celsius?

PART IIB: Equipment Setup - Measurement

1. Weigh one Styrofoam cup and record the weight of the cup.
2. Make a calorimeter by placing a rubber band about the middle of the Styrofoam cup. Nest this cup inside another cup of the same dimension.
3. Use a 1/4" paper punch to make a hole in the lid of the inside cup.
4. Put 50 mL of water and 50 g of ice in the inside cup.
5. Carefully measure 2.9 g of sodium chloride. Add the salt to the ice/water mixture.
6. Put the lid on the cup. Place the Temperature Sensor in the hole in the lid.



Molal Freezing Point Depression Constant (kf)

PART III: Data Recording

1. Start recording data.
2. Gently swirl the calorimeter to help the salt dissolve until the reaction is complete.
3. Stop the data recording after approximately 90 seconds (1.5 minutes).
4. Remove any remaining chunks of ice from the inner cup. Weigh the inner cup with the remaining water and record the total weight of the cup plus water.

Name _____ Class _____ Date _____

Analyzing the Data

1. Use the Graph analysis tools to determine the maximum temperature (maximum 'y') and minimum temperature (minimum 'y').

- Hint: Use the Smart Tool in *DataStudio* or the Smart Cursor in *ScienceWorkshop*.

2. Record the maximum temperature and the minimum temperature.

Calculations

1. Calculate the change in temperature and record it.

2. Calculate the mass of the water remaining in the cup after the salt dissolved.

3. Calculate the number of moles of solute (salt).

4. Determine the molality of the ice/water/salt mixture.

5. Calculate the Molal Freezing Point Depression Constant, K_f.

6. Compare your value for the Molal Freezing Point Depression Constant, K_f, to the accepted value.

- Note: A mass of 2.9 g sodium chloride is equal to 0.05 moles of sodium chloride, or 0.1 moles of dissolved ions.

- The molality of a solution is equal to the moles of solute divided by the weight (in kg) of solvent.

$$m\ (molality) = \frac{moles\ of\ solute}{weight\ of\ solvent}$$

- The Molal Freezing Point Depression Constant formula is:

$$\Delta\ \textbf{freezing temperature of water} = \textbf{m (molality)} \times K_f$$

$$K_f = \frac{\Delta\ temperature}{m\ (molality)}$$

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C26: Molal Freezing Point Depression Constant, K_f

What do you think?

Freezing a milk/cream mixture makes ice cream. The freezing usually takes place in an ice cream maker that has an inner and outer lining. The milk/cream mixture is placed into the inner container and ice, water and salt are placed in the outer container. The ice used in the outer container is initially at zero degrees Celsius. Water and salt are then added to this ice and the resulting mixture is used to "freeze" the milk/cream into ice cream. Milk and cream require a temperature colder than zero degrees Celsius to be turned into ice cream. Just how does this "freezing" temperature come about?

Data Table

Mass of empty cup	kg
Mass of cup plus water	kg
Mass of water used	kg
Minimum Temperature	˚C
Maximum Temperature	˚C
Change in Temperature	˚C

1. Calculate the number of moles of solute (salt).

2. Determine the molality of the ice/water/salt mixture.

3. Calculate the Molal Freezing Point Depression Constant, K_f.

Questions

1. If ionic solutions, like sodium chloride, form ions and effect the freezing point so much more than non-ionic solutions, like ethylene glycol (Zerex™), why are non-ionic materials used in cars?

2. Why is calcium chloride ($CaCl_2$) more effective as an anti-icing material than sodium chloride (NaCl)?

3. What is your value of Kf? How does this compare with the accepted value for Kf? (The accepted value of Kf for water is 1.86 ˚C kg/mol.)

Questions About the Observation (Optional)

- Does a phase change occur for the water in the test tube?

- Can you determine the freezing point of water in this activity?

- Can ice be colder than zero degrees Celsius?

Name _____ Class _____ Date _____

Activity C27: Determine the Concentration of a Solution – Beer's Law (Colorimeter)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Chemical unknown	C27 Beer's Law.DS	C27 Beer's Law	C27_BEER.SWS

Equipment Needed	**Qty**	**Chemicals and Consumables**	**Qty**
Colorimeter (CI-6747)	1	Copper sulfate, 0.4 molar	30 mL
Beaker, 100 mL	2	Copper sulfate, unknown	5 mL
Cuvette (w/sensor)	1	Label	6
Pipette, 10 mL	2	Tissue	6
Stirring rod	1	Water, distilled	100 mL
Test tube, 25 by 150 mm	6		
Test tube rack	1		
Protective gear	PS		

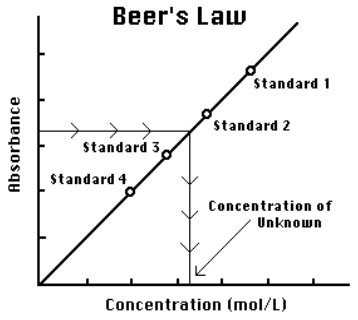
What Do You Think?

The German astronomer Wilhem Beer discovered that the absorbance of light by a solution has a linear relationship to the concentration of a substance in the solution. Can you use the relationship between absorbance and concentration to determine the concentration on an unknown solution?

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

Background

A Colorimeter sends light from a light emitting diode (LED) through a solution placed in a cuvette inside the Colorimeter. The light that passes through the solution strikes a photodiode. A higher concentration of the colored solution absorbs more light and transmits less light than a solution of lower concentration. The Colorimeter monitors the light received by the photodiode as either an *absorbance* or a *percent transmittance* value.



You can use the amount of light that penetrates the solution and strikes the photodiode to compute the absorbance of each solution. A graph of absorbance versus concentration for a series of standard solutions shows a linear relationship (see the figure). The direct relationship between absorbance and concentration for a solution is known as Beer's law.

$$A = \text{constant} \times c = \log_{10} \frac{I_0}{I}$$

In Beer's law, **A** is the absorbance, **c** is the concentration, $\mathbf{I_0}$ is the intensity of radiation before passage through the solution, and **I** is the intensity of radiation transmitted through the solution.

SAFETY REMINDERS

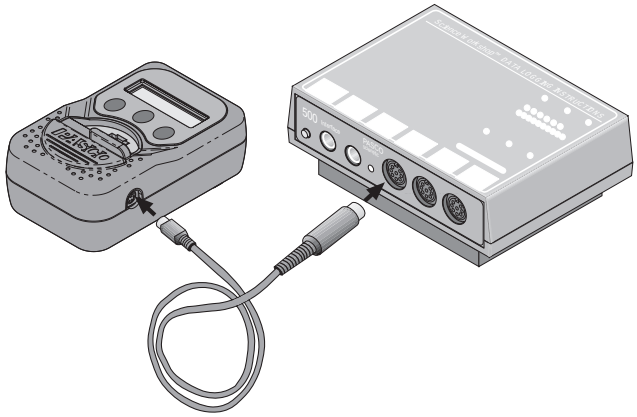
- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

CAUTION: Never pipette by mouth. Always use a pipette bulb or a pipette pump. Be careful when handling any acid or base solutions.

For You To Do

Use the Colorimeter to generate a graph of absorbance versus concentration using solutions of known concentration. Then use the Colorimeter to measure the absorbance of the unknown solution. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use the graph of absorbance versus concentration that you plotted for the standard solutions to determine the concentration of the unknown solution.

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 Colorimeter cable to Analog Channel A on the interface.

- The Colorimeter will automatically turn itself on when it is connected to the *ScienceWorkshop* interface.

3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C27 Beer's Law.DS	C27 Beer's Law	C27_BEER.SWS

- The *DataStudio* file has a Digits display, a Table display, and a Graph display of absorbance versus concentration. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Digits display, a Table display and a Graph display of absorbance versus concentration.
- Data recording is set at one measurement per second (1 Hz). Data recording is also set so that you can manually enter the concentration of the known solutions.

PART II: Sensor Calibration and Equipment Setup

About the Colorimeter

The Colorimeter analyzes colors of light that pass through a solution. The solution is put into a rectangular container called a cuvette, which is then placed inside the Colorimeter. The measure of the amount of light that passes through a solution is called "transmittance". Transmittance is a ratio of the intensity of the transmitted light to the intensity of the original light, and is usually expressed as a percentage.

Absorbance is related to transmittance. The light absorbed by a solution depends on the absorbing ability of the solution, the distance traveled by the light through the solution, and the concentration of the solution. The relationship of absorbance to transmittance is: $A = 2 - \log\%T$

Calibration

The general method for calibrating the Colorimeter is as follows:

- First, calibrate the Colorimeter with a clear cuvette containing distilled water.
- Second, calibrate the software (either *DataStudio* or *ScienceWorkshop*) for one of the four colors of light that can be selected in the Colorimeter. (For this activity you will use the RED wavelength.)

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Note: The cuvette has two clear sides and two ridged sides.

- All cuvettes should be wiped clean and dry on the outside with a tissue.
- Handle cuvettes only by the top edge of the ridged sides.
- All solutions should be free of bubbles.
- Always position the cuvette so the light beam will pass through the clear sides.

Calibrate the Colorimeter

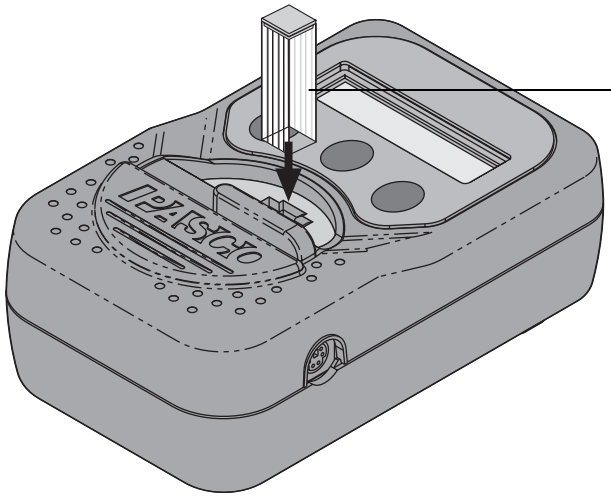
When the Colorimeter comes on, the liquid crystal display (LCD) should say "Please calibrate".

To calibrate the Colorimeter with a clear cuvette, fill a clean cuvette with distilled water and cap the cuvette. (The clear cuvette is a control or 'reference' that accounts for the small amount of light scattered or reflected by the walls of the cuvette.)

On the Colorimeter, press the 'Select' button (Select) and the 'Start/Stop' button (Start/Stop) at the same time.

The Colorimeter's LCD will say "Insert reference then push SELECT".

Place the closed cuvette inside the Colorimeter. Make sure that the clear sides of the cuvette (without ridges) are lined up with the light path in the Colorimeter. Close the lid on the Colorimeter.



On the Colorimeter, press the 'Select' button.

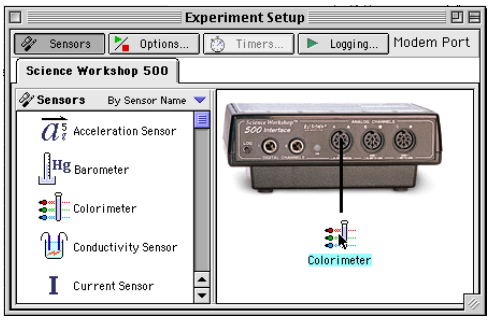
The Colorimeter will *automatically* calibrate itself for all four wavelengths assuming that the light passing through the clear cuvette represents "100% Transmittance". (The automatic calibration takes only a few seconds.)

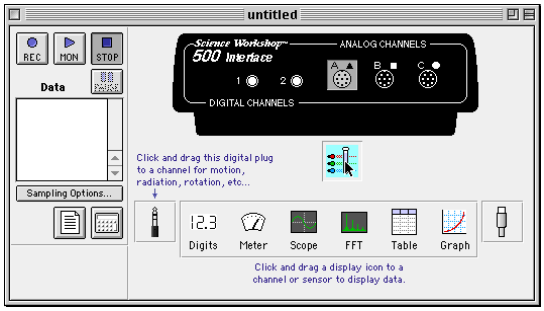
The Colorimeter's LCD will say "CAL done, push SELECT or START".

Calibrate the Software

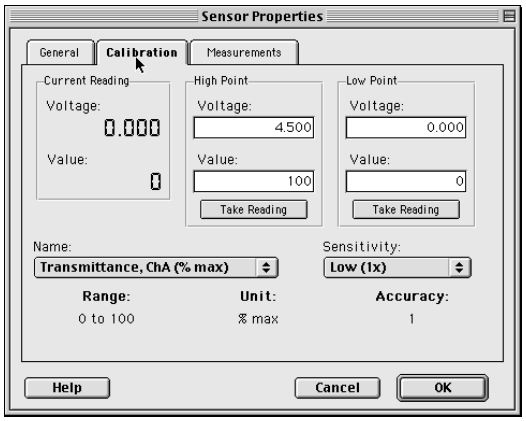
Follow these steps to calibrate the software for one of the four colors of light:

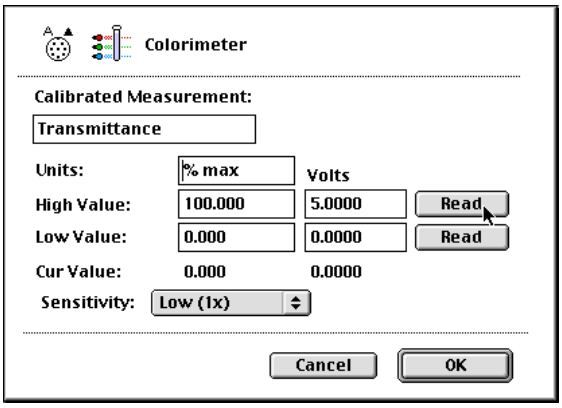
1. Leave the cuvette with distilled water inside the Colorimeter.
2. In the Experiment Setup window, double-click the Colorimeter icon.





- In *DataStudio*, the Sensor Properties window will open. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window will open.





3. Select the color of light.

• NOTE: The default color is RED, so you do not need to change the selection for this activity.

4. Calibrate the software.

- **First**, press the 'Start/Stop' button (

) to start the Colorimeter. (The LCD shows the color and wavelength, the percent transmittance, and "RUN".)
- **Second**, check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*.
- **Third**, 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*.
- **Fourth**, press the 'Start/Stop' button to stop the Colorimeter. (The LCD changes to "STOP".)

5. Click 'OK' to return to the Experiment Setup window.
- The software is now calibrated for the Colorimeter.

Equipment Setup

1. Add about 30 mL of 0.40 Molar copper sulfate ($CuSO_4$) stock solution to a 100-mL beaker. Add about 30 mL of distilled water to another 100-mL beaker.
2. Label four clean, dry, test tubes 1 through 4 (the fifth solution is the beaker of 0.40 M $CuSO_4$).
3. Pipette 2, 4, 6, and 8 mL of 0.40 M $CuSO_4$ solution into Test Tubes 1 through 4, respectively.
4. With a second pipette, deliver 8, 6, 4, and 2 mL of distilled water into Test Tubes 1 through 4, respectively.
5. *Thoroughly* mix each solution with a stirring rod. *Clean and dry the stirring rod between stirrings*.
6. Keep the remaining 0.40 M $CuSO_4$ in the 100-mL beaker to use in the fifth trial.

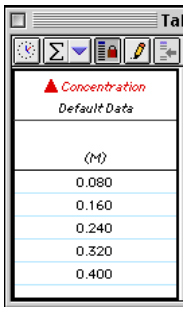
• Volumes and concentrations for the trials are summarized below:

	Volume	Volume	
Trial #	0.40 M $CuSO_4$ (mL)	H_2O (mL)	Concentration (M)
1	2	8	0.08
2	4	6	0.16
3	6	4	0.24
4	8	2	0.32
5	~10	0	0.40

7. Empty the water from the cuvette used during calibration. Using the solution in Test Tube 1, rinse the cuvette twice with approximately 1 mL amounts of solution from the test tube, and then fill the cuvette with solution. Cap the cuvette.
8. Wipe the outside of the cuvette with a tissue and place the cuvette in the Colorimeter. Close the lid.

PART IIIA: Data Recording with *DataStudio* – Solutions with Known Concentrations

1. Arrange the Table display so you can see it clearly.



2. When everything is ready, press the 'Start/Stop' button (

) on the Colorimeter and then start recording data. (Hint: Click 'Start' in *DataStudio*.)

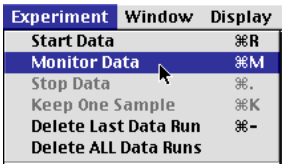
- In *DataStudio*, the 'Start' button changes to a 'Keep' button (

). The Table display shows default values for Concentration.

3. When the Absorbance value stabilizes, click 'Keep' to record the Absorbance value in the Table display.
4. Press the 'Start/Stop' button on the Colorimeter to stop the Colorimeter. Remove the cuvette from the Colorimeter and empty the cuvette. Rinse the cuvette carefully with distilled water. Empty the water from the cuvette.
5. Using the solution in Test Tube 2, rinse the cuvette twice with approximately 1 mL amounts and then fill the cuvette with solution from Test Tube 2. Cap the cuvette. Wipe the outside with a tissue and place the cuvette in the Colorimeter. Close the Colorimeter lid.
6. Press the 'Start/Stop' button on the Colorimeter to start the Colorimeter. When the Absorbance value stabilizes, click 'Keep' in *DataStudio* to record the new Absorbance value.
7. Continue with each of your other samples (for concentrations of 0.24, 0.32, and 0.40 respectively for solutions 3, 4, and 5).
8. After you record the Absorbance for the last solution, stop recording data. Press the 'Start/Stop' button to stop the Colorimeter. Rinse the cuvette with distilled water.

PART IIIB: Data Recording with *DataStudio* - Solution of Unknown Concentration

1. Measure about 10 mL of the unknown $CuSO_4$ into a clean, dry, test tube. Rinse the cuvette twice with approximately 1 mL amounts of the unknown solution and then fill the cuvette with the unknown solution. Cap the cuvette. Wipe the outside with a tissue and place the cuvette in the Colorimeter. Close the Colorimeter lid.



- For this part of data recording, you will monitor the Absorbance of the unknown solution on the Digits display.

2. Press the 'Start/Stop' button to start the Colorimeter. In *DataStudio*, click the Experiment menu and select 'Monitor Data'.
3. When the Absorbance value displayed in the Digits display stabilizes, record the value of Absorbance in your Data Table as the value for the unknown solution.
4. Stop recording data. Press the 'Start/Stop' button to stop the Colorimeter.
5. Discard of the solutions as directed.

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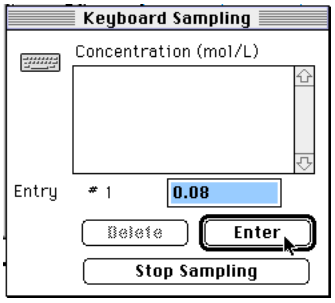
PART IIIA: Data Recording with *ScienceWorkshop* – Solutions with Known Concentrations

1. Click on the Digits display to make it active. Arrange the display so you can see it while recording data.

2. When everything is ready, press the 'Start/Stop' button (Start / Stop) to start the Colorimeter and click the 'REC' button to begin recording data.

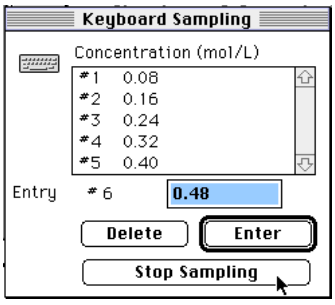


- The Keyboard Sampling window will appear.

3. Wait for the Absorbance value displayed in the Digits display to stabilize. Then enter '0.08' (the concentration of the solution in Test Tube 1) in the Concentration box for Entry # 1, and click the 'Enter' button (Enter).

- The concentration will appear in the list area of the Keyboard Sampling window and the data pair you just collected should appear on the Graph and in the Table display of Absorbance and Concentration.

4. Press the 'Start/Stop' button to stop the Colorimeter. Remove the cuvette from the Colorimeter and empty the cuvette. Rinse the cuvette carefully with distilled water. Empty the water from the cuvette.



5. Using the solution in Test Tube 2, rinse the cuvette twice with approximately 1 mL amounts and then fill the cuvette with solution from Test Tube 2. Cap the cuvette. Wipe the outside with a tissue and place the cuvette in the Colorimeter. Close the Colorimeter lid.

6. Press the 'Start/Stop' button to start the Colorimeter. When the Absorbance value displayed in the Digits display stabilizes, enter the new concentration, 0.16, as before.

7. Continue with each of your other samples entering concentrations of 0.24, 0.32, and 0.40 respectively for solutions 3, 4, and 5.

8. Click 'Stop Sampling' (Stop Sampling) to end data recording for Part IIIA. The Keyboard Sampling window will automatically close. Press the 'Start/Stop' button to stop the Colorimeter.

PART IIIB: Data Recording with *ScienceWorkshop* - Solution of Unknown Concentration

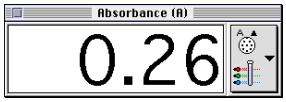
1. Measure about 8 mL of the unknown $CuSO_4$ into a clean, dry, test tube. Rinse the cuvette twice with approximately 1 mL amounts of the unknown solution and then fill the cuvette with the unknown solution. Cap the cuvette. Wipe the outside with a tissue and place the cuvette in the Colorimeter. Close the Colorimeter lid.

- For this part of data recording, you will monitor the Absorbance on the Digits display.

2. Press the 'Start/Stop' button to start the Colorimeter. Click the 'MON' button to begin monitoring the data.

- (The Keyboard Sampling window will open. Ignore it for this part of the experiment.)

3. When the Absorbance value displayed in the Digits display stabilizes, record the value of Absorbance in your Data Table as the value for the unknown solution.

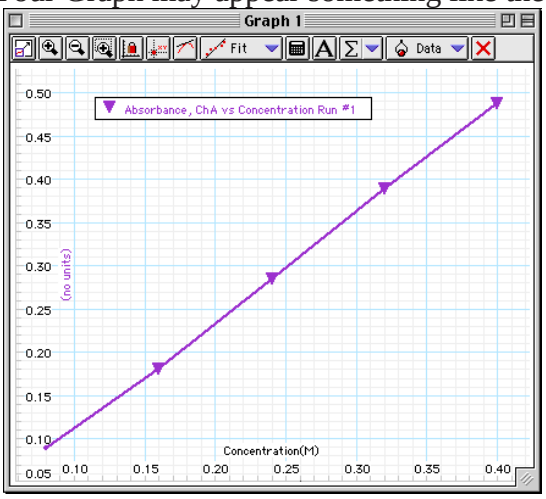


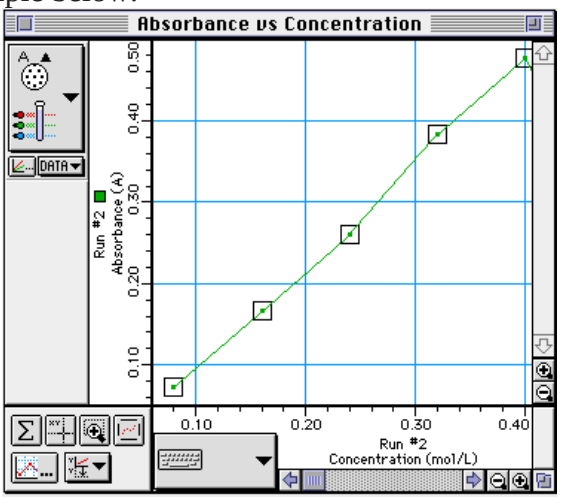
4. Click the 'STOP' button to end data monitoring. Press the 'Start/Stop' button to stop the Colorimeter.

5. Discard of the solutions as directed.

Analyzing the Data

- Your Graph may appear something like the example below.





1. Use the built-in analysis tools in the Graph display to determine the concentration of the unknown solution.

- Hint: Click the 'Smart Tool' () in *DataStudio*. Click the 'Smart Cursor' () in *ScienceWorkshop*.

2. Move the cursor/crosshair so it is on the line joining the data points. Adjust the position of the cursor/crosshair until the y-coordinate matches the Absorbance of the unknown solution.

3. Record the x-coordinate of this point as the concentration of the unknown solution.

Record your results in the Lab Report section.

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Lab Report - Activity C27: Determine the Concentration of a Solution – Beer's Law

What Do You Think?

The German astronomer Wilhem Beer discovered that the absorbance of light by a solution has a linear relationship to the concentration of a substance in the solution. Can you use the relationship between absorbance and concentration to determine the concentration on an unknown solution?

Data Table: Beer's Law

Trial	Absorbance	Concentration (mol/L)
1		
2		
3		
4		
5		
unknown		

Concentration of the unknown	mol/L

Question

1. What is the concentration of the unknown solution?

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Activity C28: Reduction Potentials in Micro-Voltaic Cells (Voltage Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Electrochemistry	C28 Reduction Potentials. DS	C28 Reduction Potentials	C28_REDU.SWS

Equipment Needed	**Qty**	**Chemicals and Consumables**	**Qty**
Voltage Sensor (CI-6503)	1	Filter paper, 11 cm diameter	1 sheet
Eyedropper or pipette	1	Sand paper	1 sheet
Forceps	1 pair	Sodium nitrate, $NaNO_3$, 1.0 Molar	10 mL
Glass plate, 15 cm by 15 cm	1	Solutions of M_1^{2+}, M_2^{2+}, … M_5^{2+}, 1 Molar	2 ml ea.
Metal samples, 1 cm by 1 cm, M_1 … M_5	5		
Scissors	1 pair		
Protective gear	PS		

What Do You Think?

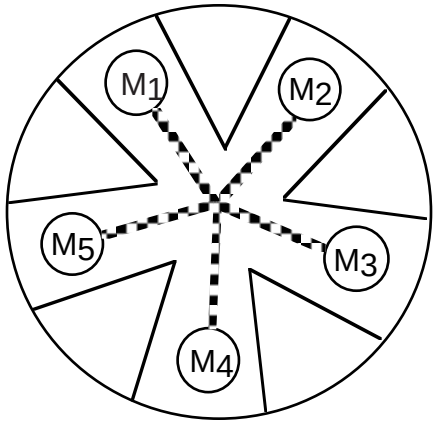
The purpose of this activity is to establish the reduction potentials of five metals relative to an arbitrarily chosen metal. Measure the voltage, or potential difference, between various pairs of 'half-cells'. Which pair of metals will have the largest reduction potential?

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

Background

A voltaic cell uses a spontaneous oxidation-reduction reaction to produce electrical energy. Placing a piece of metal into a solution containing a cation of the metal produces half-cells. For example, a piece of copper metal in a solution of copper sulfate ($CuSO_4$ or Cu^{2+}) is a half-cell.

In this micro-version of a voltaic cell, the half cell is a small piece of metal placed into three drops of corresponding cation solution on a piece of filter paper. The next figure shows the arrangement of half-cells on a piece of filter paper. A porous barrier or a salt bridge normally separates the two half-reactions. Here, the salt bridge is made from several drops of aqueous sodium nitrate ($NaNO_3$) placed on the filter paper linking the two half-cells. Using the computer as a voltmeter, the red (positive) end of the Voltage Sensor makes contact with one metal and the black (negative) end of the Voltage Sensor makes contact with another metal.



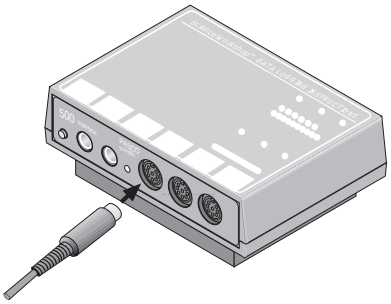
By comparing the voltage values obtained for several pairs of half-cells, and by recording which metal made contact with the red (+) and black (–) ends, you can establish the reduction potential sequence for the metals in this lab.

SAFETY REMINDERS

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

For You To Do

Use the Voltage Sensor to measure the potential difference (voltage) between pieces of different metals that are arranged in a voltaic cell. Use *DataStudio* or *ScienceWorkshop* to record, display, and analyze the data.



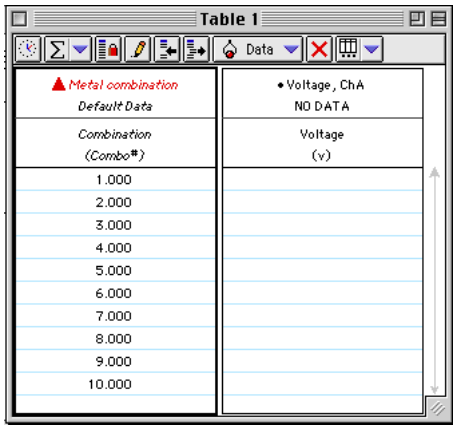
PART I: Computer Setup

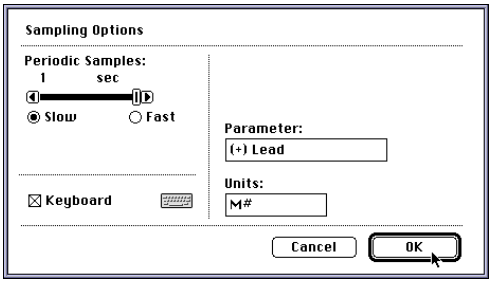
1. Connect the interface to the computer, turn on the interface, and turn on the computer.
2. Connect the DIN plug of the Voltage Sensor to Analog Channel A on the interface.
3. Open the file titled as shown:

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C28 Reduction Potentials. DS	C28 Reduction Potentials	C28_REDU.SWS

- The *DataStudio* file has a Table display with the numbers for each metal-to-metal combination already entered and a Workbook display. Read the instructions in the Workbook display.
- The *ScienceWorkshop* document has a Table display of the voltage with the number of the metal in the half-cell and a Digits display of voltage.
- Data recording is set so there is one measurement per second.
- You will enter the number of each metal-to-metal combination using Manual Sampling in *DataStudio* or Keyboard Sampling in *ScienceWorkshop*.

Note: See the appendix of this activity for instructions on using Keyboard Sampling in *ScienceWorkshop*.





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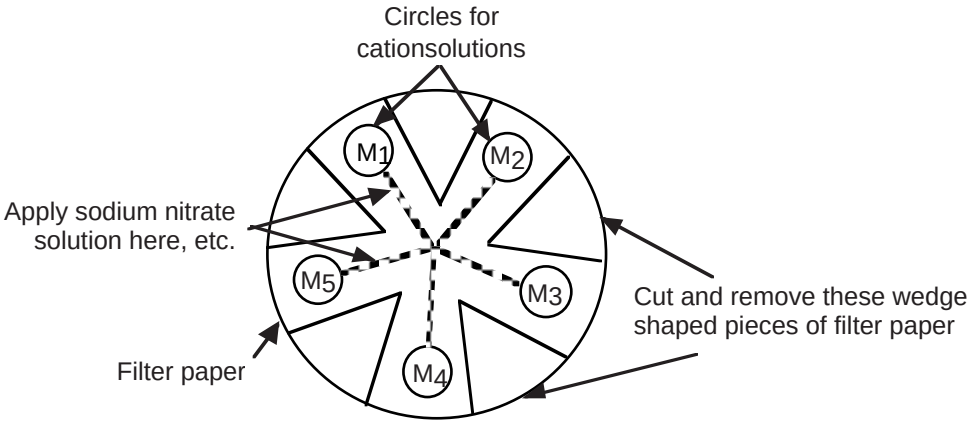
PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Voltage Sensor.

1. Draw five small circles with connecting lines on a piece of circular filter paper, as shown in the diagram.
2. Using a pair of scissors cut wedges between the circles as shown.
3. Label the circles M_1, M_2, M_3, M_4, and M_5. Place the filter paper on top of the glass plate.



Reduction Potentials – Micro-Voltaic Cells

4. Get small pieces of the five metals designated as follows:

Number	M_1	M_2	M_3	M_4	M_5
Metal	Copper	Zinc	Lead	Silver	Iron

5. Sand each piece of metal on both sides. Place each metal near the circle on the filter paper that has the same number.
6. Place three drops of each solution on the appropriate circle (M_1^{2+} on M_1, etc.). Then place the piece of metal on the wet spot with its respective cation.

Caution!

Handle these solutions with care. Some are toxic and others cause hard-to-remove stains. If a spill occurs, inform your instructor.

Number	M_1^{2+}	M_2^{2+}	M_3^{2+}	M_4^{2+}	M_5^{2+}
Solution	Copper sulfate	Zinc sulfate	Lead nitrate	Silver nitrate	Iron sulfate

7. The top side of the metal should be kept dry.
8. Add enough 1 Molar sodium nitrate ($NaNO_3$) solution to make a continuous trail along a line drawn between each circle and the center of the filter paper.
9. You may have to dampen the filter paper with more NaNO3 during the experiment.

PART IIIA: Data Recording – Copper (M_1) as the Reference Metal

1. Click on the Digits display to make it active. Move it so you can see it while recording data.
2. Use M1 (copper) as the reference metal.

- You will measure the potential of four cells by connecting M1 to M2 (copper to zinc), M1 to M3 (copper to lead), M1 to M4 (copper to silver), and M1 to M5 (copper to iron).

3. When everything is ready, start recording data. In *DataStudio*, the 'Start' button changes to a 'Keep' button 

.

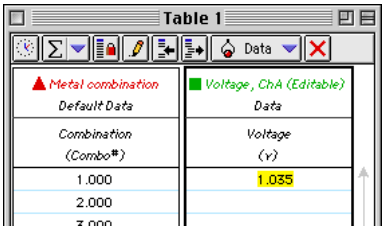
Note: For *ScienceWorkshop* instructions, see the appendix at the end of the activity.

4. Touch the tip of the red (+) end of the Voltage Sensor to one metal sample (for example, M_1) and the tip of the black (-) end to the other metal sample (for example, M_2).

- If the voltage drops to 0.00 V, reverse the ends of the Voltage Sensor, that is, switch the red (+) end of the sensor with the black (-) end of the sensor.

5. Wait about 5 seconds. Record which metal (copper, M_1, or zinc, M_2) is touched by the red (+) end of the Voltage Sensor and which is touched by the black (–) end of the Voltage Sensor. Click 'Keep' to record the voltage in the Table display.

- The voltage value will appear in the cell in the Table next to *"1"* in the Combination (Combo #) column.



6. Use the same procedure to measure the potential of the other three 'cells' (pieces of metal) using copper, M_1, as the reference electrode.

- In other words, measure the potential between copper, M_1, and lead, M_3, then between copper, M_1, and silver, M_4, and finally between copper, M_1, and iron, M_5.

7. Touch the ends of the Voltage Sensor to the next pair of metal samples (M_1 and M_3).

- Remember to switch the ends of the sensor if the voltage drops to 0.00 V.

8. Click 'Keep', to record the voltage in the Table.
9. Record which metal was touched by the tip of the red (+) end of the Voltage Sensor and which metal was touched by the black (-) end of the sensor.
10. Analyze your data for copper and *make predictions* about the rest of the half-cell combinations before you make any measurements of voltage for the other half-cell combinations.

Record your data in the Lab Report section.

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Analyzing the Data: PART IIIA - Copper (M_1) as the Reference Metal

1. After finishing Part IIIA of the procedure, use the measured voltages from your Table to arrange the five metals (including copper, M_1) in Data Table 2 from the lowest reduction potential at the top (most negative) to the highest reduction potential at the bottom (most positive).

- **Give copper, M_1, the reference metal, an arbitrary value of 0.000 V.**
- **If the other metal (e.g., zinc, M_2, lead, M_3, silver, M_4, or iron, M_5) was touched by the *negative* (black) end of the Voltage Sensor, place it *above* copper, M_1, in the chart (with a negative E° value).**
- **If the other metal was touched by the *positive* (red) end of the Voltage Sensor, place it *below* copper, M_1, in the chart (with a positive E° value).**

2. Also in Data Table 2, record the numerical value of the Reduction Potential (voltage) relative to copper, M_1, for each of the other metals (zinc, M_2, lead, M_3, silver, M_4, and iron M_5).

- **The Reduction Potential is the value that is recorded in the *DataStudio* Table display.**
- **Remember: If the metal is *above* copper in the list in Data Table 2, the Reduction Potential is negative. If the metal is *below* copper in the list in Data Table 2, the Reduction Potential is positive.**

Predictions

1. Calculate a predicted potential difference for each of the remaining half-cell combinations shown in Data Table 3 (M_2/M_3, M_2/M_4, M_3/M_5 and M_3/M_4, M_3/M_5 and M_4/M_5) using the reduction potentials you just determined (in Data Table 2).
2. Record the predicted cell potential differences in Data Table 3.

Record your predictions in the Lab Report section.

3. Go on to Part IIIB and finish the activity.

PART IIIB: Data Recording – Non-copper Reference Metals

1. Go back to data recording.
2. Measure the potential differences of the six remaining half-cell combinations using the same procedure as in Part IIIA.

- If the NaNO3 salt bridge solution has dried, you may re-moisten it.

3. Click 'Keep' to record each measured Reduction Potential (voltage) in the *DataStudio* Table display.
4. When you have finished your measurements, stop recording data.

Clean-Up

1. Use forceps to remove each of the pieces of metal from the filter paper. Remember to avoid getting the solutions on your hands.
2. Rinse each piece of metal with tap water, dry, and return it to the correct container.
3. Remove the filter paper from the glass plate using the forceps, and discard it as directed by your teacher. Rinse the glass plate with tap water, making sure that your hands do not come in contact with wet spots on the glass.
4. Clean and dry the ends of the Voltage Sensor. (Do not wash them. Instead, wipe the ends with a slightly damp paper towel and then dry them.)

Analyzing the Data: PART IIIB - Non-copper Reference Metals

1. Compare the measured half-cell reduction potentials with your *predicted* half-cell reduction potentials in Data Table 3.
2. Calculate the percent difference between your prediction and the measured value for each of the potentials you measured in Part IIIB.

- **Optional:** Find the reduction potential chart in your textbook and identity of metals M_2 through M_5. If your book has an oxidation potential chart, all the reactions will be reversed and the signs will be switched on all the potentials. Reminder: H_2 has a reduction potential of 0.00 V on the textbook chart. Locate copper, M_1, on the chart, and then determine possible identities of the other metals using your experimental reduction potential sequence in Data Table 2. You must add the difference in potential between H_2 and copper to all values in Table 2. Note: One of the metals has a 1^+ oxidation state; the remainder of the metals have 2^+ oxidation states.

Record your data in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C28: Reduction Potentials in Micro-voltaic Cells

What do you think?

The purpose of this activity is to establish the reduction potentials of five metals relative to an arbitrarily chosen metal. Measure the voltage, or potential difference, between various pairs of 'half-cells'. Which pair of metals will have the largest reduction potential?

Data Table 1: Copper as the Reference Metal

Number	Combination	Potential	Metal For Red (+) Tip	Metal For Black (-) Tip
1	Copper/Zinc			
2	Copper/Lead			
3	Copper/Silver			
4	Copper/Iron			

Data Table 2: Rank the Metals

Metal	Lowest (-) Reduction Potential, E°
	Highest (+) Reduction Potential, E°

Data Table 3: Predictions and Results

Number	Half-Cell Combination	Predicted Potential	Measured Potential	Percent Difference (%)
5	Zinc/Lead			
6	Zinc/Silver			
7	Zinc/Iron			
8	Lead/Silver			
9	Lead/Iron			
10	Iron/Silver			

Question

1. How well did your predictions match the measured values for the potential differences measured using non-copper reference metals?

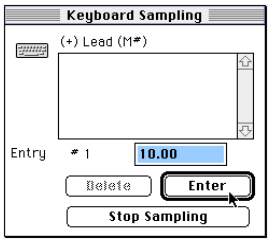
Appendix: Using Keyboard Sampling in ScienceWorkshop

- Do the following to record voltage data and the metal-to-metal combination using Keyboard Sampling in ScienceWorkshop.

1. Click on the Digits display to make it active. Move it so you can see it while recording data.
2. Use M1 (copper) as the reference metal.

- You will measure the potential of four cells by connecting M1 to M2 (copper to zinc), M1 to M3 (copper to lead), M1 to M4 (copper to silver), and M1 to M5 (copper to iron).

3. When everything is ready, start recording data.

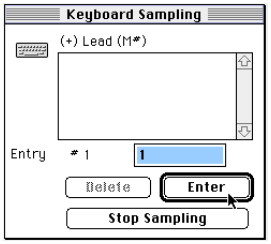


- **The Keyboard Sampling window will appear.**

4. Touch the red (+) end of the Voltage Sensor to one metal sample (copper, M_1) and the black (-) end to the other metal sample (zinc, M_2).

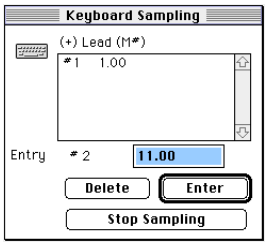
- **If the voltage drops to 0.00 V, reverse the leads, that is, switch the red (+) lead and the black (-) lead.**

5. Wait about 5 seconds. Read the voltage in the Digits display and record the value in Data Table 1. Also record which metal (M_1 or M_2) is touched by the red (+) end of the Voltage Sensor and which is touched by the black (–) end of the Voltage Sensor.
6. Once you have recorded the voltage of the half-cell and which metal was touched by the red end of the sensor in your Data Table, go the Keyboard Sampling window.
7. In the Keyboard Sampling window, enter the <u>number</u> of the metal sample (either 1 or 2) that was touched by the red (+) lead of the Voltage Sensor. Click "Enter".



- **Your number will replace the default value in the Keyboard Sampling window. (NOTE: In this example, the number is "1".)**
- **This process creates the Table of Voltage (V) and [+] Lead (M#) and makes a record of the potentials measured.**

8. Use the same procedure and measure the potential of the other three cells, continuing to use M_1 as the reference electrode. (In other words, measure the potential between M_1 and M_3, then between M_1 and M_4, and finally between M_1 and M_5).



9. Touch the ends of the sensor to the next pair of metal samples (M_1 and M_3). Remember; switch the ends of the sensor if the voltage drops to 0.00 V.
10. Read and record the voltage in Data Table 1.
11. Also record the label (e.g., M_1 or M_3, etc.) of the metal that was touched by the red (+) end in the Data Table.
12. Go to the Keyboard Sampling window and enter the <u>number</u> of the metal (e.g., 1 or 3) that was touched by the red (+) end of the sensor. Click "Enter".
13. When you have recorded data for the half-cells using M1 (copper) as the reference metal, click the "Pause" button to temporarily halt data recording while you analyze your data for Part IIIA.

Name _____ Class _____ Date _____

Activity C29: Electroplating – Faraday's Law of Electrolysis (Power Amplifier)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Electrochemistry	C29 Electroplating.DS	C29 Electroplating	C29_ELEC.SWS

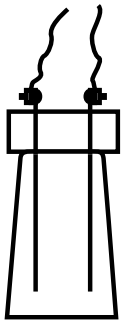
Equipment Needed	Qty	Equipment Needed	Qty
***ScienceWorkshop* 750 Interface**	1	**Patch cord (SE-9750)**	2
Power Amplifier (CI-6552A)	1	Protective gear	PS
Alligator clip adapter (SE-9756)	2		
Balance (SE-8723)	1	**Chemicals and Consumables**	**Qty**
Base and support rod (ME-9355)	1	Copper wire, heavy gauge	5 – 10 cm
Beaker, 1 L	1	Copper (II) sulfate, 1 molar	250 mL
Clamp, buret (SE-9446)	2	Metal spoon	1
Graduated cylinder	1	Towel, paper	1

What Do You Think?

What is the relationship between the moles of copper atoms oxidized from a copper wire and the number of electrons that passed through the wire?

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

Background



In 1832, Michael Faraday observed that the amount of substance undergoing oxidation or reduction at an electrode in an electrochemical cell during electrolysis is directly proportional to the amount of electricity that passes through the cell. This statement is known as Faraday's Law of Electrolysis. The quantitative unit of electricity, now called the **faraday**, is the amount of electricity that reduces one gram-equivalent weight of a substance at the cathode of an electrochemical cell and oxidizes one gram-equivalent weight of a substance at the anode. This corresponds to the gain or loss, and therefore the passage, of Avogadro's number of electrons.

The faraday is equivalent to 96,487 coulombs (ampere x seconds).

The equation for the reduction of copper (II) ions at the cathode is:

$$Cu^{2+} + 2e^{-} \longrightarrow Cu$$

One mole of copper ions needs two moles of electrons to form one mole of copper atoms.

1 mole of ions + 2 moles of electrons ---> 1 mole of atoms

63.55 g (copper ions) + 2 faradays ---> 63.55 g (copper atoms)

From this equation we see that 63.55 grams of copper "plate out" onto the cathode for every two faradays of electric charge. Of course, the same amount of copper would oxidize from the anode.

Faraday's Law of Electrolysis suggests that 31.77 grams of copper plate out for 96,487 coulombs (one faraday) of electric charge.

SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

For You To Do

Use the Power Amplifier to send a current through electrodes (a copper wire and a metal spoon) that are immersed in a copper sulfate solution. Use the *DataStudio* or *ScienceWorkshop* program to record the current, voltage and amount of time. Measure the amount of copper that oxidizes from the copper wire (the anode). Use the software to integrate under the curve of current versus time to determine the amount of charge.

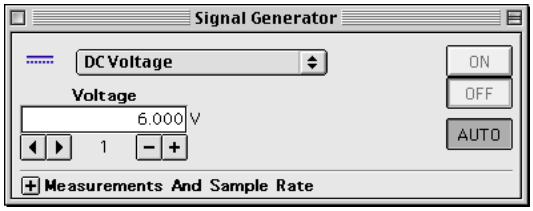
Compare the amount of charge to the mass of copper to determine the faraday.

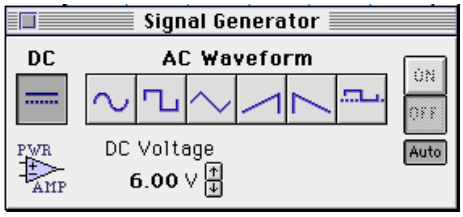
PART I: Computer Setup

1. Connect a *ScienceWorkshop* 750 interface to the computer, turn on the interface, and turn on the computer.
2. Connect the DIN plug of the Power Amplifier to Analog Channel A on the interface. DO NOT turn on the Power Amplifier yet.
3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C29 Electroplating.DS	C29 Electroplating	C29_ELEC.SWS

- The DataStudio file has a Graph of current versus time, a Digits display of current, and a Signal Generator window. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display of current versus time and a Signal Generator window.
- Data recording is set at one measurement per second (1 Hz) and will stop automatically at 3600 seconds (60 minutes).
- The Signal Generator is set to output 6.00 V DC (direct current). The 'ON/OFF button is set to 'Auto' so the Signal Generator will start automatically when you start to collect data and stop automatically when you stop collecting data.





Name _____ Class _____ Date _____

PART II: Sensor Calibration and Equipment Setup

- You do not need to calibrate the Power Amplifier.

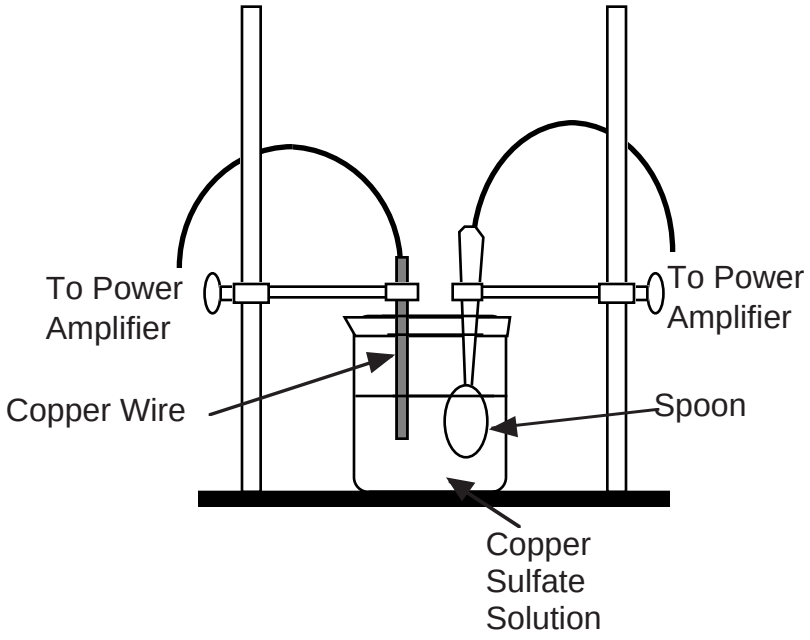
1. Put 250 mL of 1 molar copper sulfate, $CuSO_4$, solution into the beaker.

2. Carefully measure and record the mass of the piece of heavy gauge copper wire.

3. Use an alligator clip adapter to attach one end of a patch cord to one end of the heavy gauge copper wire (the anode). Connect the patch cord to the positive (red) output terminal of the Power Amplifier.

4. Attach one end of another patch cord to one end of the spoon (the cathode). Connect the patch cord to the negative (black) output terminal of the Power Amplifier.

5. Use clamps to suspend the heavy gauge copper wire and the spoon on the support rods. Position the end of the wire and the spoon so they are immersed in the solution in the beaker.



PART III: Data Recording

1. When you are ready to begin, turn on the switch on the back of the Power Amplifier.
2. Begin recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*).

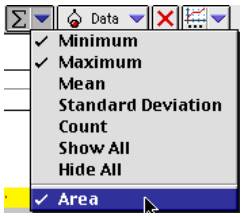
• The Power Amplifier output will automatically start when data recording begins.

3. Data recording will continue for sixty minutes and then stop automatically.
4. When data recording is complete, turn off the switch on the back of the Power Amplifier.
5. Carefully lift the heavy gauge copper wire from the solution and remove the patch cord.
6. Dry the copper wire so no copper sulfate solution remains on the wire.
7. Carefully measure and record the new mass of the copper wire.
8. Dispose of the solution as instructed.

Analyzing the Data

1. Use the built-in analysis tools in the Graph to find the area under the curve of current versus time.

• Hint: In *DataStudio*, click the 'Statistics menu' button () and then select 'Area' from the menu. In *ScienceWorkshop*, click the 'Statistics' button () to open the statistics area. Click the 'Statistics menu' button () and select 'Integration'.



2. Record the value for the area under the current versus time curve. This is the number of coulombs (ampere • seconds) of electricity.
3. Use your data to calculate the number of coulombs per faraday.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C29: Electroplating

What Do You Think?

What is the relationship between the moles of copper atoms oxidized from a copper wire and the number of electrons that passed through the wire?

Data Table

Item	Amount
mass of copper before	g
mass of copper after	g
difference in mass	g
coulombs (Amps*sec)	C

Calculations

Calculate the number of coulombs per faraday using the number of coulombs of electric charge and the difference in mass of the copper anode:

$$\frac{\#\,\textbf{coulombs}}{\textbf{faraday}} = \frac{(\quad)\,\textbf{coulombs}}{(\quad)\,\textbf{g}} \times \frac{\textbf{31.77g}}{\textbf{faraday}} =$$

Questions

1. How does your calculated value for a faraday of charge compare to the accepted value?
   (Remember, percent difference $= \left|\frac{\text{measured} - \text{accepted}}{\text{accepted}}\right| \times 100\%$.)

The accepted value is 96,487 coulombs per faraday.

2. How would your results be different if you had used a silver wire and a silver solution to silver plate the spoon?

3. If the Power Amplifier produced a lower average current but the overall time remained the same, how would this effect the following measurement or calculations?

	More	Same	Less
Mass of copper lost from the wire			
Moles of electrons moving through the wire			
Coulombs generated			
The value of a faraday			

4. You only measured the mass lost by the wire. What do you think was the change in the mass of the spoon?

5. The blue color of the copper sulfate solution is due to the Cu+2 in the solution. If the experiment would continue to run well past the sixty minutes, what would happen to the color of the copper sulfate solution? Explain your reasoning.

Name _____ Class _____ Date _____

Activity C30: pH versus Time for Antacid (pH Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Acids, bases & salts	C30 pH versus Time.DS	C30 Antacid	C30_ANTA.SWS

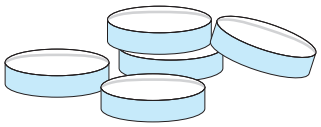
Equipment Needed	Qty	Chemicals and Consumables	Qty
pH Sensor (CI-6507A)	1	Antacid tablet	4
Base and support rod (ME-9355)	1	Buffer solution: high pH	100 mL
Beaker, 250 mL	4	Buffer solution: low pH	100 mL
Clamp, buret (SE-9446)	1	Hydrochloric acid, 0.10 molar	100 mL
Graduated cylinder	1	Paper, waxed, 10 by 10 cm	2
Magnetic stirrer and stir bar	1	Water, distilled	500 mL
Mallet	1		
Wash bottle	1		
Protective gear	PS		

What Do You Think?

How does the ability of a solid antacid tablet to neutralize excess acid compare to the ability of a crushed antacid tablet to neutralize excess acid?

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

Background



The main components of the digestive fluid in the human stomach are pepsinogen (an inactive form of the enzyme pepsin) and hydrochloric acid (HCl). The acid promotes the conversion of pepsinogen into its active form and provides the necessary pH in which the enzyme pepsin can break down protein molecules. When excessive digestive fluid (gastric juice) is secreted it may contribute to the formation of an ulcer in the stomach lining. One of the most common remedies for excessive digestive fluid (stomach acidity) is antacid tablets. These tablets neutralize excess acid in the digestive fluid. The acid-base neutralization between the antacid and the HCl in the digestive fluid is as follows:

Antacid (weak base) + HCl (stomach acid) --> H_2O + CO_2 + salts

Antacid tablets contain a buffer to moderate the change in pH. They also contain other ingredients such as flavoring agents and substances that make the tablet hold together.

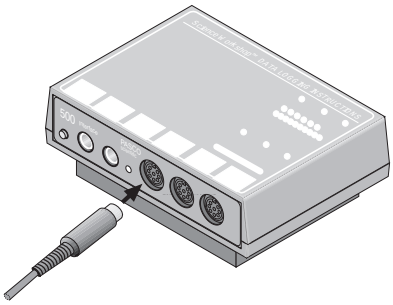
The first part of the procedure uses a solid antacid tablet. The second part uses a crushed antacid tablet.

SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

For You To Do

Use the pH Sensor to measure the change in pH of a dilute hydrochloric acid solution when you add antacid tablets to the solution. Measure the change for solid tablets and then measure the change for crushed tablets. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use your data to compare the rate at which the solid and crushed tablets neutralize the solution.



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 pH Sensor to Analog Channel A on the interface.
3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C30 pH versus Time.DS	C30 Antacid Law	C30_ANTA.SWS

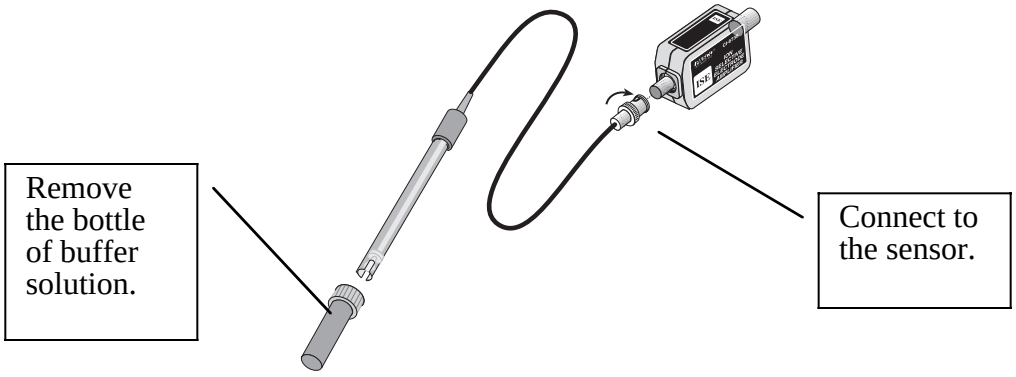
- The *DataStudio* file has a Graph display. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display of the pH versus time.
- Data recording is set at one measurement per second (1 Hz). Data recording will stop automatically at 600 seconds.

PART II: Sensor Calibration and Equipment Setup

Calibrate the Sensor

- To calibrate the pH Sensor you will need the following: wash bottle, distilled water, three beakers, buffer solutions of high pH (e.g. pH 10) and low pH (e.g. pH 4), pH Sensor.
- Put distilled water into the wash bottle and into one of the beakers. Put about 100 mL of the high pH buffer solution in one of the other two beakers and about 100 mL of the low pH buffer solution into the third beaker.

1. Remove the pH electrode from its bottle of buffer solution. Connect the electrode to the pH Sensor amplifier. To connect the electrode, push the BNC plug onto the receptacle on the Sensor amplifier and turn the BNC plug clockwise until it ‘clicks’ into place.



2. Use the wash bottle to rinse the end of the electrode. Soak the pH electrode in the beaker of distilled water for 10 minutes.

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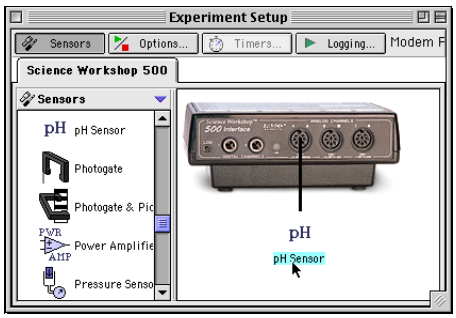
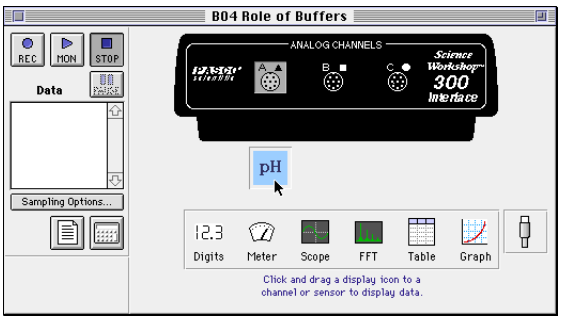
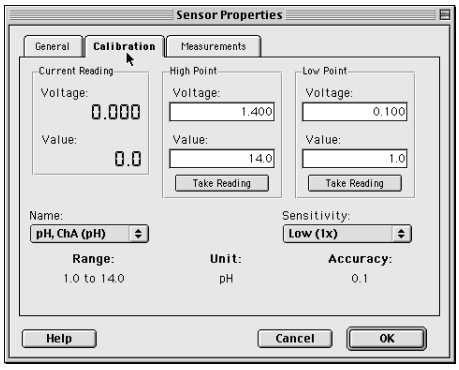
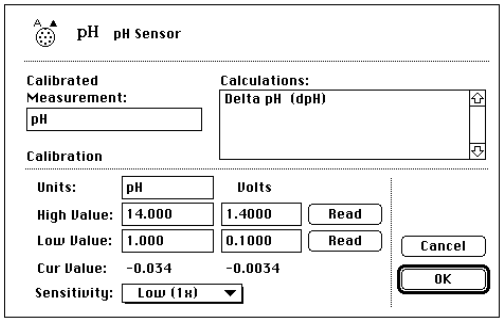
3. In the Experiment Setup window, double-click the pH Sensor icon.





- In *DataStudio*, the Sensor Properties window will open. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window will open.





4. Calibrate with the high pH buffer solution.

- Put the end of the pH electrode into the high pH buffer solution.
- 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 'High Point' in *DataStudio* or the 'Read' button in the row for 'High Value:' in *ScienceWorkshop*.
- Enter the pH value of the buffer solution.

5. Thoroughly rinse the pH electrode with distilled water and dry it with a tissue.

6. Calibrate with the low pH buffer solution.

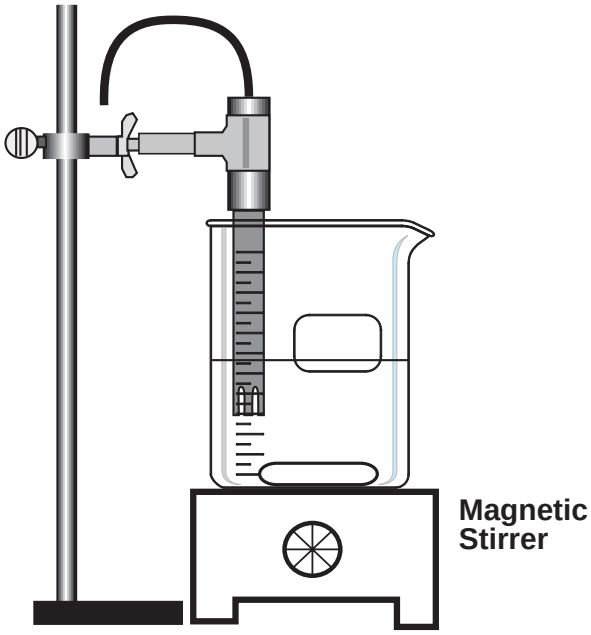
- Put the end of the pH electrode in the low pH buffer solution.
- Check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*.
- When the voltage stabilizes, click the 'Take Reading' button under 'Low Point' in *DataStudio* or the 'Read' button in the row for 'Low Value:' in *ScienceWorkshop*.
- Enter the pH value of the buffer solution. Click **OK** to return to the Experiment Setup window.

7. Thoroughly rinse the pH electrode with distilled water and dry gently.

Equipment Setup – Whole Antacid Tablets

- For this part you will need the following: two antacid tablets, acid solution, pH Sensor, clamp, base and support rod, beaker, magnetic stirrer and stir bar, each brand of antacid used you will need two beakers of acid solution and two antacid tablets.

1. Put 50 mL of 0.10 Molar hydrochloric acid (HCl) into a clean dry beaker.
2. Carefully put a spin bar in the beaker. Place the beaker and spin bar on the magnetic stirrer.
3. Use a clamp and base and support rod to position the pH electrode so the end of the electrode is in the acid solution, but will not interfere with the spin bar.
4. Turn on the magnetic stirrer. (Note: If a magnetic stirrer is not available, carefully stir the solution with a stirring rod.)



PART IIIA: Data Recording – Whole Antacid Tablet

1. When you are ready, start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)
2. Drop two whole antacid tablets into the solution.

- Data recording will stop automatically after 600 seconds.

3. When data recording stops, turn off the magnetic stirrer. Remove the pH Sensor from the solution.
4. Rinse the pH Sensor in distilled water and dry the sensor gently.
5. Carefully empty the beaker as instructed. Remove the stir bar.
6. Rinse and dry the beaker.

Equipment Setup – Crushed Antacid Tablet

- For this part you will need the following: two antacid tablets, waxed paper, mallet, acid solution, equipment setup from the first part of data recording.

1. Crush two tablets of the same kind of antacid that you used in Part IIIA. (Fold the wax paper over the tablet and use a mallet or hammer to crush the tablet. Be careful not to damage the table or lose any of the tablets.)
2. Carefully return the spin bar to the beaker.
3. Put 50 mL of 0.10 Molar hydrochloric acid into the beaker and place the beaker with the spin bar on the magnetic stirrer.
4. Use a clamp and base and support rod to position the pH electrode so the end of the electrode is in the acid solution, but will not interfere with the spin bar.
5. Turn on the magnetic stirrer.

PART IIIB: Data Recording – Crushed Antacid Tablet

1. When you are ready, start recording data.
2. Drop the crushed antacid tablets into the solution.

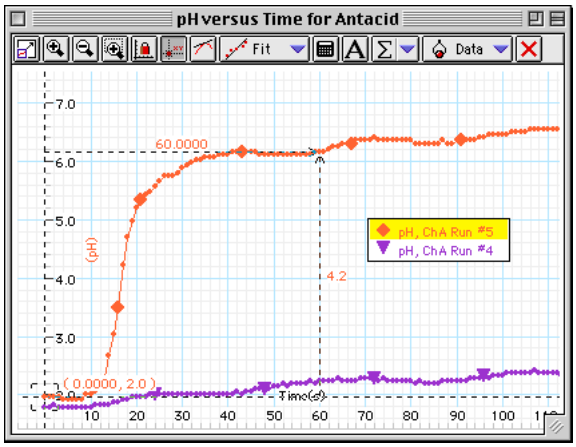
- Data recording will stop automatically after 600 seconds.

3. When data recording stops, turn off the magnetic stirrer. Remove the pH sensor from the solution.
4. Rinse the pH sensor in distilled water and dry the sensor gently.
5. Carefully empty the beaker as instructed. Remove the stir bar.
6. Rinse and dry the beaker.

Analyzing the Data

1. Use the Graph display analysis tools to find the rate of change of pH (change of pH per unit of time) for the whole antacid tablets versus the crushed antacid tablets.

- Hint: One possibility is to use the ‘Smart Tool’ in *DataStudio* or the ‘Smart Cursor’ in *ScienceWorkshop*. Put the cursor on a point at the beginning of the plot and then use the ‘delta’ function of the ‘Smart Tool’ or ‘Smart Cursor’ as you move the cursor to another point on the plot. The change in ‘x’ is the amount of time and the change in ‘y’ is the change in pH.



2. Convert the time from seconds to minutes and then calculate the change in pH per minute by dividing the change in pH by the time.

$$\frac{\Delta pH}{min} = \frac{final\ pH - initial\ pH}{final\ Time - initial\ Time}$$

3. Repeat the data analysis procedure for the crushed tablets.
4. Record your data for the whole tablets and the crushed tablets in the Lab Report section.

Optional

- If you have more than one brand of antacid, repeat the data recording and data analysis procedure for the other whole and crushed antacid tablets you have.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C30: pH versus Time for Antacid

What Do You Think?

How does the ability of a solid antacid tablet to neutralize excess acid compare to the ability of a crushed antacid tablet to neutralize excess acid?

Data Table

Antacid	Whole or Crushed	ΔpH	ΔT (min)	ΔpH/min
Sample 1				
Sample 1				
Sample 2				
Sample 2				

Questions

1. Does the rate of change of pH depend on whether the tablet is crushed or whole?

2. Does the overall change of pH depend on whether the table is crushed or whole?

Optional

1. Which type of antacid has the highest neutralization strength? Which type of antacid has the lowest strength?

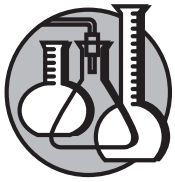
Name _____ Class _____ Date _____

Activity C31: Neutralization of Vinegar with Drain Cleaner (pH Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Acids, bases & salts	C31 Neutralize Vinegar.DS	C31 Vinegar	C31_VINESWS

Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
pH Sensor (CI-6507A)	1	Wash bottle	1
Balance (SE-8723)	1	Protective gear	PS
Base and support rod (ME-9355)	1		
Beaker, 250 mL	5	**Chemicals and Consumables**	**Qty**
Buret, 50 mL	1	Buffer solution: high pH	100 mL
Clamp, buret (SE-9446)	2	Buffer solution: low pH	100 mL
Funnel	1	Drain cleaner (w/o aluminum)	3.3 g
Graduated cylinder	1	Vinegar (5% acetic acid)	100 mL
Magnetic stirrer and stir bar	1	Water, distilled	500 mL

What Do You Think?



The first purpose of this activity is to determine the K_a (acid dissociation constant) of vinegar (mild acetic acid). The second purpose of the activity is to determine the pH of the equivalence point of the reaction between acetic acid and the base used to neutralize the acid. Will the pH of the equivalence point be acidic, basic, or neutral?

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

Background

Vinegar is a solution of acetic acid in water at a concentration of about 5% or 0.83 Molar. Granulated drain cleaner is a solid consisting mostly of lye (sodium hydroxide). Vinegar is an acid and drain cleaner is a base. An acid reacts with a base to form a salt and water in a reaction called neutralization.

All acids ionize in water to form hydronium ions (H_3O^+) and an anion. The generalized equation for this ionization is as shown where **Q** represents the anion:

$$HQ + H_2O \text{ =====> } H_3O^+ + Q^-$$

For strong acids such as hydrochloric acid (HCl), nitric (HNO_3), and sulfuric acid (H_2SO_4), ionization is complete. No acid remains in the molecular form.

$$HCl + H_2O \text{ =====> } H_3O^+ + Cl^-$$

For weak acids however, the ionization reaction reaches equilibrium. When a weak acid ionizes it reaches a point where the ions recombine to form a molecule of acid at the same rate that acid molecules ionize.

$$HX + H_2O \text{ <=====> } H_3O^+ + X^-$$

Acetic acid is a weak acid. When it dissolves it ionizes to form hydronium ions and acetate ions. However, at a particular concentration the ions recombine to form acetic acid at the same rate that the molecules of acid ionize.

$$HC_2H_3O_2 + H_2O \text{ <=====> } H_3O^+ + C_2H_3O_2^-$$

When the rate of the forward and reverse reactions are equal, the acid has reached an equilibrium between ionized and unionized molecules. This equilibrium point has a special name. It is called the K_a of the acid. Mathematically, the K_a of an acid is:

$$K_a = \frac{[H_3O^+] \times [X]}{[HX]}$$

and for acetic acid:

$$K_a = \frac{[H_3O^+] \times [C_2H_3O_2^-]}{[HC_2H_3O_2^-]}$$

When sodium hydroxide reacts with acetic acid, sodium acetate (a salt) and water are formed.

$$NaOH + HC_2H_3O_2 \text{ ========> } NaC_2H_3O_2 + H_2O$$

The degree to which the salt breaks down is the solubility product dissociation constant or K_{sp}. The K_{sp} is the negative antilog of the pH at the equivalence point of the neutralization. The pH at the equivalence point is also the pH of the salt, sodium acetate.

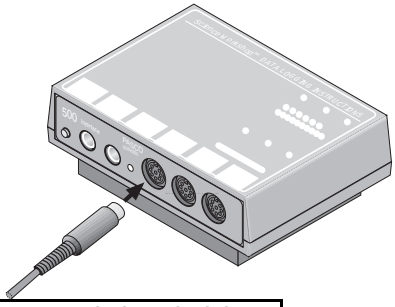
SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

For You To Do

Use the pH Sensor to measure the change in pH of a dilute acetic acid solution when you add a small quantity of drain cleaner solution to it at a constant rate. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use your data to determine the acid dissociation constant (K_a) and the pH of the equivalence point. Determine whether the equivalence point is acidic, basic, or neutral.

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 pH Sensor to Analog Channel A on the interface.
3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C31 Neutralize Vinegar.DS	C31 Vinegar	C31_VINESWS

- The *DataStudio* file has a Graph display. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display of the pH versus time.
- Data recording is set at ten measurements per second (10 Hz).

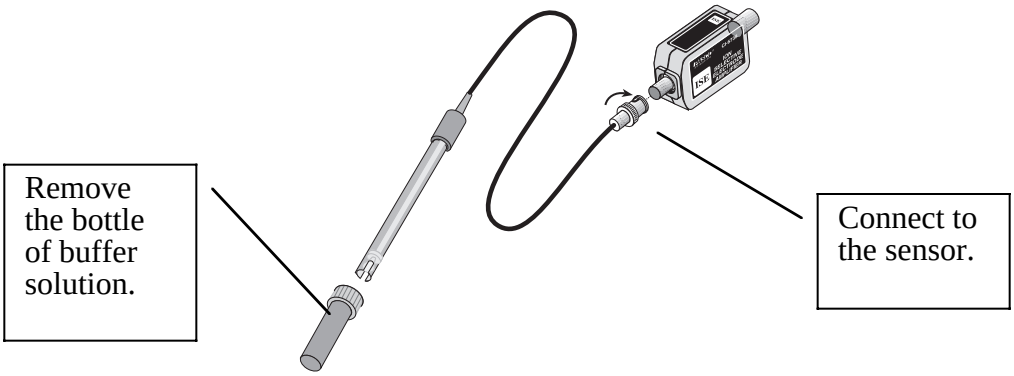
Name _____ Class _____ Date _____

PART II: Sensor Calibration and Equipment Setup

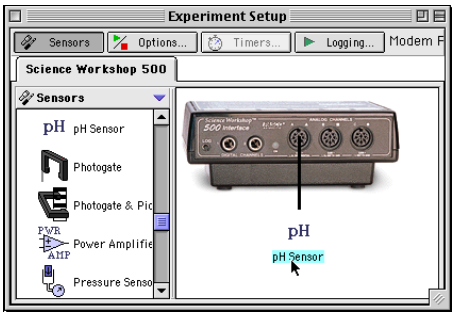
Calibrate the Sensor

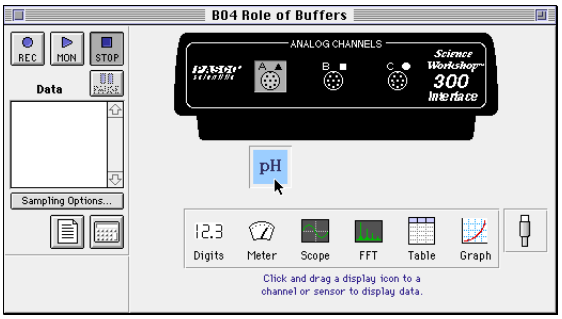
- To calibrate the pH Sensor you will need the following: wash bottle, distilled water, three beakers, buffer solutions of high pH (e.g. pH 10) and low pH (e.g. pH 4), pH Sensor.
- Put distilled water into the wash bottle and into one of the beakers. Put about 100 mL of the high pH buffer solution in one of the other two beakers and about 100 mL of the low pH buffer solution into the third beaker.

1. Remove the pH electrode from its bottle of buffer solution. Connect the electrode to the pH Sensor amplifier. To connect the electrode, push the BNC plug onto the receptacle on the Sensor amplifier and turn the BNC plug clockwise until it 'clicks' into place.

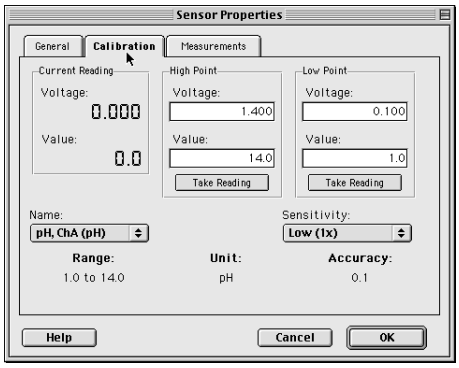


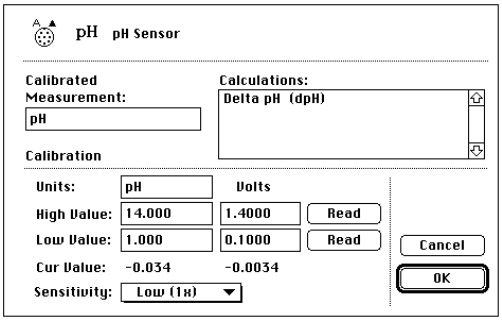
2. Use the wash bottle to rinse the end of the electrode. Soak the pH electrode in the beaker of distilled water for 10 minutes.
3. In the Experiment Setup window, double-click the pH Sensor icon.





- In *DataStudio*, the Sensor Properties window will open. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window will open.





4. Calibrate with the high pH buffer solution.

- Put the end of the pH electrode into the high pH buffer solution.
- 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 'High Point' in *DataStudio* or the 'Read' button in the row for 'High Value:' in *ScienceWorkshop*.
- Enter the pH value of the buffer solution.

5. Thoroughly rinse the pH electrode with distilled water and dry it with a tissue.
6. Calibrate with the low pH buffer solution.

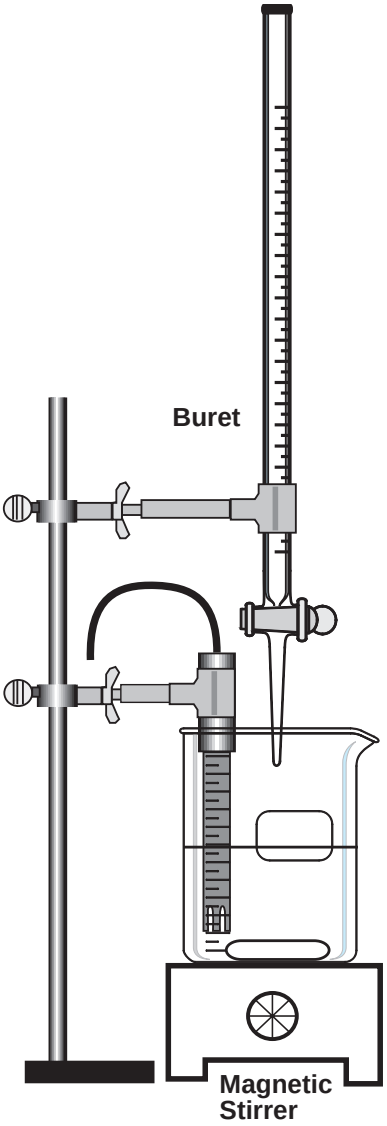
- Put the end of the pH electrode in the low pH buffer solution.
- Check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*.
- When the voltage stabilizes, click the 'Take Reading' button under 'Low Point' in *DataStudio* or the 'Read' button in the row for 'Low Value:' in ScienceWorkshop.
- Enter the pH value of the buffer solution. Click OK to return to the Experiment Setup window.

7. Thoroughly rinse the pH electrode with distilled water and dry gently.

Equipment Setup

- For this part you will need the following: balance, drain cleaner, water, two beakers, 50-mL buret, pH Sensor, two clamps, base and support rod, magnetic stirrer and stir bar, vinegar.

1. Dissolve 3.3 grams of drain cleaner in 100 mL of distilled water.
2. Place 100 mL of vinegar in a 250-mL beaker. Put a spin bar in the beaker.
3. Place the beaker with vinegar and spin bar on the magnetic stirrer.
4. Use a clamp and base and support rod to position the pH electrode so the end of the electrode is in the vinegar, but will not interfere with the spin bar.
5. Use another clamp to support the 50-mL buret so the end of the buret is above the vinegar. (Be sure the buret valve is closed!)
6. Put 50 mL of the drain cleaner solution into the buret. (Keep the other 50 mL of solution in its beaker.)
7. Turn on the magnetic stirrer. (Note: If a magnetic stirrer is not available, carefully stir the vinegar with a stirring rod.)



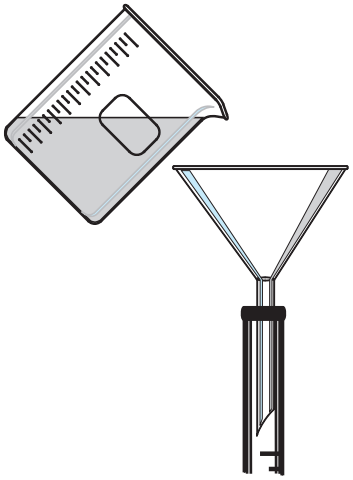
Name _____ Class _____ Date _____

PART III: Data Recording

- Have the following items ready: funnel, beaker with 50 mL of drain cleaner solution.

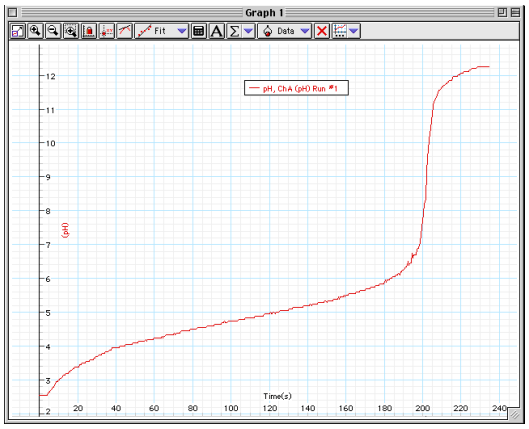
1. When you are ready, start recording data. (Hint: In *DataStudio*, click 'Start'. In *ScienceWorkshop*, click 'REC'.)
2. Open the buret valve so the drain cleaner solution pours into the vinegar at a slow, constant rate.

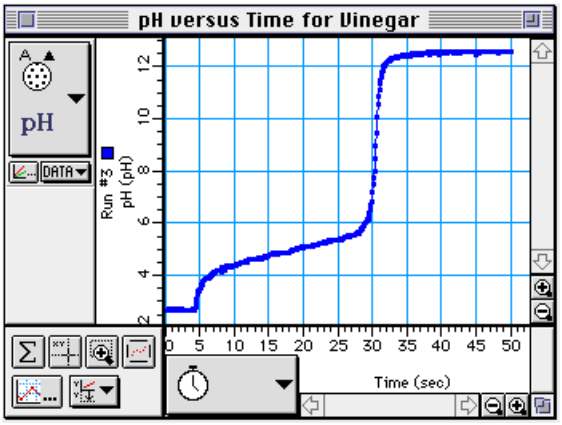
- Adjust the buret valve so the solution flows at a rate of about 3 mL per second.
- Before the buret is completely empty, put the funnel in the top of the buret and pour in the remaining 50 mL of drain cleaner solution.



3. When all of the drain cleaner solution is added to the vinegar, stop recording data.
4. Turn off the magnetic stirrer.
5. Carefully remove the pH electrode, rinse it thoroughly in distilled water, and put it in its bottle of buffer solution.
6. Carefully remove the buret and rinse it several times to remove all remnants of the drain cleaner solution.
7. Dispose of the solution in the beaker as instructed.

Analyzing the Data





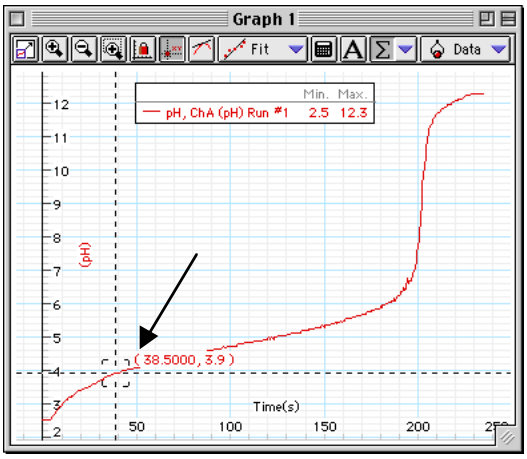
Use the software data analysis tools to determine the following:

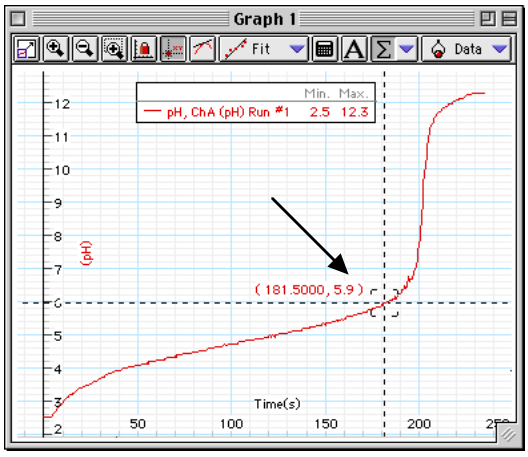
- Initial and final pH.
- Acid dissociation constant: The acid dissociation constant (K_a) is the negative antilog of pK_a, The value of pK_a is the pH at the *midpoint* of the gradual increase during the first part of the plot of data.
- Equivalence point: The equivalence point is the pH value at the midpoint of the almost vertical part of the plot of data.

1. Use the built-in statistics in the Graph display to find the initial and final pH. (Hint: In *DataStudio*, click the 'Statistics' button (). The minimum and maximum values appear in the Graph legend. In *ScienceWorkshop*, click the 'Statistics' button () to open the statistics area. Click the 'Statistics menu' button () and select 'Minimum' and 'Maximum'.)

2. Find the value of pK_a. Use the 'Smart Tool' () in *DataStudio* or the 'Smart Cursor' () in *ScienceWorkshop* to find the pH at the midpoint of the gradual increase during the first part of the plot of data.

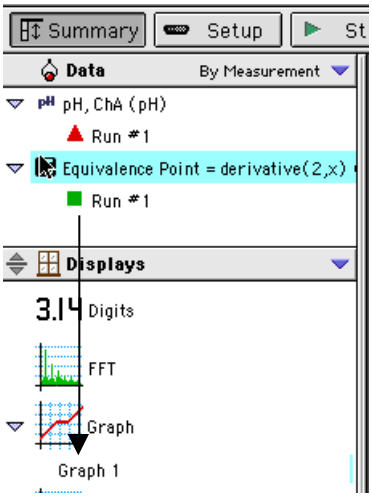
- Hint: Put the cursor at the beginning of the most linear part of the gradual increase section and make a note of the y-coordinate at that point. Then move the cursor to the point where the pH begins to rise sharply and make another note of the y-coordinate at the second point. Move the cursor to a point exactly halfway between the first and second point, and record the y-coordinate at that point.



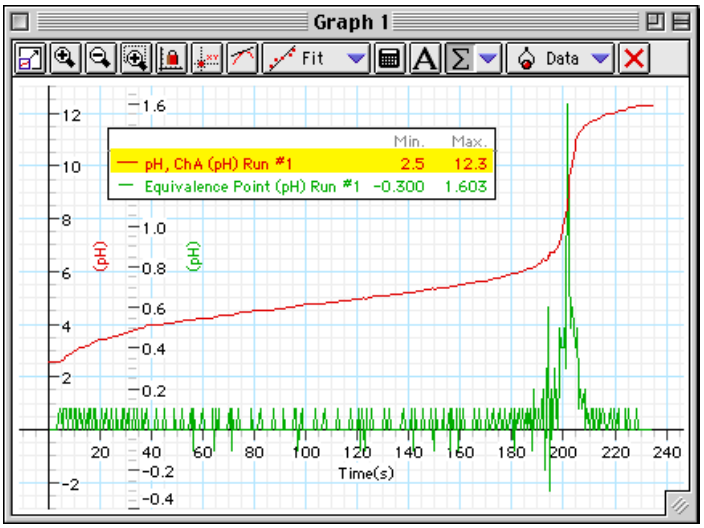


3. Find the pH at the equivalence point (the midpoint of the nearly vertical section of the plot). Use the 'Derivative' function to find the place where the *change* in pH is maximum.

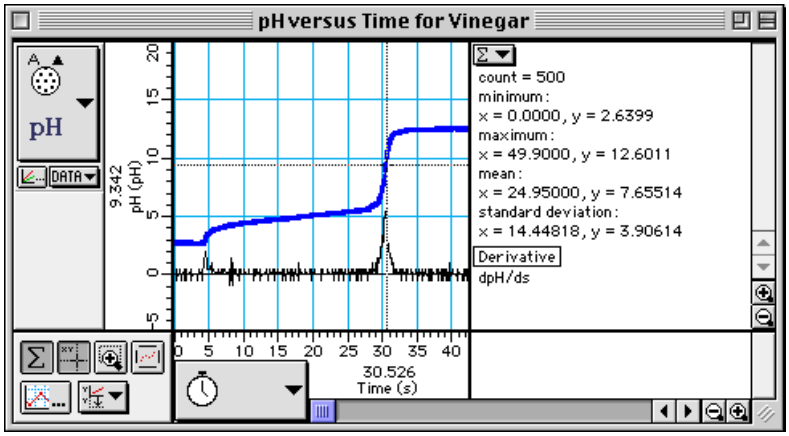
- Hint: In *DataStudio*, click-and-drag 'Run #1' under the 'Equivalence Point' calculation in the Summary list to 'Graph 1' in the Display list. (This adds a plot of the derivative of pH with respect to time to the Graph display.)



- Click the 'Graph Settings menu' button () in the Graph display and select 'Multiple Y Scales' from the menu. (This overlays the plot of the derivative of pH and the plot of pH. Notice that the maximum peak of the derivative of pH is at the midpoint of the nearly vertical section of the plot of pH.)



- Click 'pH, ChA' in the Graph's legend to make the pH plot active. Then use the 'Smart Tool' to find the coordinates of the point where the derivative plot intersects the pH plot. Record the y-coordinate of this point as the pH of the equivalence point.
- Hint: In *ScienceWorkshop*, click the 'Statistics menu' button and select 'Derivative' from the menu.



Use the 'Smart Cursor' to line up the highest peak of the derivative with a point on the plot of pH. Record the y-coordinate of this point as the pH of the equivalence point.

4. Use the value of pK_a to find the value of K_a. (Remember, K_a is the negative antilog of pK_a.)

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C31: Neutralization of Vinegar with Drain Cleaner

What Do You Think?

The first purpose of this activity is to determine the K_a (acid dissociation constant) of vinegar (mild acetic acid). The second purpose of the activity is to determine the pH of the equivalence point of the reaction between acetic acid and the base used to neutralize the acid. Will the pH of the equivalence point be acidic, basic, or neutral?

Data Table

Item	Value
beginning pH	
ending pH	
estimate of pH for pK_a	
estimate of pH for equivalence point	
K_a for the acid	

Questions

1. What was the beginning pH of the vinegar solution?

2. What was the pH of the ending solution of vinegar and drain cleaner?

3. What is the pK_a of the acid? What is the K_a of the acid?

4. The reaction of acetic acid and sodium hydroxide forms sodium acetate. What does the pH of the equivalence point (the pK_{sp} of the salt, sodium acetate) tell you about the salt?

Name _____ Class _____ Date _____

Activity C32: Acid-Base Titration (pH Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Acids, bases & salts	C32 Titration.DS	C32 Acid-Base Titration	C32_ACID.SWS

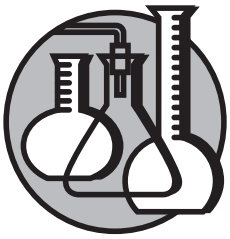
Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
pH Sensor (CI-6507A)	1	Wash bottle	1
Base and support rod (ME-9355)	1	Protective gear	PS
Beaker, 250 mL	6	**Chemicals and Consumables**	**Qty**
Buret, 50 mL	1	Buffer solution: high pH	100 mL
Clamp, buret (SE-9446)	2	Buffer solution: low pH	100 mL
Graduated cylinder	1	Hydrochloric acid, unknown	10 mL
Magnetic stirrer and stir bar	1	Sodium hydroxide, 0.10 molar	100 mL
Pipette, 10 mL	1	Water, distilled	500 mL

What Do You Think?

In this activity you can use a computer to measure pH as you add 0.10 molar sodium hydroxide to hydrochloric acid of unknown concentration. Can you use a graph of pH versus volume to determine the equivalence point? Can you use the volume of the sodium hydroxide titrant used at the equivalence point to determine the molarity of the hydrochloric acid?

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

Background



A titration is a process used to determine the volume of a solution needed to react with a given amount of another substance. For example, when a hydrochloric acid solution is titrated with a sodium hydroxide solution, the pH of the acidic solution is initially low. As the base is added, the change in pH is quite gradual until close to the equivalence point, where equimolar amounts of acid and base have been mixed. Near the equivalence point, the pH increases very rapidly. The change in pH then becomes more gradual again before leveling off with the addition of excess base.

Hydrogen ions from the hydrochloric acid react with hydroxide ions from the sodium hydroxide in a one-to-one ratio to produce water in the overall reaction:

$$H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \text{ ---> } H_2O + Cl^-(aq) + Na^+(aq)$$

Because the overall reaction is one-to-one, the number of moles of hydrochloric acid equals the number of moles of sodium hydroxide. The molarity of the hydrochloric acid is as follows:

$$\text{molarity HCl} = \frac{\#\,\text{moles HCl}}{\text{volume HCl}} = \frac{\#\,\text{moles HCl}}{0.01\ \text{L HCl}}$$

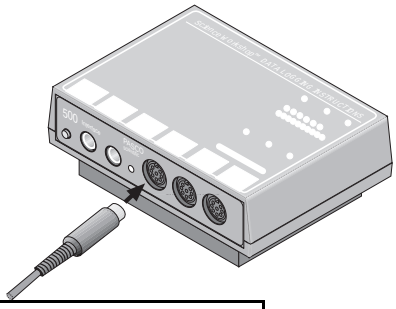
SAFETY REMINDERS

- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

CAUTION: Never pipette by mouth. Always use a pipette bulb or a pipette pump. Be careful when handling any acid or base solutions.

For You To Do

Titrate hydrochloric acid solution, HCl, with a basic sodium hydroxide solution, NaOH, of known molarity. Use the pH Sensor to measure the change in pH of the acid solution. Use *DataStudio* or *ScienceWorkshop* to record the change in pH of the acid and the volume of basic solution added. Use the software to display your data and use your data to determine the concentration (molarity) of the acid solution.



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 pH Sensor to Analog Channel A on the interface.
3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C32 Titration.DS	C32 Acid-Base Titration	C32_ACID.SWS

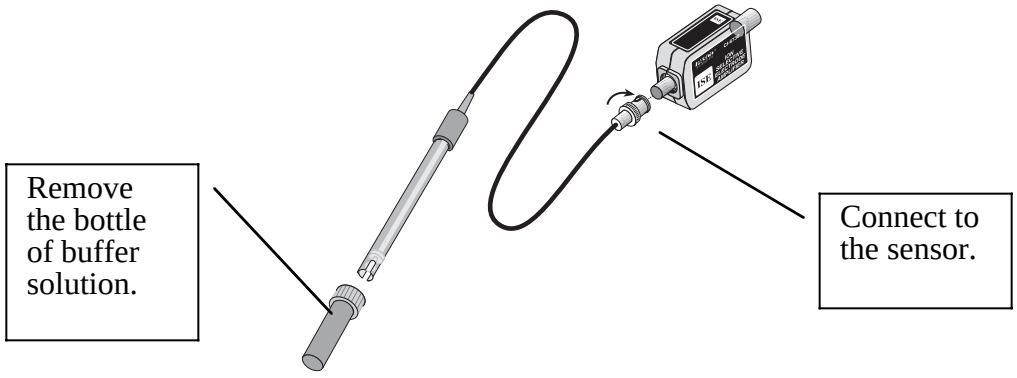
- The *DataStudio* file has a Digits display, a Table display, and a Graph display of pH versus volume. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Digits display, a Table display and a Graph display of the pH versus volume.
- Data recording is set at one measurement per second (1 Hz). Data recording is also set so that you can manually enter the volume of the sodium hydroxide titrant.

PART II: Sensor Calibration and Equipment Setup

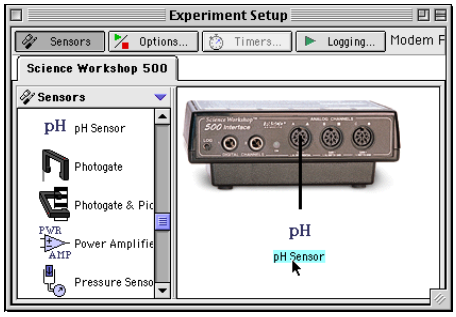
Calibrate the Sensor

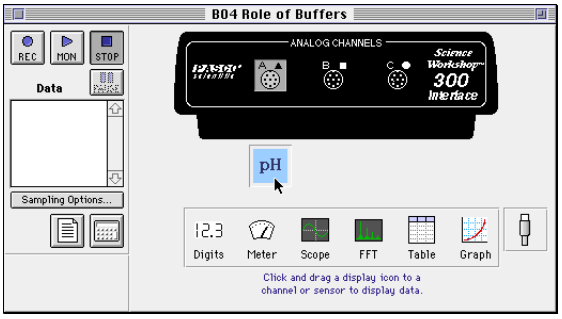
- To calibrate the pH Sensor you will need the following: wash bottle, distilled water, three beakers, buffer solutions of high pH (e.g. pH 10) and low pH (e.g. pH 4), pH Sensor.
- Put distilled water into the wash bottle and into one of the beakers. Put about 100 mL of the high pH buffer solution in one of the other two beakers and about 100 mL of the low pH buffer solution into the third beaker.

1. Remove the pH electrode from its bottle of buffer solution. Connect the electrode to the pH Sensor amplifier. To connect the electrode, push the BNC plug onto the receptacle on the Sensor amplifier and turn the BNC plug clockwise until it ‘clicks’ into place.

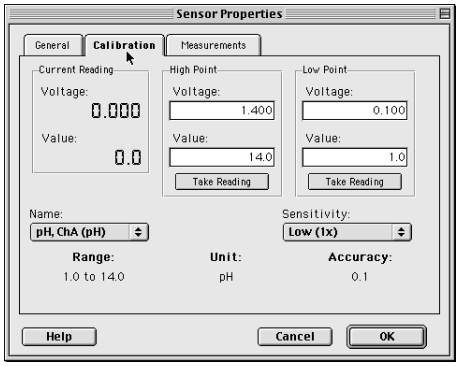


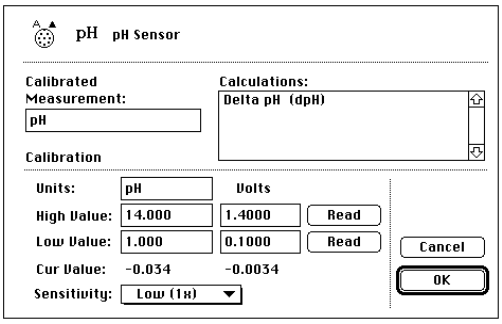
2. Use the wash bottle to rinse the end of the electrode. Soak the pH electrode in the beaker of distilled water for 10 minutes.
3. In the Experiment Setup window, double-click the pH Sensor icon.





- In *DataStudio*, the Sensor Properties window will open. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window will open.





4. Calibrate with the high pH buffer solution.

- Put the end of the pH electrode into the high pH buffer solution.
- 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 'High Point' in *DataStudio* or the 'Read' button in the row for 'High Value:' in *ScienceWorkshop*.
- Enter the pH value of the buffer solution.

5. Thoroughly rinse the pH electrode with distilled water and dry it with a tissue.
6. Calibrate with the low pH buffer solution.

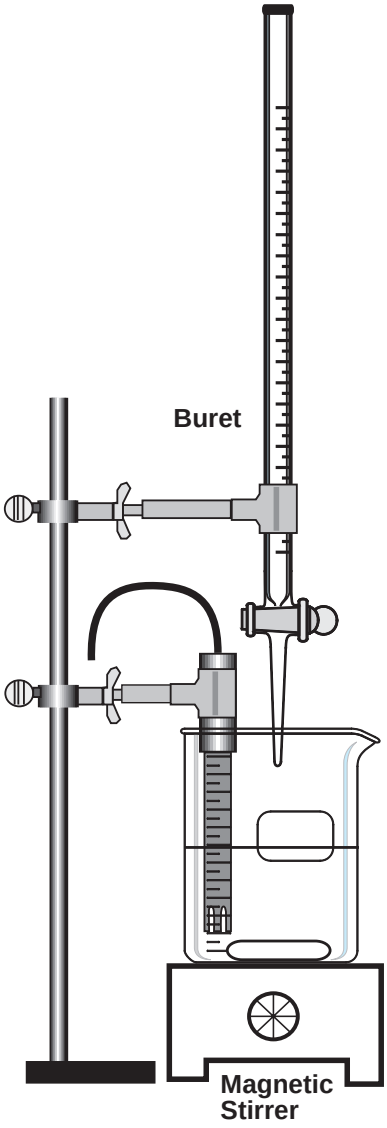
- Put the end of the pH electrode in the low pH buffer solution.
- Check the voltage under 'Current Reading' in *DataStudio* or next to 'Cur Value:' in *ScienceWorkshop*.
- When the voltage stabilizes, click the 'Take Reading' button under 'Low Point' in *DataStudio* or the 'Read' button in the row for 'Low Value:' in *ScienceWorkshop*.
- Enter the pH value of the buffer solution. Click **OK** to return to the Experiment Setup window.

7. Thoroughly rinse the pH electrode with distilled water and dry gently.

Equipment Setup

- For this part you will need the following: hydrochloric acid solution, distilled water, 250-mL beakers, 50-mL buret, pH Sensor, buret clamps, base and support rod, magnetic stirrer and stir bar, 0.10 molar sodium hydroxide solution.

1. Put 50 mL of distilled water into a clean dry 250-mL beaker.
2. Use a pipette to add 10.00 mL of the hydrochloric acid solution into the beaker with the distilled water.
3. Carefully add a spin bar to the beaker. Place the beaker on the magnetic stirrer.
4. Use a clamp and base and support rod to position the pH electrode so the end of the electrode is in the acid solution, but will not interfere with the spin bar.
5. Rinse the 50-mL buret with a few milliliters of the 0.100 molar sodium hydroxide solution. Dispose of the rinse solution as directed.
6. Use another clamp to support the 50-mL buret so the end of the buret is above the acid solution. (Be sure the buret valve is closed!)
7. Fill the buret with 0.100 molar sodium hydroxide solution. Be sure to start the titration with the buret filled exactly to the 0.00 mL mark.
8. Turn on the magnetic stirrer. (Note: If a magnetic stirrer is not available, carefully stir the solution with a stirring rod.)
9. Record the precise concentration of the sodium hydroxide solution in the Lab Report section.



PART III: Data Recording – Acid-Base Titration

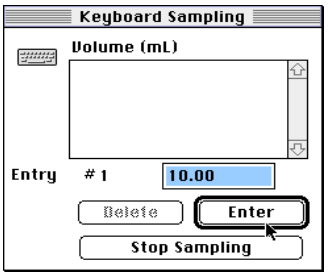
- Note: Data recording goes faster if one person controls the buret value and reads the volume of titrant added to the acid while a second person operates the computer and enters the volumes.

- In *DataStudio*, arrange the displays so you can see the Table. In *ScienceWorkshop*, arrange the displays so you can see the Digits display.

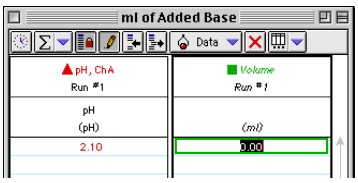
1. When you are ready, start recording data. (Hint: Click 'Start' in *DataStudio* or click 'REC' in *ScienceWorkshop*.)

- In *DataStudio*, the 'Start' button changes to a 'Keep' button (

). In *ScienceWorkshop*, the 'Keyboard Sampling' window opens.



2. In *DataStudio*, the first row of the Table shows the beginning value of pH.

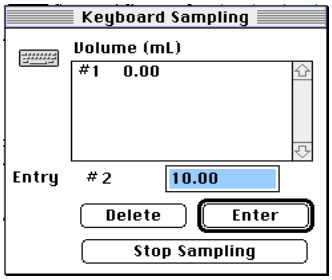


In *ScienceWorkshop*, the Digits display shows the pH reading.

NOTE: Do not add any NaOH titrant for the first reading.

When the pH value stabilizes, click the 'Keep' button in *DataStudio* and then click the Tab key to move to the next row in the Table. In *ScienceWorkshop*, type in "0.00" in the Keyboard Sampling window for Entry #1, and then click the 'Enter' button (Enter).

- In *DataStudio*, the Table shows the first 'pH, volume' pair in the first row. In *ScienceWorkshop*, the 'Keyboard Sampling' dialog box changes to show the number you entered.

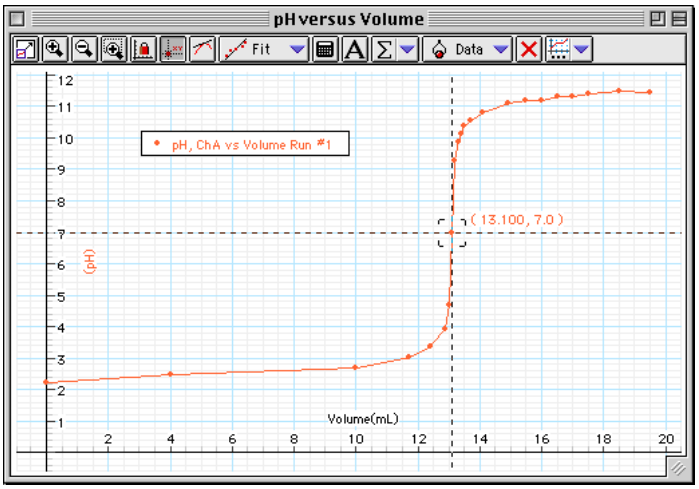


3. Open the buret's valve and add the first amount of NaOH. Add enough titrant to raise the pH by 0.15 units and then close the valve.
4. After the titrant has been added and the pH reading stabilizes, type the total volume of NaOH added into the next row in the Table in *DataStudio* and then click the 'Keep' button. In *ScienceWorkshop*, type the volume into the 'Keyboard Sampling' window and click the 'Enter' button.
5. Add the next increment of NaOH (enough to raise the pH by 0.15 units). When the pH stabilizes, type in the total amount of NaOH added and then click the 'Keep' button and then the Tab key (in *DataStudio*) or click the 'Enter' button (in *ScienceWorkshop*).
6. Continue adding NaOH solution in amounts that raise the pH by about 0.15 units and type in the total volume of NaOH added each time.
7. When pH 3.5 is reached, change to 2-drop increments. Continue to type in the total volume of NaOH added after each increment.
8. After pH 10 is reached, again add larger increments of NaOH (enough to raise the pH by about 0.15 units) and type in the total volume of NaOH added.
9. Add NaOH until the pH remains constant. Stop data recording. (Hint: In *DataStudio*, click the 'Stop' button (). In *ScienceWorkshop*, click the 'Stop Sampling' button (Stop Sampling). The Keyboard Sampling window will automatically close.)
10. When data recording stops, turn off the magnetic stirrer. Remove the pH sensor from the solution. Rinse the pH sensor in distilled water and dry the sensor gently.
11. Dispose of the solution in the beaker as instructed.

- If time permits, repeat the procedure.

Analyzing the Data

1. Use the 'Smart Tool' in *DataStudio* or the 'Smart Cursor' in *ScienceWorkshop* to find the value of the pH in the plot of Run #1 just before the largest pH increase. Record the X-coordinate as the "NaOH volume added before largest pH increase".
2. Move the 'Smart Tool' or 'Smart Cursor' to the place in the plot of Run #1 just after the largest pH increase. Record the X-coordinate as the "NaOH volume added after largest pH increase".
3. Calculate and record the average of the NaOH volumes just before and just after the largest pH increase.
4. Move the 'Smart Tool' or 'Smart Cursor' to the point on the plot of Run #1 where the pH is 7.0 (or as close as possible). Record the X-coordinate as the "NaOH volume added at the equivalence point.



- The average of the volume of NaOH just before and just after the largest pH increase should equal the volume of NaOH added at pH = 7.

5. Calculate the number of moles of NaOH used.
6. Use the equation for the neutralization reaction to calculate the number of moles of HCl used.

- Recall that you pipetted out 10.00 mL of the unknown HCl solution for the titration.

7. Calculate the HCl concentration in mole/liter (mol/L).

Optional

- If you did two titrations, determine the average concentration of HCl.

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C32: Acid-Base Titration

What Do You Think?

In this activity you can use a computer to measure pH as you add 0.10 molar sodium hydroxide to hydrochloric acid of unknown concentration. Can you use a graph of pH versus volume to determine the equivalence point? Can you use the volume of the sodium hydroxide titrant used at the equivalence point to determine the molarity of the hydrochloric acid?

Data Table

Use volume in liters for the calculations.

moles NaOH = volume x molarity.

moles HCl = # moles NaOH

$$\text{molarity HCl} = \frac{\#\,\text{moles HCl}}{\text{volume HCl}} = \frac{\#\,\text{moles HCl}}{0.01\ \text{L HCl}}$$

	Trial 1	Trial 2
Volume HCl	mL	mL
Concentration of NaOH	M	M
NaOH volume added before largest pH increase	mL	mL
NaOH volume added after largest pH increase	mL	mL
Average of NaOH before and after pH increase	mL	mL

NaOH volume added at equivalence point	mL	mL
Moles NaOH	mol	mol
Moles HCl	mol	mol
Concentration of HCl	mol/L	mol/L
Average (HCl)	M	

Question

1. Based on your data, what is the concentration of hydrochloric acid?

Name _____ Class _____ Date _____

Activity C33: Determine pK_a by Half Titration (pH Sensor)

Concept	*DataStudio*	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
Acids, bases & salts	C33 Half Titration.DS	C33 Half Titration	C33_HALF.SWS

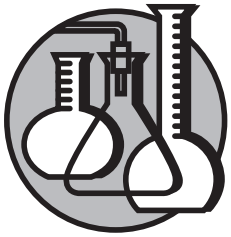
Equipment Needed	**Qty**	**Equipment Needed**	**Qty**
pH Sensor (CI-6507A)	1	Wash bottle	1
Base and support rod (ME-9355)	1	Protective gear	PS
Beaker, 250 mL	5		
Buret, 50 mL	1	**Chemicals and Consumables**	**Qty**
Clamp, buret (SE-9446)	2	Acetic acid, 0.1 molar	100 mL
Funnel	1	Buffer solution: high pH	100 mL
Graduated cylinder	1	Buffer solution: low pH	100 mL
Magnetic stirrer and stir bar	1	Sodium hydroxide, 0.10 molar	50 mL
Pipette, 10 mL	1	Water, distilled	500 mL

What Do You Think?

How does the strength of an acid as measured by its pKa affect the shape of the acid's titration curve?

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

Background



All acids ionize in water to form hydrogen (H^+) or hydronium ions (H_3O^+). The degree of ionization is an indication of the strength of an acid. An acid that ionizes completely is said to be 'strong'. The ionization is complete and no molecular acid remains in solution. The rate constant ($\mathbf{k_f}$) is a number which indicates the degree of dissociation of the acid. For strong acids like this example, $\mathbf{k_f}$ (forward reaction rate) is large and there is no reverse reaction ($k_r = 0$).

Strong Acid

$$HX \xrightarrow{k_f} H^+ + X^-$$

A 'weak' acid ionizes but the ions can reform the original molecular form of the acid. Acids that ionize and then recombine again to form molecules eventually reach equilibrium. Equilibrium is the condition when the rate of the ionization equals the rate of formation of the molecular species.

Weak Acid

$$HX \xrightarrow{k_f} \xleftarrow[k_r]{} H^+ + X^-$$

For a weak acid the ratio of $\mathbf{k_f}$ to $\mathbf{k_r}$ is a number less than one. The ratio $\mathbf{k_f}/\mathbf{k_r}$ is also known as $\mathbf{K_a}$ or the equilibrium constant. The $\mathbf{K_a}$ for the above reaction can be written:

$$\mathbf{K_a} = \frac{[\mathbf{H^+}] \times [\mathbf{X^-}]}{[\mathbf{HX}]}$$

The **negative log of K_a** is known as the **pK_a** of the acid. The smaller the equilibrium constant, the less ionized and weaker the acid. The smaller the K_a, the larger the pK_a because the pK_a is the negative log of K_a. If a base is added to an acid, the acid is neutralized to form a salt and water.

$$\mathbf{HX + NaOH \text{ =========> } NaX + H_2O}$$

The salt of a weak acid in solution with the weak acid is said to form a buffer. A buffer is a solution which resists large changes in pH because it provides an acid source, in this case, the remaining HX and a base source, in this case, NaX. The sodium salt of the weak acid can react with hydrogen ions to reform an acid that does not ionize very well.

$$\mathbf{X^- + H^+ \text{ ========> } HX}$$

The behavior of a buffer system is given by this buffer equation:

$$\mathbf{pH = pK_a + \log [salt] / [acid]}$$

A buffer solution can be used to determine the pKa of an acid under special conditions.

For example, if 50 milliliters (mL) of a 0.1 Molar solution of a weak acid, HA, with a pK_a of 4.0 is reacted with 50 mL of 0.1 Molar base (sodium hydroxide, or NaOH), the solution will reach the equivalence point and all of the acid will be neutralized. However, if only 25 mL of base are added, the acid will be 50 percent neutralized. The molar concentrations of the salt and the acid will be equal. This causes the log term in the buffer equation to cancel. The pH of the solution will equal the pK_a of the weak acid:

$$\mathbf{pH = pK_a + \log [salt] / [acid]}$$

$$= 4.0 + \log [0.05] / [0.05]$$

$$= 4.0 + \log 1$$

$$= 4.0 + 0$$

pH = 4.0 (the pK_a of the acid)

This relationship can be used to ascertain the pH at the midpoint in the titration of a weak acid.

SAFETY REMINDERS

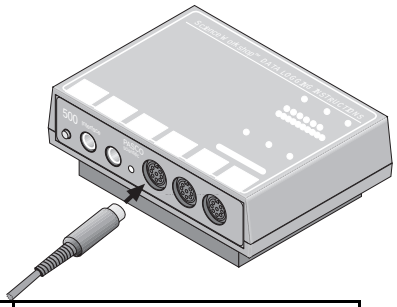
- Wear protective gear.
- Follow directions for using the equipment.
- Handle and dispose of all chemicals and solutions properly.

For You To Do

Titrate a weak acid solution (acetic acid) with a basic sodium hydroxide solution, NaOH, of known molarity. Add the sodium hydroxide solution at a constant rate. Use the pH Sensor to measure the change in pH of the acid solution. Use *DataStudio* or *ScienceWorkshop* to record and display the data. Use the data to determine the pKa of the weak acid solution.

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 pH Sensor to Analog Channel A on the interface.
3. Open the file titled as shown;

DataStudio	*ScienceWorkshop* (Mac)	*ScienceWorkshop* (Win)
C33 Half Titration.DS	C33 Half Titration	C33_HALF.SWS

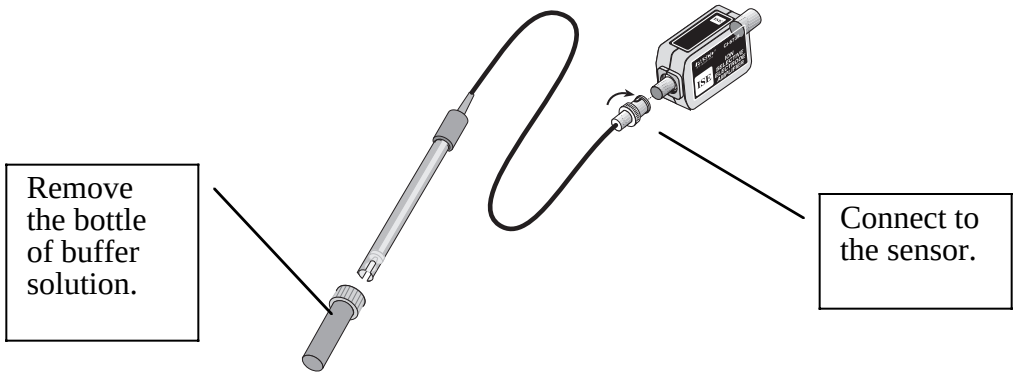
- The *DataStudio* file has a Digits display of pH and a Graph display of pH versus time. Read the Workbook display for more information.
- The *ScienceWorkshop* document has a Graph display of the pH versus time.
- Data recording is set at five measurements per second (5 Hz).

PART II: Sensor Calibration and Equipment Setup

Calibrate the Sensor

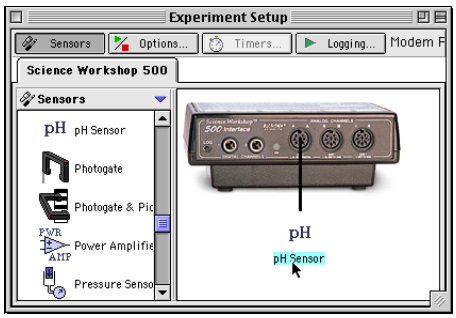
- To calibrate the pH Sensor you will need the following: wash bottle, distilled water, three beakers, buffer solutions of high pH (e.g. pH 10) and low pH (e.g. pH 4), pH Sensor.
- Put distilled water into the wash bottle and into one of the beakers. Put about 100 mL of the high pH buffer solution in one of the other two beakers and about 100 mL of the low pH buffer solution into the third beaker.

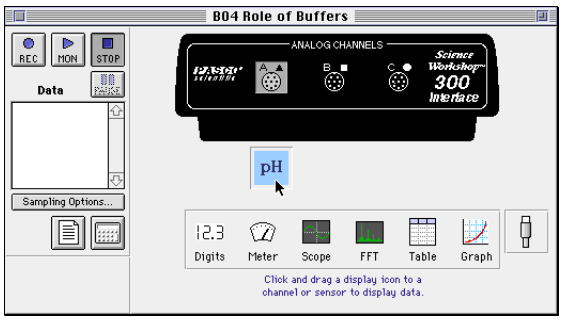
1. Remove the pH electrode from its bottle of buffer solution. Connect the electrode to the pH Sensor amplifier. To connect the electrode, push the BNC plug onto the receptacle on the Sensor amplifier and turn the BNC plug clockwise until it 'clicks' into place.



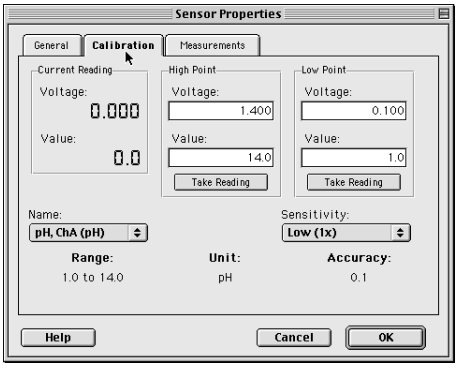
2. Use the wash bottle to rinse the end of the electrode. Soak the pH electrode in the beaker of distilled water for 10 minutes.

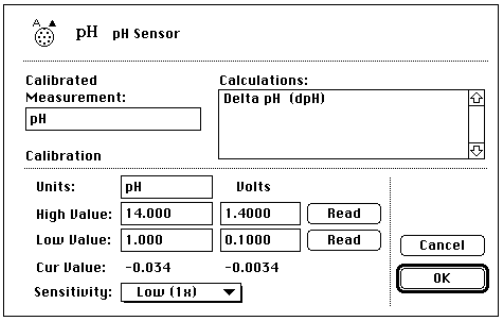
3. In the Experiment Setup window, double-click the pH Sensor icon.





- In *DataStudio*, the Sensor Properties window will open. Click the 'Calibration' tab. In *ScienceWorkshop*, the Sensor Setup window will open.





4. Calibrate with the high pH buffer solution.

- Put the end of the pH electrode into the high pH buffer solution.
- 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 'High Point' in *DataStudio* or the 'Read' button in the row for 'High Value:' in *ScienceWorkshop*.
- Enter the pH value of the buffer solution.

5. Thoroughly rinse the pH electrode with distilled water and dry it with a tissue.

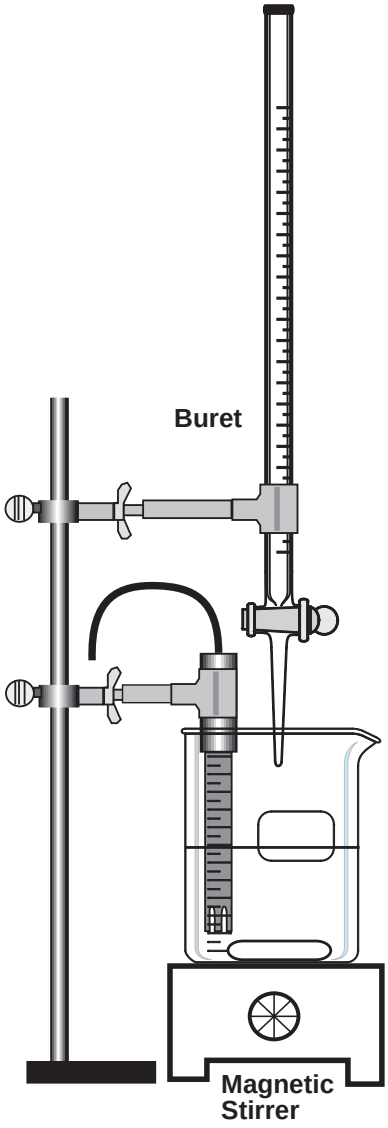
6. Calibrate with the low pH buffer solution.

- Put the end of the pH electrode in the low pH buffer solution.
- 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 the pH value of the buffer solution. Click **OK** to return to the Experiment Setup window.

7. Thoroughly rinse the pH electrode with distilled water and dry gently.

Equipment Setup

1. Place 100 mL of acetic acid in a 250-mL beaker. Put a spin bar in the beaker.
2. Place the beaker with acid and spin bar on the magnetic stirrer.
3. Use the buret clamp and base and support rod to position the pH electrode so the end of the electrode is in the acid, but will not interfere with the spin bar.
4. Use another clamp to support the 50-mL buret so the end of the buret is above the acetic acid. (Be sure the buret valve is closed!)
5. Put 50 mL of the sodium hydroxide solution into the buret.
6. Turn on the magnetic stirrer.



PART III: Data Recording

1. When you are ready, start recording data.
2. Open the buret valve so the base solution pours into the acetic acid at a slow, constant rate.

• Adjust the buret valve so the solution flows at a rate of about 1 mL per second.

3. When all of the sodium hydroxide is added to the acid, stop data recording.
4. Turn off the magnetic stirrer.
5. Carefully remove the pH electrode, rinse it thoroughly in distilled water, and put it in its bottle of buffer solution.
6. Dispose of the mixture as instructed.

Analyzing the Data

1. Use the built-in analysis tools in the Graph display to find the minimum pH and the maximum pH. (Hint: In *DataStudio*, click the 'Statistics menu' button (). In *ScienceWorkshop*, click the 'Statistics' button () to open the statistics area in the Graph display. Click the 'Statistics menu' button () and select Minimum and Maximum.)

3. Record the pH of the acid solution at the beginning (Minimum "y") before the reaction. Record the pH of the acid solution at the end of the reaction (Maximum "y").

Record your results in the Lab Report section.

Name _____ Class _____ Date _____

Lab Report - Activity C33: Determine pKa by Half-Titration

What Do You Think?

How does the strength of an acid as measured by its pKa affect the shape of the acid's titration curve?

Data Table

Item	Value
Beginning pH	
Ending pH	

Questions

1. What was the pH of the starting acetic acid solution?

2. What happened to the pH of the solution as the sodium hydroxide was added? Is this what you expected to happen?

3. The pH at the end of the plot gives the pK_a of the acid. What is the pK_a of the acetic acid?

4. The negative antilog of the pKa is the Ka of the acid. What is the Ka of the acid?

5. Sketch the titration graph for a similar titration with a different acid that has a pKa equal to 2.5. Is this acid a weak or strong acid?

6. The acid used in this experiment is a monoprotic acid which means only one hydrogen ion is ionized. What would happen to the titration graph if a diprotic (two hydrogen ions are ionized) acid would replace the acetic acid used in this experiment.