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Atlanta, GA

HANDS-ON ACTIVITIES

Evaporation of Alcohols
- Stainless Steel Temperature Probe

Boyle's Law
- Go Direct Gas Pressure Sensor

Beer's Law
- Go Direct Colorimeter
- Go Direct SpectroVis Plus Spectrophotometer

Acid/Base Titration
- Go Direct pH Sensor and Drop Counter

Conductivity of Solutions
- Go Direct Conductivity Sensor

Evaporation and Intermolecular Attractions

In this experiment, Temperature Probes are placed in various liquids. Evaporation occurs when the probe is removed from the liquid's container. This evaporation is an endothermic process that results in a temperature decrease. The magnitude of a temperature decrease is, like viscosity and boiling temperature, related to the strength of intermolecular forces of attraction. In this experiment, you will study temperature changes caused by the evaporation of several liquids and relate the temperature changes to the strength of intermolecular forces of attraction. You will use the results to predict, and then measure, the temperature changes for several other liquids.

You will encounter two types of organic compounds in this experiment—alkanes and alcohols. The two alkanes are pentane, C_5H_{12}, and hexane, C_6H_{14}. In addition to carbon and hydrogen atoms, alcohols also contain the -OH functional group. Methanol, CH_3OH, and ethanol, C_2H_5OH, are two of the alcohols that we will use in this experiment. You will examine the molecular structure of alkanes and alcohols for the presence and relative strength of two intermolecular forces—hydrogen bonding and dispersion forces.

OBJECTIVES

- Study temperature changes caused by the evaporation of several liquids.
- Relate the temperature changes to the strength of intermolecular forces of attraction.

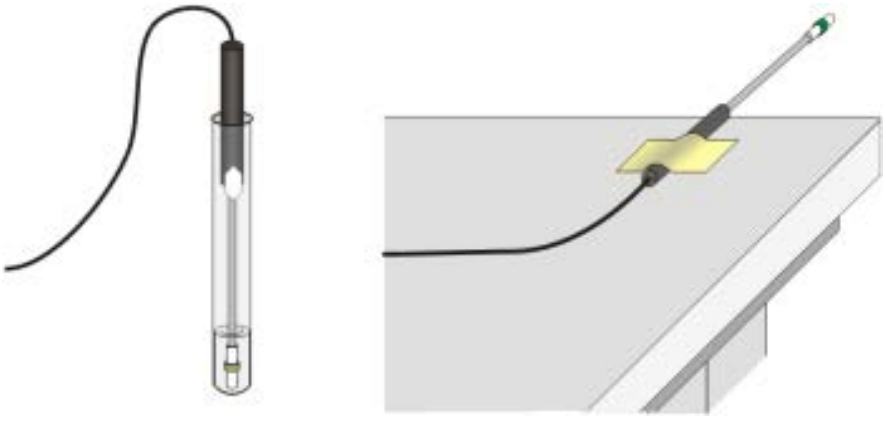

Figure 1

MATERIALS

LabQuest
LabQuest App
two Vernier Temperature Probes
methanol (methyl alcohol)
ethanol (ethyl alcohol)
1-propanol
1-butanol
n-pentane
n-hexane
6 pieces of filter paper (2.5 cm × 2.5 cm)
2 small rubber bands
masking tape

PRE-LAB EXERCISE

Prior to doing the experiment, complete the Pre-Lab table. The name and formula are given for each compound. Draw a structural formula for a molecule of each compound. Then determine the molecular weight of each of the molecules. Dispersion forces exist between any two molecules, and generally increase as the molecular weight 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, O, or F atom within the molecule. Tell whether or not each molecule has hydrogen-bonding capability.

PROCEDURE

1. Obtain and wear goggles! **Caution**: *The compounds used in this experiment are flammable and poisonous. Avoid inhaling their vapors. Avoid contacting them with your skin or clothing. Be sure there are no open flames in the lab during this experiment. Notify your teacher immediately if an accident occurs.*

2. Connect the Temperature Probes to LabQuest and choose New from the File menu.

3. On the Meter screen, tap Duration. Change the data-collection duration to 240 seconds. Select OK. Data collection will last 4 minutes.

4. Wrap Probe 1 and Probe 2 with square pieces of filter paper secured by small rubber bands as shown in Figure 1. Roll the filter paper around the probe tip in the shape of a cylinder. **Hint**: First slip the rubber band on the probe, wrap the paper around the probe, and then finally slip the rubber band over the paper. The paper should be even with the probe end.

5. Stand Probe 1 in the ethanol container and Probe 2 in the 1-propanol container. Make sure the containers do not tip over.

   DANGER: *Denatured ethanol,* CH_3CH_2OH: *Highly flammable liquid and vapor. Keep away from heat, sparks, open flames, and hot surfaces. Do not eat or drink when using this product—harmful if swallowed. Causes skin and serious eye irritation. May cause respiratory irritation. Avoid breathing mist, vapors or spray. Causes damage to organs. Addition of denaturant makes the product poisonous. Cannot be made nonpoisonous.*

DANGER: *1-Propanol: Keep away from heat, sparks, open flames, and hot surfaces—highly flammable liquid and vapor. Do not eat or drink when using this product—harmful if swallowed. Causes mild skin irritation and serious eye damage. May be harmful if inhaled. May cause drowsiness or dizziness.*

6. Prepare 2 pieces of masking tape, each about 10 cm long, to be used to tape the probes in position during Step 7.

7. After the probes have been in the liquids for at least 30 seconds, start data collection. A live graph of temperature *vs*. time for both Probe 1 and Probe 2 is being plotted on the screen. Live readings are displayed to the right of the graph. Monitor the temperature for 15 seconds to establish the initial temperature of each liquid. Then simultaneously remove the probes from the liquids and tape them so the probe tips extend 5 cm over the edge of the table top as shown in Figure 1.

8. Data collection will stop after 4 minutes, or you can stop data collection before 4 minutes has elapsed if the lowest temperature has been reached. Examine the graph of temperature *vs*. time. Based on your data, determine the maximum temperature, t_1, and minimum temperature, t_2, for both probes. Record t_1 and t_2 for each probe.

9. For each liquid, subtract the minimum temperature from the maximum temperature to determine Δt, the temperature change during evaporation.

10. Based on the Δt values you obtained for these two substances, plus information in the Pre-Lab exercise, *predict* the size of the Δt value for 1-butanol. Compare its hydrogen-bonding capability and molecular weight to those of ethanol and 1-propanol. Record your predicted Δt, then explain how you arrived at this answer in the space provided. Do the same for n-pentane. 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.

11. Test your prediction in Step 10 by repeating Steps 5–9 using 1-butanol with Probe 1 and n-pentane with Probe 2.

    DANGER: *1-Butanol,* C_4H_9OH: *Keep away from heat, sparks, open flames, and hot surfaces—highly flammable liquid and vapor. Toxic if swallowed, in contact with skin, or if inhaled. Do not eat or drink when using this product. Do not breathe mist, vapors, or spray. Causes skin and serious eye irritation. Causes damage to organs.*

    DANGER: *n-Pentane,* $CH_3(CH_2)_3CH_3$: *Keep away from heat, sparks, open flames, and hot surfaces—highly flammable liquid and vapor. Do not eat or drink when using this product—harmful if swallowed or in contact with skin. Avoid breathing mist, vapors or spray. May cause drowsiness or dizziness.*

12. Based on the Δt values you obtained for all four liquids, plus information in the Pre-Lab, predict the Δt values for methanol and n-hexane. Compare the hydrogen-bonding capability and molecular weight of methanol and n-hexane to those of the previous four liquids. Record your predicted Δt, then explain how you arrived at this answer.

13. Test your prediction in Step 12 by repeating Steps 5–9, using methanol with Probe 1 and n-hexane with Probe 2.

    DANGER: *Methanol,* CH_3OH: *Keep away from heat, sparks, open flames, and hot surfaces—highly flammable liquid and vapor. Toxic if swallowed, in contact with skin, or if inhaled. Do not eat or drink when using this product. Do not breathe mist, vapors, or spray. Causes skin and serious eye irritation. Causes damage to organs.*

    DANGER: *Hexanes,* C_6H_{14}: *Keep away from heat, sparks, open flames, and hot surfaces—highly flammable liquid and vapor. Do not eat or drink when using this product. Avoid breathing mist, vapors, or spray. May be fatal if swallowed and enters airways. May cause damage to organs. Causes skin and eye irritation. May cause drowsiness or dizziness. Suspected of damaging fertility or the unborn child. Do not handle until all safety precautions have been understood.*

PROCESSING THE DATA

1. Two of the liquids, n-pentane and 1-butanol, had nearly the same molecular weights, 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 stronger intermolecular forces of attraction? The weaker intermolecular forces? Explain using the results of this experiment.

4. Plot a graph of Δt values of the four alcohols versus their respective molecular weights. Plot molecular weight on the horizontal axis and Δt on the vertical axis.

PRE-LAB

Substance	Formula	Structural formulas	Molecular weight	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}			

DATA TABLE

Substance	t_1 (°C)	t_2 (°C)	Δt ($t_1 - t_2$) (°C)
ethanol			
1-propanol			
1-butanol			
n-pentane			
methanol			
n-hexane			

	Predicted Δt (°C)	Explanation
1-butanol		
n-pentane		
methanol		
n-hexane		

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

- 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.

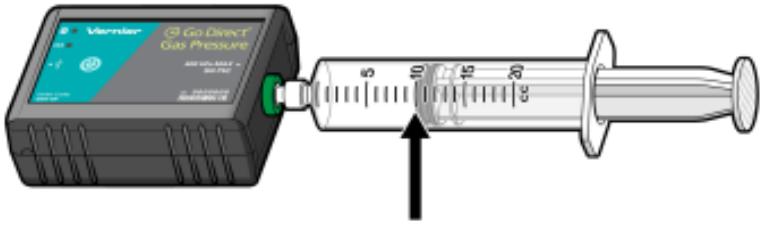

Figure 1

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Gas Pressure
20 mL gas syringe

PROCEDURE

1. Prepare the data-collection equipment and an air sample for data collection.

   a. Launch Graphical Analysis. Connect the Gas Pressure Sensor to your Chromebook, computer, or mobile device.

   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.

2. Set up the data-collection mode.

   a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.

   b. Enter **Volume** as the Event Name and **mL** as the Units. Click or tap Done.

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. Click or tap Collect to 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. Click or tap Keep and enter **5.8**, the gas volume (in mL). Remember, you are adding 0.8 mL to the volume of the syringe for the total volume. Click or tap Keep Point to store this pressure-volume data pair.

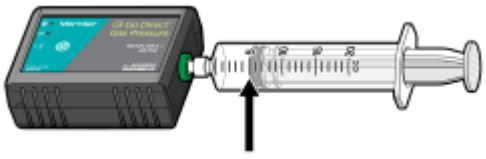

Figure 2

   d. Continue this procedure using syringe volumes of 10.0, 12.5, 15.0, 17.5, and 20.0 mL.

   e. Click or tap Stop to 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, decide what kind of mathematical relationship exists between these two variables, direct or inverse. To see if you made the right choice:
   a. Click or tap Graph Tools, , and choose Apply Curve Fit.
   b. Select Power as the curve fit and Dismiss the Curve Fit box. The curve fit statistics 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 (that is, pass through or near the plotted points).
   d. Rescale the axes on your graph by clicking or tapping Graph Tools, . Choose Edit Graph Options and set the x-axis to display 0 to 25 mL and the y-axis to display 0 to 300 kPa. Dismiss the Graph Options box.
   e. (optional) Export, download, or print the graph with the curve fit displayed.
7. With the best-fit curve still displayed, proceed directly to the Processing the Data section.

DATA AND CALCULATIONS

Volume (mL)	Pressure (kPa)	Constant, *k* (P / V or P • V)

PROCESSING THE DATA

1. With the best-fit curve still displayed, click or tap Graph Tools, , and turn on Interpolate. Dismiss the Graph Tools box and click the graph to interpolate. Move along the regression line until the volume value is 5.0 mL. Note the corresponding pressure value. Now move to the point where the volume value is doubled (10.0 mL). What does your data show happens to the pressure when the volume is *doubled*? Show the pressure values in your answer.

2. Using the same technique as in Question 1, what does your data show happens to the pressure if the volume is *halved* from 20.0 mL to 10.0 mL? Show the pressure values in your answer.

3. Using the same technique as in Question 1, what does your data show happens to the pressure if the volume is *tripled* from 5.0 mL to 15.0 mL? 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 *vs.* 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? Explain or show work to support your answer.

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.

EXTENSIONS

1. To confirm that an inverse relationship exists between pressure and volume, a graph of pressure *vs. reciprocal of volume* (1/volume) may also be plotted. To do this, it is necessary to create a new column of data, reciprocal of volume, based on your original volume data:

   a. Click or tap More Options, ⋯, in the Volume column header in the table. Choose Add Calculated Column.

   b. Enter **1/volume** as the Name and **1/mL** as the Units.

   c. Click or tap Insert Expression and choose A/X as the expression.

   d. Enter **1** as Parameter A and select Volume as the Column.

   e. Click or tap Apply.

2. Plot a best-fit regression line on your graph of pressure *vs.* 1/volume:

   a. Click or tap Graph Tools, , and choose Edit Graph Options.

   b. Enter **0** as the value for both the Left value for the x-axis and the Bottom value for the y-axis.

   c. Dismiss the Graph Options box. Your graph should now include the origin (0,0).

   d. Click or tap Graph Tools, , and choose Apply Curve Fit.

   e. Select Linear as the curve fit and Dismiss the Curve Fit box. The linear-regression statistics are displayed in the form:

   $$y = mx + b$$

   where x is 1/volume, y is pressure, m is a proportionality constant, and b is the y-intercept.

   f. If the relationship between P and V is an inverse relationship, the graph of pressure *vs.* 1/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.

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. 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.

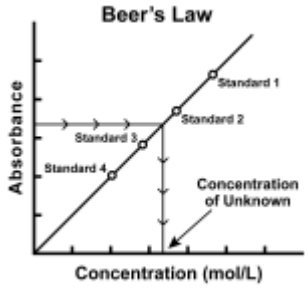

Figure 1

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

- 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

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Colorimeter
one cuvette
five 20 × 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 pump or pipet bulb
distilled water
test tube rack
tissues (preferably lint-free)

PROCEDURE

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. **DANGER**: *Nickel sulfate solution,* $NiSO_4$: *Causes skin, respiratory tract, and eye irritation. Do not breathe mist, vapors, or spray—toxic if swallowed.*

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 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.

5. Launch Graphical Analysis. Connect the Colorimeter to your Chromebook, computer, or mobile device.

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. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.

   b. Enter **Concentration** as the Event Name and **mol/L** as the Units. Click or tap Done.

8. You are now ready to collect absorbance-concentration data for the five standard solutions.

   a. Click or tap Collect to 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. Close the lid on the Colorimeter.

   c. When the value has stabilized, click or tap Keep and enter **0.080** as the concentration in mol/L. Click or tap Keep Point. 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 click or tap Keep. Enter **0.16** as the concentration in mol/L. Click or tap Keep Point.

   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 $NiSO_4$. **Note**: Wait until Step 10 to test the unknown.

   f. Click or tap Stop to stop data collection.

   g. To examine the data pairs on the displayed graph, click or tap 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. Click or tap Graph Tools, , and choose Edit Graph Options.

   b. Enter **0** as the value for both the Left value for the x-axis and the Bottom value for the y-axis. Dismiss the Graph Options box.

   c. Click or tap Graph Tools, , and choose Apply Curve Fit.

   d. Select Linear as the curve fit and Dismiss the Curve Fit box. 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.

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. 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.
    b. 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.
    c. Monitor the absorbance value. When this value has stabilized, record it in your data table.
11. Discard the solutions as directed by your instructor. Before closing Graphical Analysis, continue to the Processing the Data section.

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. Click or tap Graph Tools, , and turn on Interpolate.
    b. Click or tap any point on the curve to find the absorbance value that is closest to the absorbance reading you obtained during the Procedure. Record the corresponding $NiSO_4$ concentration, in mol/L, 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

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 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.

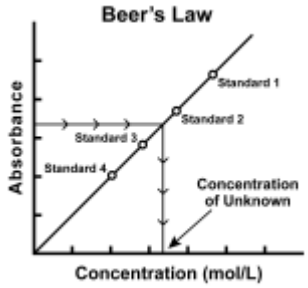

Figure 1

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

- 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

Chromebook, computer, **or** mobile device
Vernier Spectral Analysis app
Go Direct SpectroVis Plus
one cuvette
five 20 × 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 pump or pipet bulb
distilled water
test tube rack
tissues (preferably lint-free)

PROCEDURE

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. **DANGER**: *Nickel sulfate solution,* $NiSO_4$: *Causes skin, respiratory tract, and eye irritation. Do not breathe mist, vapors, or spray—toxic if swallowed.*

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 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.

5. Launch Spectral Analysis. Connect the Go Direct SpectroVis Plus to your Chromebook, computer, or mobile device. Click or tap Absorbance vs. Concentration.

6. To calibrate the Spectrometer, place the blank cuvette in the Spectrometer and select Finish Calibration. **Note**: If necessary, wait for the Spectrometer to warm up before selecting Finish Calibration.

7. Determine the optimal wavelength for creating the standard curve.

   a. Remove the blank cuvette, and place the 0.40 M standard into the cuvette slot.

   b. The live graph will update with the spectrum of the sample. Click or tap the desired wavelength or enter the Wavelength. Click or tap Done.

8. You are now ready to collect absorbance-concentration data for the five standard solutions.

   a. Click or tap Collect to start data collection.

   b. Empty the 0.40 M solution 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.

   c. When the value has stabilized, click or tap Keep and enter **0.080** as the concentration in mol/L. Click or tap Keep Point. 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 click or tap Keep. Enter **0.16** as the concentration in mol/L. Click or tap Keep Point.

   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 $NiSO_4$. **Note**: Wait until Step 10 to test the unknown.

   f. Click or tap Stop to stop data collection.

   g. To examine the data pairs on the displayed graph, click or tap any data point. 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. Click or tap Graph Tools, , and choose Edit Graph Options.

   b. Enter **0** as the value for both the Left value for the x-axis and the Bottom value for the y-axis. Dismiss the Graph Options box.

   c. Click or tap Graph Tools, , and choose Apply Curve Fit.

   d. Select Linear as the curve fit and Dismiss the Curve Fit box. 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.

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. 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.
    b. 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.
    c. Monitor the absorbance value. When this value has stabilized, record it in your data table.
11. Discard the solutions as directed by your instructor. Before closing Spectral Analysis, continue to the Processing the Data section.

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. Click or tap Graph Tools, , and turn on Interpolate.
    b. Click or tap any point on the curve to find the absorbance value that is closest to the absorbance reading you obtained during the Procedure. Record the corresponding $NiSO_4$ concentration, in mol/L, 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:

$$H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \rightarrow H_2O(l) + Na^+(aq) + Cl^-(aq)$$

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.

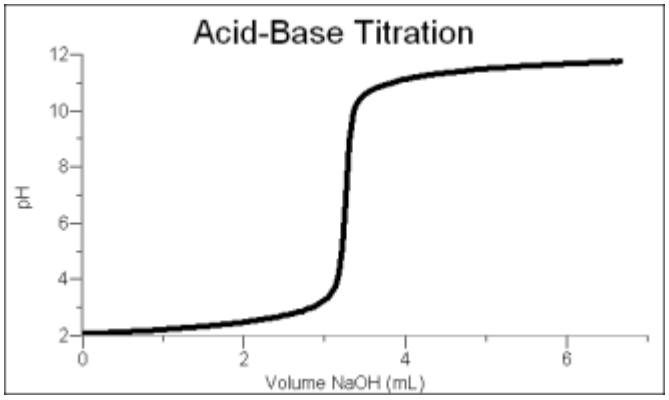

Figure 1

OBJECTIVES

- 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)

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct pH
Stir Station
magnetic stirring bar
(optional) Phenolphthalein
HCl solution, unknown concentration
~0.1 M NaOH solution
pipet bulb or pump
250 mL beaker
wash bottle
distilled water

Materials required only for Method 1 (buret)

Electrode Support
50 mL buret
10 mL pipet
buret clamp or utility clamp
2nd 250 mL beaker

Materials required only for Method 2 (Drop Counter)

Go Direct Drop Counter
60 mL reagent reservoir
5 mL pipet or graduated 10 mL pipet
100 mL beaker
10 mL graduated cylinder
utility clamp

CHOOSE A METHOD

Method 1: 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: Use 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. **DANGER**: *Hydrochloric acid solution,* HCl: *Causes severe skin and eye damage. Do not breathe mist, vapors, or spray. May cause respiratory irritation. May be harmful if swallowed.*

3. Place the beaker on a Stir Station and add a stirring bar.

4. Launch Graphical Analysis. Connect the pH Sensor to your Chromebook, computer, or mobile device.

5. Set up the data-collection mode.

   a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.

   b. Enter **Volume** as the Event Name and **mL** as the Units. Click or tap Done.

6. Use an Electrode Support to suspend a pH Sensor on a Stir Station (see Figure 2). Position the pH Sensor in the HCl solution and adjust its position so it will not be struck by the stirring bar. Turn on the Stir Station, and adjust it to a medium stirring rate (with no splashing of solution). Check to see that the pH value is between 1.5 and 2.5.

Figure 2

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. **WARNING**: *Sodium hydroxide solution*, NaOH: *Causes skin and eye irritation.*

   Use a buret clamp or a utility clamp to attach the buret to the Stir Station 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.

8. You are now ready to perform the titration. This process is faster if one person manipulates and reads the buret while another person enters volumes.

   a. Click or tap Collect to start data collection.

   b. Before you have added any drops of NaOH solution, click or tap Keep and enter **0** as the buret volume in mL. Click or tap Keep Point 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, click or tap Keep, enter the current buret reading (to the nearest 0.01 mL), and then click or tap Keep Point.

   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. Click or tap Stop to stop data collection.

10. Examine the data on the 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. Move to the region of the graph with the largest increase in pH (you can adjust the Examine line by dragging the flag). 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) Export, download, or 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. **DANGER**: *Hydrochloric acid solution,* HCl: *Causes severe skin and eye damage. Do not breathe mist, vapors, or spray. May cause respiratory irritation. May be harmful if swallowed.*

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. **WARNING**: *Sodium hydroxide solution,* NaOH: *Causes skin and eye irritation.*

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 the reagent reservoir with a few mL of the ~0.1 M NaOH solution. Attach the reagent reservoir to the Stir Station. 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. Launch Graphical Analysis. Connect the pH Sensor and the Drop Counter to your Chromebook, computer, or mobile device.

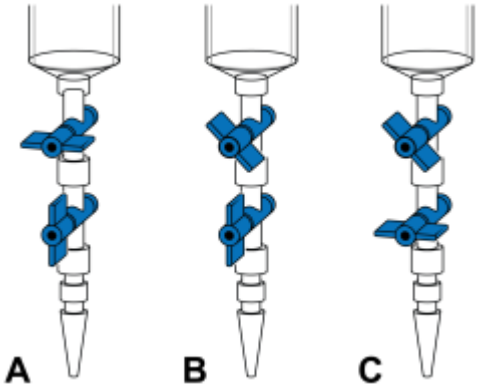

Figure 3

Figure 4

6. Calibrate the Drop Counter so that a precise volume of titrant is recorded in units of milliliters.
   a. Attach the Drop Counter to the Stir Station.
   b. Adjust the handles on the reagent reservoir so the top valve is closed (horizontal) and the bottom valve is open (vertical) (see Figure 3A).
   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. Click or tap the Volume meter and choose Calibrate.
   e. Follow the on-screen prompts to calibrate the Drop Counter. To adjust the drop flow, slowly open the top valve of the reagent reservoir (see Figure 3B) so that drops are released at a slow rate (~1 drop every two seconds). When the volume of solution in the graduated cylinder is between 9 and 10 mL close the bottom valve (see Figure 3C).
   f. Discard the solution in the graduated cylinder as indicated by your instructor and set the graduated cylinder aside.
7. Assemble the apparatus.
   a. Insert the pH Sensor through the large hole in the Drop Counter.
   b. Adjust the positions of the Drop Counter and reagent reservoir so they are both lined up with the center of the Stir Station.
   c. Lift up the pH Sensor, and slide the beaker containing the HCl solution onto the Stir Station. Lower the pH Sensor into the beaker. Check to see that the pH value is between 1.5 and 2.5.
   d. Place the stirring bar in the beaker and adjust the position of the pH Sensor so that it will not be struck by the stirring bar.
   e. Adjust the reagent reservoir so its tip is just above the Drop Counter slot.
8. Turn on and adjust the Stir Station so it is stirring at a fast rate.

9. You are now ready to begin collecting data. Click or tap Collect to 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.

10. 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 click or tap Stop to stop data collection. Turn the bottom valve of the reagent reservoir to a closed (horizontal) position.

11. Dispose of the beaker contents as directed by your teacher.

12. Examine the data on the 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.

13. (optional) Export, download, or print the graph.

14. 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. Click or tap View, ☐, and select Graph and Table.
   b. Click or tap More Options, ⋯, in the pH column header in the table. Then, choose Add Calculated Column.
   c. Enter **d1** as the Name and leave the Units field blank.
   d. Click or tap Insert Expression and choose 1st Derivative(Y,X) as the expression.
   e. Select pH as Column Y and Volume as Column X. Click or tap Apply.
   f. To display a graph of d1 *vs.* volume, click or tap the y-axis label, select only d1, and dismiss the box.
   g. On the graph of d1 *vs.* volume, examine the data 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. Click or tap More Options, ⋯, in the Volume column header in the table. Then, choose Add Calculated Column.
   b. Enter **d2** as the Name and leave the Units field blank.
   c. Click or tap Insert Expression and choose 2nd Derivative(Y,X) as the expression.

d. Select pH as Column Y and Volume as Column X. Click or tap Apply.

e. Click or tap the y-axis label, select only d2 to display a graph of d1 *vs.* volume, and dismiss the box.

f. Click or tap the y-axis label, select only the d2 column, and dismiss the box. On the displayed graph of d2 *vs.* volume, examine the data to determine the volume when the 2nd derivative equals approximately zero.

DATA TABLE

Concentration of NaOH	M	M
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	

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:

$$NaCl(s) \rightarrow Na^{+}(aq) + Cl^{-}(aq)$$

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 (µS/cm).

OBJECTIVES

- 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.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct Conductivity
Stir Station
magnetic stir bar
Electrode Support
1.0 M NaCl
1.0 M $AlCl_3$
1.0 M $CaCl_2$
stirring rod
100 mL beaker
distilled water
wash bottle
tissue

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. **WARNING**: *Sodium chloride solution,* NaCl: *May be harmful if swallowed. Skin and eye irritant.*

3. Launch Graphical Analysis. Connect the Conductivity Probe to your Chromebook, computer, or mobile device.

4. Set up the data-collection mode.

   a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.

   b. Enter **Volume** as the Event Name and **drops** as the Units. Click or tap Done.

5. Before adding any drops of solution:

   a. Click or tap Collect to start data collection.

   b. Set up a Stir Station and Electrode Support as shown in Figure 1. Place the beaker on the Stir Station and place the magnetic stir bar in the beaker. Lower the Conductivity Probe until the hole near the probe end is completely submerged in the solution, but not so low that the stirring bar will strike the probe. Set the Stir Station to a gentle stirring speed.

   c. Before you have added any drops of NaCl solution, click or tap Keep. Enter **0**, the volume (in drops) and then click or tap Keep Point to save this data pair.

Figure 1

6. You are now ready to begin adding salt solution.

   a. Add 1 drop of NaCl solution to the distilled water. Make sure the solution is being properly mixed.

   b. When the conductivity readings stabilize, click or tap Keep. Enter **1** as the volume in drops and then click or tap Keep Point.

7. Repeat the Step 6 procedure, entering **2** this time.

8. Continue this procedure, adding 1-drop portions of NaCl solution, measuring conductivity, and entering the total number of drops added—until a total of 8 drops has been added.

9. Click or tap Stop to stop data collection.

10. To analyze the relationship between conductivity and volume, use this method to calculate the linear-regression statistics for your data. Then plot the linear regression curve on your graph.

    a. Click or tap Graph Tools, , and choose Apply Curve Fit.

b. Select Linear as the curve fit and Dismiss the Curve Fit box. **Note**: Since increasing the volume (drops) of NaCl increases the concentration of NaCl in the solution, the graph actually represents the relationship between *conductivity* and *concentration*. The linear-regression statistics 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.

11. Repeat Steps 5–10, this time using 1.0 M $AlCl_3$ solution in place of 1.0 M NaCl solution. **Note**: The previous data set is automatically saved. **WARNING**: *Aluminum chloride solution,* $AlCl_3$: *May be harmful if swallowed. Causes skin and eye irritation.*

12. Repeat Steps 5–10, this time using 1.0 M $CaCl_2$ solution. **WARNING**: *Calcium chloride solution,* $CaCl_2$: *May be harmful if swallowed. Causes skin and eye irritation.*

13. To view a graph of concentration *vs*. volume showing all three data runs, click or tap the y-axis label and select the data sets you want to display. Dismiss the box to view the graph.

14. (optional) Print a copy of the graph. Label each data set 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.

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 $CaCl_2$	