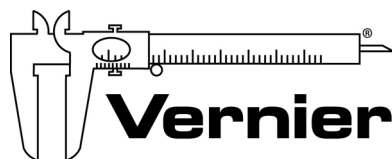


Chemistry with Vernier

LabQuest Instructions



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HANDS-ON EXPERIMENTS

Endothermic and Exothermic Reactions

- Stainless Steel Temperature Probe

Boyle's Law

- Gas Pressure Sensor

Conductivity of Solutions: The Effect of Concentration

- Conductivity Probe

Determining the Concentration of a Solution: Beer's Law

- Colorimeter or SpectroVis Plus Spectrophotometer

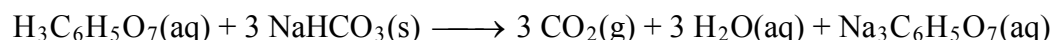
Acid-Base Titration

- pH Sensor and Drop Counter or Buret

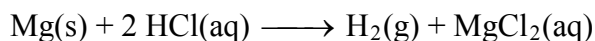
Endothermic and Exothermic Reactions

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.

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



In Part II, you will study the reaction between magnesium metal and hydrochloric acid. An equation for this reaction is:



Another objective of this experiment is for you to become familiar with using LabQuest. In this experiment, you will use the program to collect and display data as a graph or list, to examine your experimental data values on a graph, and to print graphs and data lists.

OBJECTIVES

In this experiment, you will

- Study one exothermic and one endothermic reaction.
- Become familiar with using LabQuest App.
- Collect and display data on a graph.

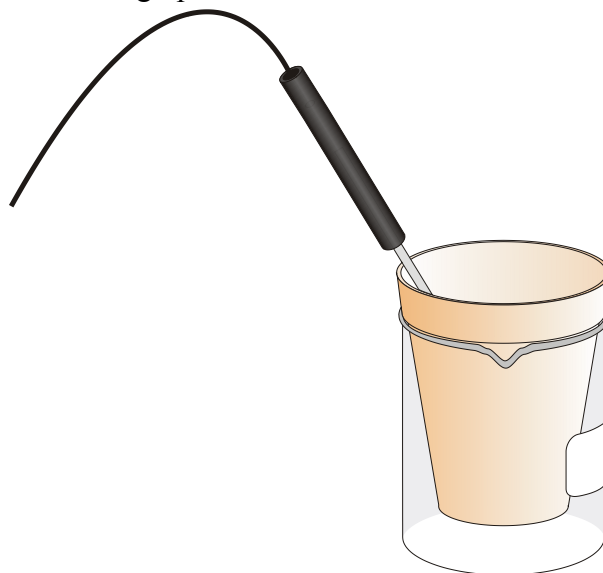


Figure 1

MATERIALS

LabQuest
LabQuest App
Temperature Probe
50 mL graduated cylinder
balance
Styrofoam cup

250 mL beaker
citric acid, $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$, solution
baking soda, NaHCO_3
hydrochloric acid, HCl , solution
magnesium, Mg

PROCEDURE

1. Obtain and wear goggles.

Part I Citric Acid plus Baking Soda

2. Connect the Temperature Probe to LabQuest.
3. Place a Styrofoam cup into a 250 mL beaker as shown in Figure 1. Measure out 30 mL of citric acid solution into the Styrofoam cup. Place the Temperature Probe into the citric acid solution.
4. Weigh out 10.0 g of solid baking soda on a piece of weighing paper.
5. Press the power button on LabQuest to turn it on. Choose New from the File menu. If you have an older sensor that does not auto-ID, manually set up the sensor by choosing Sensor Setup from the Sensors menu.
6. On the Meter screen, tap Rate. Change the data-collection rate to 0.5 samples/second (interval of 2 seconds/sample) and the data-collection length to 300 seconds. Select OK.
7. You are now ready to begin collecting data.
 - a. Start data collection.
 - b. After about 20 seconds have elapsed, add the baking soda to the citric acid solution. Gently stir the solution with the Temperature Probe to ensure good mixing.
 - c. A real-time graph of temperature vs. time will be displayed on the screen during data collection.
 - d. Temperature readings (in $^{\circ}\text{C}$) can also be monitored in a display box to the right of the graph.
8. Dispose of the reaction products as directed by your instructor.
9. When data collection is complete, a graph of temperature vs. time will be displayed. To examine the data pairs on the displayed graph, tap any data point. As you tap each data point, its temperature and time values are displayed in the display box to the right of the graph.
Note: You can also advance the examine cursor point by point using the ► or ◀ keys on LabQuest. Determine the initial temperature, t_1 and final (or minimum) temperature, t_2 . Record the temperature values in your data table.
10. Store the data from the first run so that it can be used later by tapping the File Cabinet icon.

Part II Hydrochloric Acid Plus Magnesium

11. Measure out 30 mL of HCl solution into the Styrofoam cup. Place the Temperature Probe into the HCl solution. **Note:** The Temperature Probe must be in the HCl solution for at least 30 seconds before doing Step 13.
12. Obtain a piece of magnesium metal from your instructor.
13. Start data collection. After about 20 seconds have elapsed, add the Mg to the HCl solution. Gently stir the solution with the Temperature Probe to ensure good mixing. **Caution:** Do not breathe the vapors. Data collection will stop after 5 minutes.
14. Dispose of the reaction products as directed by your instructor. Rinse the Temperature Probe.
15. When data collection is complete, a graph of temperature vs. time will be displayed. Examine the data points along the displayed curve. Determine the initial temperature, t_1 , and the final (or maximum) temperature, t_2 . Record the temperature values in your data table.
16. You can also examine the data by viewing the data table.
 - a. Tap the Table tab to view the data table. The data Part I and Part II will be displayed.
 - b. Tap the Graph tab to return to the graph when you have finished viewing the data table.
17. A good way to compare the two curves is to view both sets of data on one graph.
 - a. On the Graph tab, tap Run 2 in the upper-right corner of the screen.
 - b. Select All Runs. Both temperature runs should now be displayed on the same graph.
18. (optional) Print a graph of temperature vs. time (with two curves displayed). On your paper copy, label each curve as “endothermic reaction” or “exothermic reaction”.

DATA TABLE

	Part I	Part II
Final temperature, t_2	°C	°C
Initial temperature, t_1	°C	°C
Temperature change, Δt	°C	°C

PROCESSING THE DATA

1. Calculate the temperature change, Δt , for each reaction by subtracting the initial temperature, t_1 , from the final temperature, t_2 ($\Delta t = t_2 - t_1$).
2. Tell which reaction is exothermic. Explain.
3. Which reaction had a negative Δt value? Is the reaction endothermic or exothermic? Explain.
4. For each reaction, describe three ways you could tell a chemical reaction was taking place.
5. Which reaction took place at a greater rate? Explain your answer.

Boyle's Law: Pressure-Volume Relationship in Gases

The primary objective of this experiment is to determine the relationship between the pressure and volume of a confined gas. The gas we use will be air, and it will be confined in a syringe connected to a Gas Pressure Sensor (see Figure 1). When the volume of the syringe is changed by moving the piston, a change occurs in the pressure exerted by the confined gas. This pressure change will be monitored using a Gas Pressure Sensor. It is assumed that temperature will be constant throughout the experiment. Pressure and volume data pairs will be collected during this experiment and then analyzed. From the data and graph, you should be able to determine what kind of mathematical relationship exists between the pressure and volume of the confined gas. Historically, this relationship was first established by Robert Boyle in 1662 and has since been known as Boyle's law.

OBJECTIVES

In this experiment, you will

- Use a Gas Pressure Sensor and a gas syringe to measure the pressure of an air sample at several different volumes.
- Determine the relationship between pressure and volume of the gas.
- Describe the relationship between gas pressure and volume in a mathematical equation.
- Use the results to predict the pressure at other volumes.

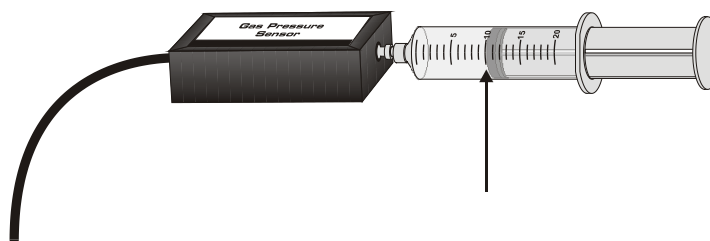


Figure 1

MATERIALS

LabQuest
LabQuest App

Vernier Gas Pressure Sensor
20 mL gas syringe

PROCEDURE

1. Prepare the Gas Pressure Sensor and an air sample for data collection.
 - a. Connect the Gas Pressure Sensor to LabQuest and choose New from the File menu. If you have an older sensor that does not auto-ID, manually set up the sensor.
 - b. With the 20 mL syringe disconnected from the Gas Pressure Sensor, move the piston of the syringe until the front edge of the inside black ring (indicated by the arrow in Figure 1) is positioned at the 10.0 mL mark.
 - c. Attach the 20 mL syringe to the valve of the Gas Pressure Sensor.

LabQuest 6

2. Set up the data-collection mode.
 - a. On the Meter screen, tap Mode. Change the mode to Events with Entry.
 - b. Enter the Name (Volume) and Units (mL). Select OK.
3. To obtain the best data possible, you will need to correct the volume readings from the syringe. Look at the syringe; its scale reports its own internal volume. However, that volume is not the total volume of trapped air in your system since there is a little bit of space inside the pressure sensor.

To account for the extra volume in the system, you will need to add 0.8 mL to your syringe readings. For example, with a 5.0 mL syringe volume, the total volume would be 5.8 mL. *It is this total volume that you will need for the analysis.*

4. You are now ready to collect pressure and volume data. It is easiest if one person takes care of the gas syringe and another enters volumes.
 - a. Start data collection.
 - b. Move the piston so the front edge of the inside black ring (see Figure 2) is positioned at the 5.0 mL line on the syringe. Hold the piston firmly in this position until the pressure value displayed on the screen stabilizes.
 - c. Tap Keep and enter **5.8**, the gas volume (in mL) on the screen. Remember, you are adding 0.8 mL to the volume of the syringe for the total volume. Select OK to store this pressure-volume data pair.

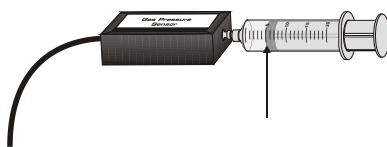


Figure 2

- d. Continue this procedure to collect 5-6 more readings, using syringe volumes between 5.00 mL and 20.0 mL.
 - e. Stop data collection.
5. When data collection is complete, a graph of pressure vs. volume will be displayed. To examine the data pairs on the displayed graph, tap any data point. As you tap each data point, the pressure and volume values are displayed to the right of the graph. Record the pressure and volume data values in your data table.
6. Based on the graph of pressure vs. volume, choose the mathematical relationship exists between these two variables, direct or inverse. To check your choice:
 - a. Choose Curve Fit from the Analyze menu.
 - b. Select Power as the Fit Equation. The curve fit statistics for these two data columns are displayed for the equation in the form

$$y = Ax^B$$

where x is volume, y is pressure, A is a proportionality constant, and B is the exponent of x (volume) in this equation. **Note:** The relationship between pressure and volume can be determined from the value and sign of the exponent, B .

- c. If you have correctly determined the mathematical relationship, the regression line should very nearly *fit* the points on the graph (i.e., pass through or near the plotted points).
 - d. Select OK.

7. (optional) If directed by your instructor, proceed directly to the Extension that follows Processing the Data.

DATA AND CALCULATIONS

Volume (mL)	Pressure (kPa)	Constant, k (P/V or $P \cdot V$)

PROCESSING THE DATA

1. If the volume is *doubled* from 5.0 mL to 10.0 mL, what does your data show happens to the pressure? Show the pressure values in your answer.
2. If the volume is *halved* from 20.0 mL to 10.0 mL, what does your data show happens to the pressure? Show the pressure values in your answer.
3. If the volume is *tripled* from 5.0 mL to 15.0 mL, what does your data show happened to the pressure? Show the pressure values in your answer.
4. From your answers to the first three questions, and the shape of the curve in the plot of pressure versus volume, do you think the relationship between the pressure and volume of a confined gas is direct or inverse? Explain your answer.
5. Based on your data, what would you expect the pressure to be if the volume of the syringe was increased to 40.0 mL? Explain or show work to support your answer.
6. Based on your data, what would you expect the pressure to be if the volume of the syringe was decreased to 2.5 mL?
7. What experimental factors are assumed to be constant in this experiment?
8. One way to determine if a relationship is inverse or direct is to find a proportionality constant, k , from the data. If this relationship is direct, $k = P/V$. If it is inverse, $k = P \cdot V$. Based on your answer to Question 4, choose one of these formulas and calculate k for the seven ordered pairs in your data table (divide or multiply the P and V values). Show the answers in the third column of the Data and Calculations table.
9. How *constant* were the values for k you obtained in Question 8? Good data may show some minor variation, but the values for k should be relatively constant.

10. Using P , V , and k , write an equation representing Boyle's law. Write a verbal statement that correctly expresses Boyle's law.

EXTENSION

1. To confirm that an inverse relationship exists between pressure and volume, a graph of pressure *vs.* *reciprocal of volume* ($1/\text{volume}$) may also be plotted. To do this using LabQuest:
 - a. Tap the Table tab to display the data table.
 - b. Choose New Calculated Column from the Table menu.
 - c. Enter the Name ($1/\text{Volume}$) and Units ($1/\text{mL}$). Select the equation, A/X . Use Volume as the Column for X , and **1** as the value for A .
 - d. Select OK.
2. Follow this procedure to calculate regression statistics and to plot a best-fit regression line on your graph of pressure *vs.* $1/\text{volume}$:
 - a. Choose Graph Options from the Graph menu.
 - b. Select Autoscale from 0 and select OK.
 - c. Choose Curve Fit from the Analyze menu.
 - d. Select Linear as the Fit Equation. The linear-regression statistics for these two data columns are displayed in the form:

$$y = mx + b$$

where x is $1/\text{volume}$, y is pressure, m is a proportionality constant, and b is the y -intercept.

- e. Select OK. If the relationship between P and V is an inverse relationship, the graph of pressure *vs.* $1/\text{volume}$ should be direct; that is, the curve should be linear and pass through (or near) the origin. Examine your graph to see if this is true for your data.

Conductivity of Solutions: The Effect of Concentration

If an ionic compound is dissolved in water, it dissociates into ions and the resulting solution will conduct electricity. Dissolving solid sodium chloride in water releases ions according to the equation:



In this experiment, you will study the effect of increasing the concentration of an ionic compound on conductivity. Conductivity will be measured as concentration of the solution is gradually increased by the addition of concentrated NaCl drops. The same procedure will be used to investigate the effect of adding other solutions with the same concentration (1.0 M), but different numbers of ions in their formulas: aluminum chloride, AlCl_3 , and calcium chloride, CaCl_2 . The Conductivity Probe will be used to measure conductivity of the solution. Conductivity is measured in microsiemens per centimeter ($\mu\text{S}/\text{cm}$).

OBJECTIVES

In this experiment, you will

- Use a Conductivity Probe to measure the conductivity of solutions.
- Investigate the relationship between the conductivity and concentrations of a solution.
- Investigate the conductivity of solutions resulting from compounds that dissociate to produce different number of ions.

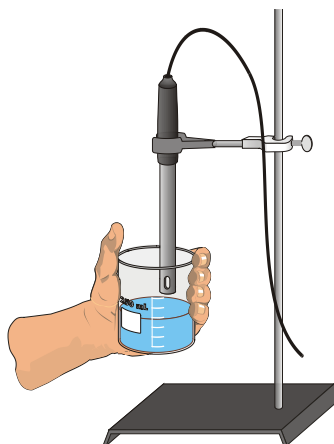


Figure 1

MATERIALS

LabQuest
LabQuest App
Vernier Conductivity Probe
ring stand
utility clamp
stirring rod

100 mL beaker
distilled water
wash bottle
1.0 M NaCl
1.0 M AlCl_3
1.0 M CaCl_2

PROCEDURE

1. Obtain and wear goggles.
2. Add 70 mL of distilled water to a clean 100 mL beaker. Obtain a dropper bottle that contains 1.0 M NaCl solution.
3. Set the selector switch on the side of the Conductivity Probe to the 0–2000 $\mu\text{S}/\text{cm}$ range. Connect the Conductivity Probe to LabQuest and choose New from the File menu. If you have an older sensor that does not auto-ID, manually set up the sensor.
4. Set up the data-collection mode.
 - a. On the Meter screen, tap Mode. Change the mode to Events with Entry.
 - b. Enter the Name (Volume) and Units (drops). Select OK.
5. Before adding any drops of solution:
 - a. Start data collection.
 - b. Carefully raise the beaker and its contents up around the Conductivity Probe until the hole near the probe end is completely submerged in the solution being tested. **Important:** Since the two electrodes are positioned on either side of the hole, this part of the probe must be completely submerged.
 - c. Before you have added any drops of NaCl solution, tap Keep. Enter **0**, the volume (in drops) and then select OK to save this data pair for this experiment.
 - d. Lower the beaker away from the probe.
6. You are now ready to begin adding salt solution.
 - a. Add 1 drop of NaCl solution to the distilled water. Stir to ensure thorough mixing.
 - b. Carefully raise the beaker and its contents up around the Conductivity Probe until the hole near the probe end is completely submerged in the solution being tested.
 - c. Briefly swirl the beaker contents. Monitor the conductivity of the solution for about 5 seconds.
 - d. When the conductivity readings stabilize, tap Keep. Enter **1** as the volume in drops and then select OK. The conductivity and volume values have now been saved for the second trial.
 - e. Lower the beaker away from the probe.
7. Repeat the Step 6 procedure, entering **2** this time.
8. Continue this procedure, adding the NaCl solution a drop at a time, until a total of 8 drops have been added.
9. Stop data collection.
10. To analyze the relationship between conductivity and volume, calculate the linear-regression statistics for your data:
 - a. Choose Curve Fit ► Conductivity from the Analyze menu.
 - b. Select Linear for the Fit Equation. **Note:** The graph represents the relationship between *conductivity* and *concentration* of NaCl solution. The linear-regression statistics for these two lists are displayed for the equation in the form

$$y = mx + b$$

where y is conductivity, x is volume, m is the slope, and b is the y-intercept.

- c. Record the value for the slope, m , in your data table.
- d. Select OK.
11. Store the data from the first run by tapping the File Cabinet icon.
12. Repeat Steps 5–11, this time using 1.0 M AlCl_3 solution.
13. Repeat Steps 5–10, this time using 1.0 M CaCl_2 solution. **Important:** Do not store this run as you did in the first two runs—proceed directly to Step 14 after you complete Step 10.
14. To view a graph of concentration vs. volume showing all three data runs, tap Run 3 and select All Runs. All three runs will now be displayed on the same graph axes.
15. (optional) Print a copy of the graph displayed in Step 14. Label each run as “1.0 M NaCl,” “1.0 M AlCl_3 ,” or “1.0 M CaCl_2 ”.

PROCESSING THE DATA

1. Describe the appearance of each of the three curves on your graph in Step 14.
2. Describe the change in conductivity as the concentration of the NaCl solution was increased by the addition of NaCl drops. What kind of mathematical relationship does there appear to be between conductivity and concentration?
3. Write a chemical equation for the dissociation of NaCl, AlCl_3 , and CaCl_2 in water.
4. Which graph had the largest slope value? The smallest? Since all solutions had the same original concentration (1.0 M), what accounts for the difference in the slope of the three plots? Explain.

DATA TABLE

Solution	Slope, m
1.0 M NaCl	
1.0 M AlCl_3	
1.0 M CaCl_2	

Determining the Concentration of a Solution: Beer's Law

The primary objective of this experiment is to determine the concentration of an unknown nickel (II) sulfate solution. You will be using a Colorimeter or Spectrometer. The wavelength of light used should be one that is absorbed by the solution. The NiSO_4 solution used in this experiment has a deep green color, so Colorimeter users will be instructed to use the red LED. Spectrometer users will determine an appropriate wavelength based on the absorbance spectrum of the solution. The light striking the detector is reported as *absorbance* or *percent transmittance*. A higher concentration of the colored solution absorbs more light (and transmits less) than a solution of lower concentration.

You will prepare five nickel sulfate solutions of known concentration (standard solutions). Each is transferred to a small, rectangular cuvette that is placed into the Colorimeter or Spectrometer. The amount of light that penetrates the solution and strikes the photocell is used to compute the absorbance of each solution. When a graph of absorbance vs. concentration is plotted for the standard solutions, a direct relationship should result, as shown in Figure 1. The direct relationship between absorbance and concentration for a solution is known as Beer's law.

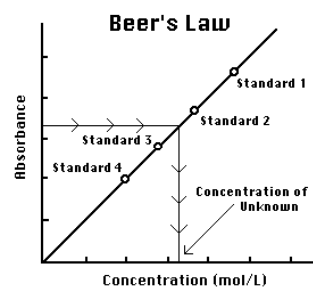


Figure 1

You will determine the concentration of an *unknown* NiSO_4 solution by measuring its absorbance. By locating the absorbance of the unknown on the vertical axis of the graph, the corresponding concentration can be found on the horizontal axis (follow the arrows in Figure 1). The concentration of the unknown can also be found using the slope of the Beer's law curve.

OBJECTIVES

In this experiment, you will

- Prepare NiSO_4 standard solution.
- Measure the absorbance value of each standard solution.
- Find the relationship between absorbance and concentration of a solution.
- Determine the concentration of an unknown NiSO_4 solution.

MATERIALS

LabQuest
LabQuest App
Vernier Colorimeter or Spectrometer
one cuvette
five 20 x 150 mm test tubes
30 mL of 0.40 M NiSO_4
5 mL of NiSO_4 unknown solution

two 10 mL pipets (or graduated cylinders)
two 100 mL beakers
pipet or pipet bulb
distilled water
test tube rack
stirring rod
tissues (preferably lint-free)

PROCEDURE

Both Colorimeter and Spectrometer Users

1. Obtain and wear goggles. **CAUTION:** *Be careful not to ingest any NiSO_4 solution or spill any on your skin. Inform your teacher immediately in the event of an accident.*
2. Add about 30 mL of 0.40 M NiSO_4 stock solution to a 100 mL beaker. Add about 30 mL of distilled water to another 100 mL beaker.
3. Label four clean, dry, test tubes 1–4 (the fifth solution is the beaker of 0.40 M NiSO_4). Pipet 2, 4, 6, and 8 mL of 0.40 M NiSO_4 solution into Test Tubes 1–4, respectively. With a second pipet, deliver 8, 6, 4, and 2 mL of distilled water into Test Tubes 1–4, respectively. *Thoroughly* mix each solution with a stirring rod. Clean and dry the stirring rod between stirrings. Keep the remaining 0.40 M NiSO_4 in the 100 mL beaker to use in the fifth trial. Volumes and concentrations for the trials are summarized below:

Trial number	0.40 M NiSO_4 (mL)	Distilled 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

4. Prepare a *blank* by filling an empty cuvette 3/4 full with distilled water. To correctly use a Colorimeter cuvette, remember:
 - All cuvettes should be wiped clean and dry on the outside with a tissue.
 - Handle cuvettes only by the top edge of the ribbed sides.
 - All solutions should be free of bubbles.
 - Always position the cuvette so the light passes through the clear sides.

Colorimeter Users Only (Spectrometer users proceed to the Spectrometer section)

5. Connect the Colorimeter to LabQuest and choose New from the File menu.
6. Calibrate the Colorimeter.
 - a. Place the blank in the cuvette slot of the Colorimeter and close the lid.
 - b. Press the < or > buttons on the Colorimeter to set the wavelength to 635 nm (Red). Then calibrate by pressing the CAL button on the Colorimeter. When the LED stops flashing, the calibration is complete.
7. Set up the data-collection mode.
 - a. On the Meter screen, tap Mode. Change the mode to Events with Entry.
 - b. Enter the Name (Concentration) and Units (mol/L). Select OK.
 - c. Proceed directly to Step 8.

Spectrometer Users Only

5. Connect the Spectrometer to LabQuest and choose New from the File menu.

6. Calibrate the Spectrometer.
 - a. Place the blank cuvette in the spectrometer.
 - b. Choose Calibrate from the Sensors menu. The following message is displayed: "Waiting 90 seconds for lamp to warm up." After 90 seconds, the message will change to "Warmup complete."
 - c. Select Finish Calibration. When the message "Calibration completed" appears, select OK.
7. Determine the optimal wavelength for creating the standard curve and set up the data-collection mode.
 - a. Remove the blank cuvette, and place the 0.40 M standard into the cuvette slot.
 - b. Start data collection. A full spectrum graph of the solution will be displayed. Stop data collection.
 - c. Choose an absorbance peak in the red region of the spectrum, by tapping the graph (or use the ◀ or ▶ keys on LabQuest).
 - d. Tap the Meter tab. On the Meter screen, tap Mode. Change the mode to Events with Entry.
 - e. Enter the Name (Concentration) and Units (mol/L). Select OK.

Both Colorimeter and Spectrometer Users

8. You are now ready to collect absorbance-concentration data for the five standard solutions.
 - a. Start data collection.
 - b. Empty the water from the cuvette. Using the solution in Test Tube 1, rinse the cuvette twice with ~1 mL amounts and then fill it 3/4 full. Wipe the outside with a tissue and place it in the device (Colorimeter or Spectrometer). Close the lid on the Colorimeter.
 - c. When the value displayed on the screen has stabilized, tap Keep and enter **0.080** as the concentration in mol/L. Select OK. The absorbance and concentration values have now been saved for the first solution.
 - d. Discard the cuvette contents as directed by your instructor. Using the solution in Test Tube 2, rinse the cuvette twice with ~1 mL amounts, and then fill it 3/4 full. Place the cuvette in the device, wait for the value displayed on the screen to stabilize, and tap Keep. Enter **0.16** as the concentration in mol/L. Select OK.
 - e. Repeat the procedure for Test Tube 3 (0.24 M) and Test Tube 4 (0.32 M), as well as the stock 0.40 M NiSO₄. **Note:** Wait until Step 10 to test the unknown.
 - f. Stop data collection.
 - g. To examine the data pairs on the displayed graph, tap any data point. As you tap each data point, the absorbance and concentration values are displayed to the right of the graph. Record the absorbance and concentration data values in your data table.
9. Display a graph of absorbance vs. concentration with a linear regression curve.
 - a. Choose Graph Options from the Graph menu.
 - b. Select Autoscale from 0 and select OK.
 - c. Choose Curve Fit from the Analyze menu.
 - d. Select Linear as the Fit Equation. The linear-regression statistics for these two data columns are displayed for the equation in the form

$$y = mx + b$$

where x is concentration, y is absorbance, m is the slope, and b is the y-intercept.

Note: One indicator of the quality of your data is the size of b . It is a very small value if

the regression line passes through or near the origin. The correlation coefficient, r , indicates how closely the data points match up with (or *fit*) the regression line. A value of 1.00 indicates a nearly perfect fit.

- e. Select OK. The graph should indicate a direct relationship between absorbance and concentration, a relationship known as Beer's law. The regression line should closely fit the five data points *and* pass through (or near) the origin of the graph.
10. Determine the absorbance value of the unknown NiSO_4 solution.
 - a. Tap the Meter tab.
 - b. Obtain about 5 mL of the *unknown* NiSO_4 in another clean, dry, test tube. Record the number of the unknown in your data table.
 - c. Rinse the cuvette twice with the unknown solution and fill it about 3/4 full. Wipe the outside of the cuvette and place it into the device.
 - d. Monitor the absorbance value. When this value has stabilized, record it in your data table.
 11. Discard the solutions as directed by your instructor. Proceed to Step 1 of Processing the Data.

PROCESSING THE DATA

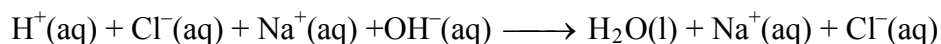
1. To determine the concentration of the unknown NiSO_4 solution, interpolate along the regression line to convert the absorbance value of the unknown to concentration.
 - a. Tap the Graph tab.
 - b. Choose Interpolate from the Analyze menu.
 - c. Tap any point on the regression curve (or use the ◀ or ▶ keys on LabQuest) to find the absorbance value that is closest to the absorbance reading you obtained in Step 10. The corresponding NiSO_4 concentration, in mol/L, will be displayed to the right of the graph.
 - d. Record the concentration value in your data table.
2. (optional) Print a graph of absorbance *vs.* concentration, with a regression line and interpolated unknown concentration displayed.

DATA AND CALCULATIONS

Trial	Concentration (mol/L)	Absorbance
1	0.080	
2	0.16	
3	0.24	
4	0.32	
5	0.40	
6	Unknown number ____	
Concentration of unknown		mol/L

Acid-Base Titration

A titration is a process used to determine the volume of a solution needed to react with a given amount of another substance. In this experiment, you will titrate hydrochloric acid solution, HCl, with a basic sodium hydroxide solution, NaOH. The concentration of the NaOH solution is given and you will determine the unknown concentration of the HCl. Hydrogen ions from the HCl react with hydroxide ions from the NaOH in a one-to-one ratio to produce water in the overall reaction:



When an HCl solution is titrated with an NaOH solution, the pH of the acidic solution is initially low. As base is added, the change in pH is quite gradual until close to the equivalence point, when equimolar amounts of acid and base have been mixed. Near the equivalence point, the pH increases very rapidly, as shown in Figure 1. The change in pH then becomes more gradual again, before leveling off with the addition of excess base.

In this experiment, you will use a pH Sensor to monitor pH as you titrate. The region of most rapid pH change will then be used to determine the equivalence point. The volume of NaOH titrant used at the equivalence point will be used to determine the molarity of the HCl.

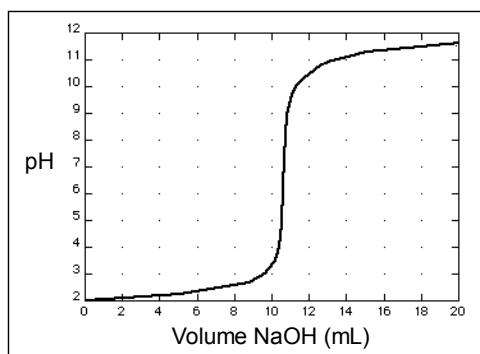


Figure 1

OBJECTIVES

In this experiment, you will

- Use a pH Sensor to monitor changes in pH as sodium hydroxide solution is added to a hydrochloric acid solution.
- Plot a graph of pH vs. volume of sodium hydroxide solution added.
- Use the graph to determine the equivalence point of the titration.
- Use the results to calculate the concentration of the hydrochloric acid solution.

MATERIALS

Materials for *both* Method 1 (buret) and Method 2 (Drop Counter)

LabQuest	magnetic stirrer (if available)
LabQuest App	stirring bar or Microstirrer (if available)
Vernier pH Sensor	wash bottle
HCl solution, unknown concentration	distilled water
~0.1 M NaOH solution	ring stand
pipet bulb or pump	1 utility clamp
250 mL beaker	

Materials required *only* for Method 1 (buret)

50 mL buret	2nd utility clamp
10 mL pipet	2nd 250 mL beaker

Materials required *only* for Method 2 (Drop Counter)

Vernier Drop Counter	100 mL beaker
60 mL reagent reservoir	10 mL graduated cylinder
5 mL pipet or graduated 10 mL pipet	

CHOOSING A METHOD

Method 1 has the student deliver volumes of NaOH titrant from a buret. After titrant is added, and pH values have stabilized, the student is prompted to enter the buret reading manually and a pH-volume data pair is stored

Method 2 uses a Vernier Drop Counter to take volume readings. NaOH titrant is delivered drop by drop from the reagent reservoir through the Drop Counter slot. After the drop reacts with the reagent in the beaker, the volume of the drop is calculated, and a pH-volume data pair is stored.

METHOD 1: MEASURING VOLUME USING A BURET

1. Obtain and wear goggles.
2. Use a pipet bulb (or pipet pump) to pipet 10 mL of the HCl solution into a 250 mL beaker. Add 50 mL of distilled water. **CAUTION:** *Handle the hydrochloric acid with care. It can cause painful burns if it comes in contact with the skin.*
3. Place the beaker on a magnetic stirrer and add a stirring bar. If no magnetic stirrer is available, you need to stir with a stirring rod during the titration.
4. Connect the pH Sensor to LabQuest and choose New from the File menu. If you have an older sensor that does not auto-ID, manually set up the sensor.
5. Set up the data-collection mode.
 - a. On the Meter screen, tap Mode. Change the data-collection mode to Events with Entry.
 - b. Enter the Name (Volume) and Units (mL). Select OK.

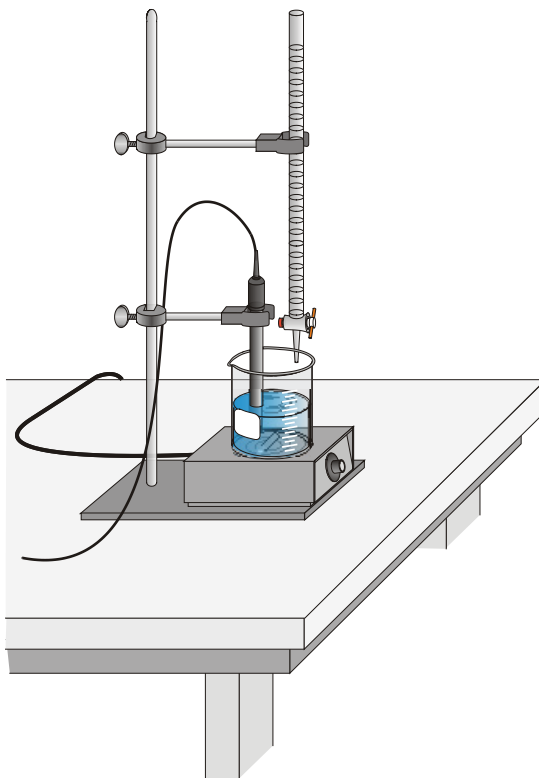


Figure 2

6. Use a utility clamp to suspend a pH Sensor on a ring stand as shown in Figure 2. Position the pH Sensor in the HCl solution and adjust its position so that it is not struck by the stirring bar.
7. Obtain a 50 mL buret and rinse the buret with a few mL of the ~ 0.1 M NaOH solution. Dispose of the rinse solution as directed by your teacher. Use a utility clamp to attach the buret to the ring stand as shown in Figure 2. Fill the buret a little above the 0.00 mL level of the buret with ~ 0.1 M NaOH solution. Drain a small amount of NaOH solution so it fills the buret tip *and* leaves the NaOH at the 0.00 mL level of the buret. Record the precise concentration of the NaOH solution in your data table. **CAUTION:** *Sodium hydroxide solution is caustic. Avoid spilling it on your skin or clothing.*
8. You are now ready to perform the titration. This process is faster if one person manipulates and reads the buret while another person operates and enters volumes.
 - a. Start data collection.
 - b. Before you have added any drops of NaOH solution, tap Keep and enter **0** as the buret volume in mL. Select OK to store the first data pair for this experiment.
 - c. Add the next increment of NaOH titrant (enough to raise the pH about 0.15 units). When the pH stabilizes, tap Keep, enter the current buret reading (to the nearest 0.01 mL), and then select OK. You have now saved the second data pair for the experiment.
 - d. Continue adding NaOH solution in increments that raise the pH by about 0.15 units and enter the buret reading after each increment. When a pH value of approximately 3.5 is reached, change to a one-drop increment. Enter a new buret reading after each increment. **Note:** It is important that all increment volumes in this part of the titration be equal; that is, one-drop increments.
 - e. After a pH value of approximately 10 is reached, again add larger increments that raise the pH by about 0.15 pH units, and enter the buret level after each increment.

- f. Continue adding NaOH solution until the pH value remains constant.
9. Stop data collection.
10. Examine the data on the displayed graph of pH vs. volume to find the *equivalence point*—that is the largest increase in pH upon the addition of 1 drop of NaOH solution. To examine the data pairs on the displayed graph, tap any data point. As you tap each data point (or use the ► or ◀ keys on LabQuest), the pH and volume values are displayed. Move to the region of the graph with the largest increase in pH. Find the NaOH volume just *before* this jump. Record this value in the data table. Then record the NaOH volume *after* the drop producing the largest pH increase was added. **Note:** Another method for determining the equivalence-point volume is described in the Alternate Equivalence Point Method of this experiment.
11. (optional) Print a copy of the graph of pH vs. volume.
12. Dispose of the beaker contents as directed by your teacher. Rinse the pH Sensor and return it to the pH storage solution.

METHOD 2: MEASURING VOLUME WITH A DROP COUNTER

1. Obtain and wear goggles.
2. Add 40 mL of distilled water to a 100 mL beaker. Use a pipet bulb (or pipet pump) to pipet 5.00 mL of the HCl solution into the 100 mL beaker with distilled water. **CAUTION:** *Handle the hydrochloric acid with care. It can cause painful burns if it comes in contact with the skin.*
3. Obtain approximately 40 mL of ~0.1 M NaOH solution in a 250 mL beaker. Record the precise NaOH concentration in your data table. **CAUTION:** *Sodium hydroxide solution is caustic. Avoid spilling it on your skin or clothing.*
4. Obtain the plastic 60 mL reagent reservoir. **Note:** The bottom valve will be used to open or close the reservoir, while the top valve will be used to finely adjust the flow rate. For now, close both valves by turning the handles to a horizontal position.

Rinse it with a few mL of the ~0.1 M NaOH solution. Use a utility clamp to attach the reagent reservoir to the ring stand. Add the remainder of the NaOH solution to the reagent reservoir.

Drain a small amount of NaOH solution into the 250 mL beaker so it fills the reservoir's tip. To do this, turn both valve handles to the vertical position for a moment, then turn them both back to horizontal.

5. Connect the pH Sensor to CH 1 of LabQuest. Lower the Drop Counter onto a ring stand and connect it to DIG 1. Choose New from the File menu. If both sensors are identified, proceed to Step 6.

If you have older sensors that do not auto-ID, manually set them up:

- a. Choose Sensor Setup from the Sensors menu.
- b. Select Drop Counter from the DIG 1 sensor list, or pH Sensor from the CH 1 sensor list.
- c. Select OK.
6. Calibrate the Drop Counter so that a precise volume of titrant is recorded in units of milliliters.

- a. Choose Calibrate ► Drop Counter from the Sensors menu:
 - If you have previously calibrated the drop size of your reagent reservoir and want to continue with the same drop size, tap Equation. Enter the values for Drops/mL. Select Apply, then OK. Proceed directly to Step 7.
 - If you want to perform a new calibration, continue with this step.
 - b. Select Calibrate Now.
 - c. Place a 10 mL graduated cylinder directly below the slot on the Drop Counter, lining it up with the tip of the reagent reservoir.
 - d. Open the bottom valve on the reagent reservoir (vertical). Keep the top valve closed (horizontal).
 - e. Slowly open the top valve of the reagent reservoir so that drops are released at a slow rate (~1 drop every two seconds). You should see the drops being counted on the screen.
 - f. When the volume of NaOH solution in the graduated cylinder is between 9 and 10 mL, close the bottom valve of the reagent reservoir.
 - g. Enter the precise Volume of NaOH. Select Stop. Record the number of drops/mL displayed on the screen for possible future use. Select OK.
7. Discard the NaOH solution in the graduated cylinder as indicated by your instructor and set the graduated cylinder aside.
8. Assemble the apparatus.
- a. Place the magnetic stirrer on the base of the ring stand.
 - b. Insert the pH Sensor through the large hole in the Drop Counter.
 - c. Attach the Microstirrer to the bottom of the pH Sensor, as shown in the small picture. Rotate the paddle wheel of the Microstirrer and make sure that it does not touch the bulb of the pH Sensor.
 - d. Adjust the positions of the Drop Counter and reagent reservoir so they are both lined up with the center of the magnetic stirrer.
 - e. Lift up the pH Sensor, and slide the beaker containing the HCl solution onto the magnetic stirrer. Lower the pH Sensor into the beaker.
 - f. Adjust the position of the Drop Counter so that the Microstirrer on the pH Sensor is just touching the bottom of the beaker.
 - g. Adjust the reagent reservoir so its tip is just above the Drop Counter slot.
9. Turn on the magnetic stirrer so that the Microstirrer is stirring at a fast rate.
10. You are now ready to begin collecting data. Check to see that the pH value is between 1.5 and 2.5. Start data collection. No data will be collected until the first drop goes through the Drop Counter slot. Fully open the bottom valve—the top valve should still be adjusted so drops are released at a rate of about 1 drop every 2 seconds. When the first drop passes through the Drop Counter slot, check the graph to see that the first data pair was recorded.
11. Continue watching your graph to see when a large increase in pH takes place—this will be the equivalence point of the reaction. When this jump in pH occurs, let the titration proceed for several more milliliters of titrant, then stop data collection to view a graph of pH vs. volume. Turn the bottom valve of the reagent reservoir to a closed (horizontal) position.
12. Dispose of the beaker contents as directed by your teacher.



13. Examine the data on the displayed graph of pH vs. volume to find the *equivalence point*. Move to the region of the graph with the largest increase in pH. Find the NaOH volume just *before* this jump. Record this value in the data table. Then record the NaOH volume *after* the drop producing the largest pH increase was added. **Note:** Another method for determining the equivalence-point volume is described in the Alternate Equivalence Point Method of this experiment.
14. (optional) Print copies of the graph.
15. If time permits, repeat the procedure.

ALTERNATE EQUIVALENCE POINT METHOD

An alternate way of determining the precise equivalence point of the titration is to take the first and second derivatives of the pH-volume data.

1. Determine the peak value on the first derivative vs. volume plot.
 - a. Tap the Table tab. Choose New Calculated Column from the Table menu.
 - b. Enter d1 as the Calculated Column Name. Select the equation, 1st derivative (Y,X). Use Volume as the Column for X, and pH as the Column for Y. Select OK.
 - c. On the displayed plot of d1 vs. volume, examine the graph to determine the volume at the peak value of the first derivative.
2. Determine the zero value on the second derivative vs. volume plot.
 - a. Tap the Table tab. Choose New Calculated Column from the Table menu.
 - b. Enter d2 as the Calculated Column Name. Select the equation, 2nd derivative (Y,X). Use Volume as the Column for X, and pH as the Column for Y. Select OK.
 - c. On the displayed plot of d2 vs. volume, examine the graph to determine the volume when the 2nd derivative equals approximately zero.

PROCESSING THE DATA

1. Use your printed graph and data table to confirm the volume of NaOH titrant you recorded *before* and *after* the largest increase in pH values upon the addition of 1 drop of NaOH solution.
2. Determine the volume of NaOH added at the equivalence point. To do this, add the two NaOH values determined above and divide by two.
3. Calculate the number of moles of NaOH used.
4. See the equation for the neutralization reaction given in the introduction. Determine the number of moles of HCl used.
5. Recall that you pipetted out 10.0 mL of the unknown HCl solution for the titration. Calculate the HCl concentration.

DATA AND CALCULATIONS

Concentration of NaOH	M	M
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Acid-Base Titration

NaOH volume added before largest pH increase	mL	mL
NaOH volume added after largest pH increase	mL	mL
Volume of NaOH added at equivalence point	mL	mL
Moles NaOH	mol	mol
Moles HCl	mol	mol
Concentration of HCl	mol/L	mol/L
Average [HCl]		M