Advanced Chemistry through Inquiry

Student Guide

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1. MODELING CHEMISTRY

Initial Question

Exploring chemical and physical changes in a laboratory experiment is not as easy as one may think. The general appearance of a substance can tell us something about events on the molecular level, but this provides limited information. Measuring parameters like conductivity, temperature, pH, or pressure with digital sensors can provide data that helps us understand more about what is going on, but even that may not be enough to completely understand that which is too small to see. This is the challenge of being a chemist.

What tools allow us to examine physical and chemical changes?

Materials and Equipment

Model 1

- Data collection system
- Temperature sensor
- pH sensor
- Conductivity sensor
- Graduated cylinder, 100-mL
- Beakers (6), glass, 100-mL
- Stirring rod
- Unknowns 1A–1D , 100 mL each
- Distilled water wash bottle

Model 2

- Data collection system
- Absolute pressure sensor[1,3]
- Tubing and tubing connector (2)
- Quick release connector
- Sensor extension cable
- Test tube rack
- Test tubes (2), 20mm × 150 mm, glass
- Rubber stopper, #2, two-hole
- Syringe, 10-mL, to fit stopcock
- Stopcock to fit two-hole stopper
- Graduated cylinder, 10 mL
- Unknown 2A, 2 mL
- Unknown 2B, fill approximately 1/4 of the test tube
- Glycerin, several drops
- Tongs
- Paper towel

Model 3

- Data collection system
- Temperature sensor
- pH sensor
- Conductivity sensor
- Graduated cylinder, 100-mL
- Beaker, glass, 100-mL
- Stirring rod
- Distilled water, 50 mL
- Distilled water wash bottle
- Each group is assigned one of the following:
  Sucrose ($C_{12}H_{22}O_{11}$), about 0.5 g
  Sodium chloride (NaCl), about 0.5 g
  Sodium acetate ($NaCH_3COO$), about 0.5 g
  Calcium (Ca) metal turning, about the size of half a pea
  Ammonium nitrate (NH_4NO_3), about 0.5 g

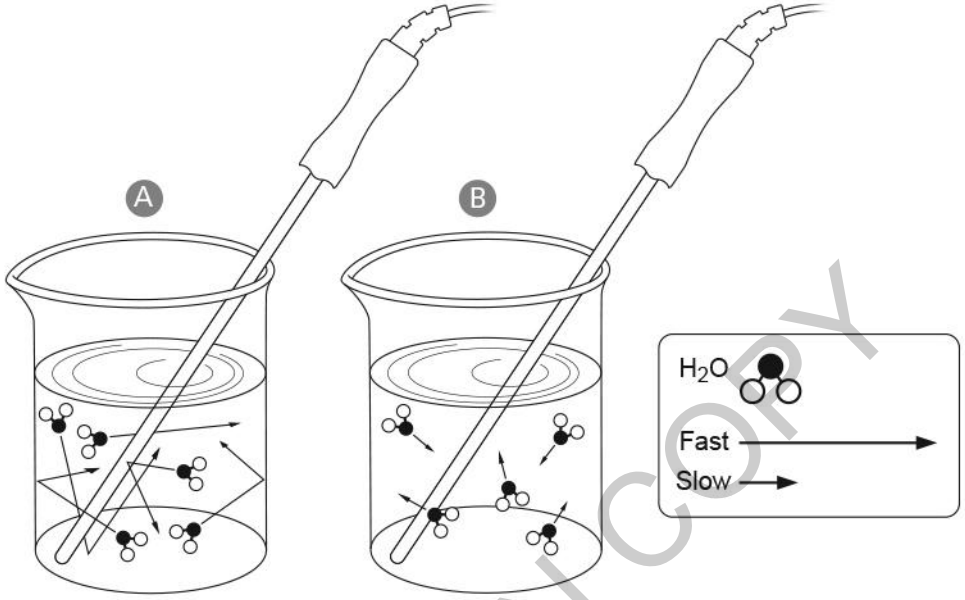
Safety

Add these important safety precautions to your normal laboratory procedures:

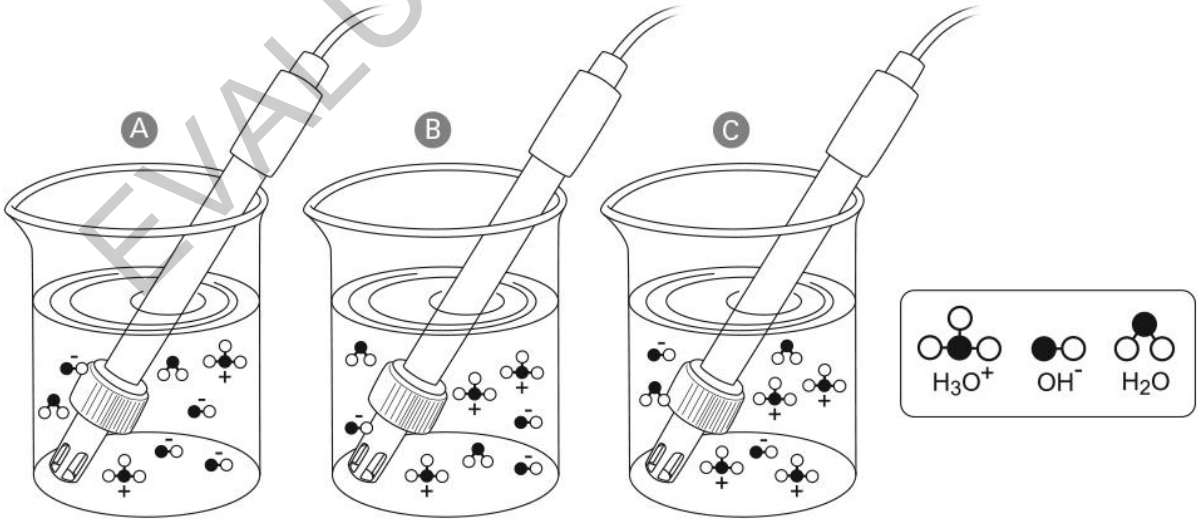
- Treat all unknowns as a hazardous, toxic, and harmful material.
- All unknowns should be disposed of in the proper waste container.
- Some of the unknowns in this lab are flammable. No unknowns should be used around an open flame.

Getting Your Brain in Gear

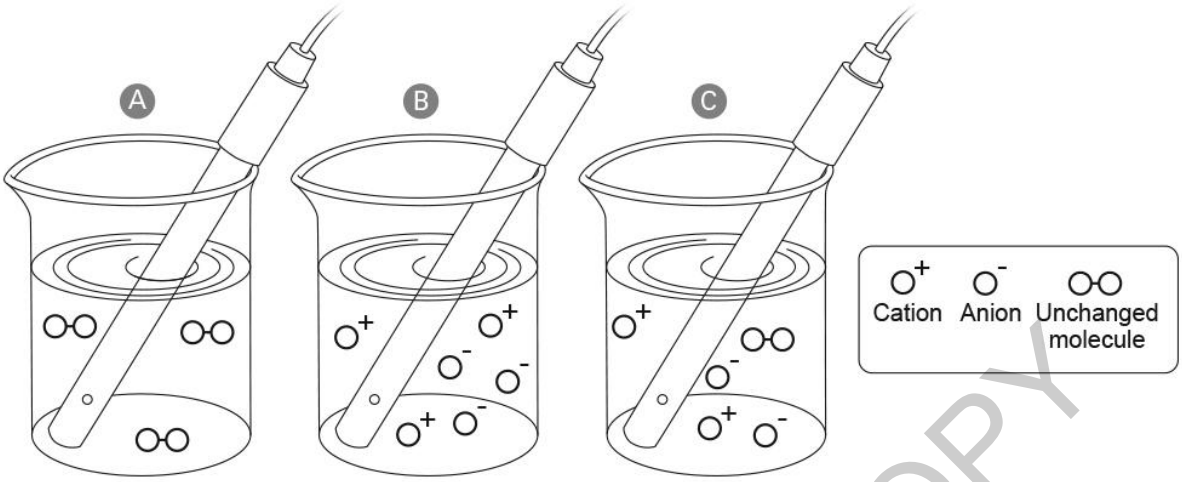
1. In this lab you use a temperature probe. Consider the following particulate-level representations. Which beaker contains the hot water and which contains the cold water? Explain your reasoning.



2. In this lab you use a pH sensor. Consider the following particulate-level representations. Label the beakers as "Acid", "Base", or "Neutral". Explain your reasoning.



3. In this lab you also use a conductivity sensor. Consider the following particulate-level representations. Label the beakers as "Low conductivity", "Medium conductivity", or "High conductivity". Explain your reasoning.



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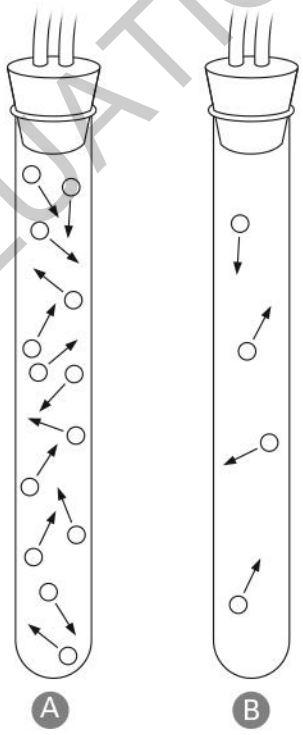
4. Finally, in this lab you use a pressure sensor. Consider the following particulate-level representations. Label the tubes as "High pressure" or "Low pressure". Explain your reasoning.



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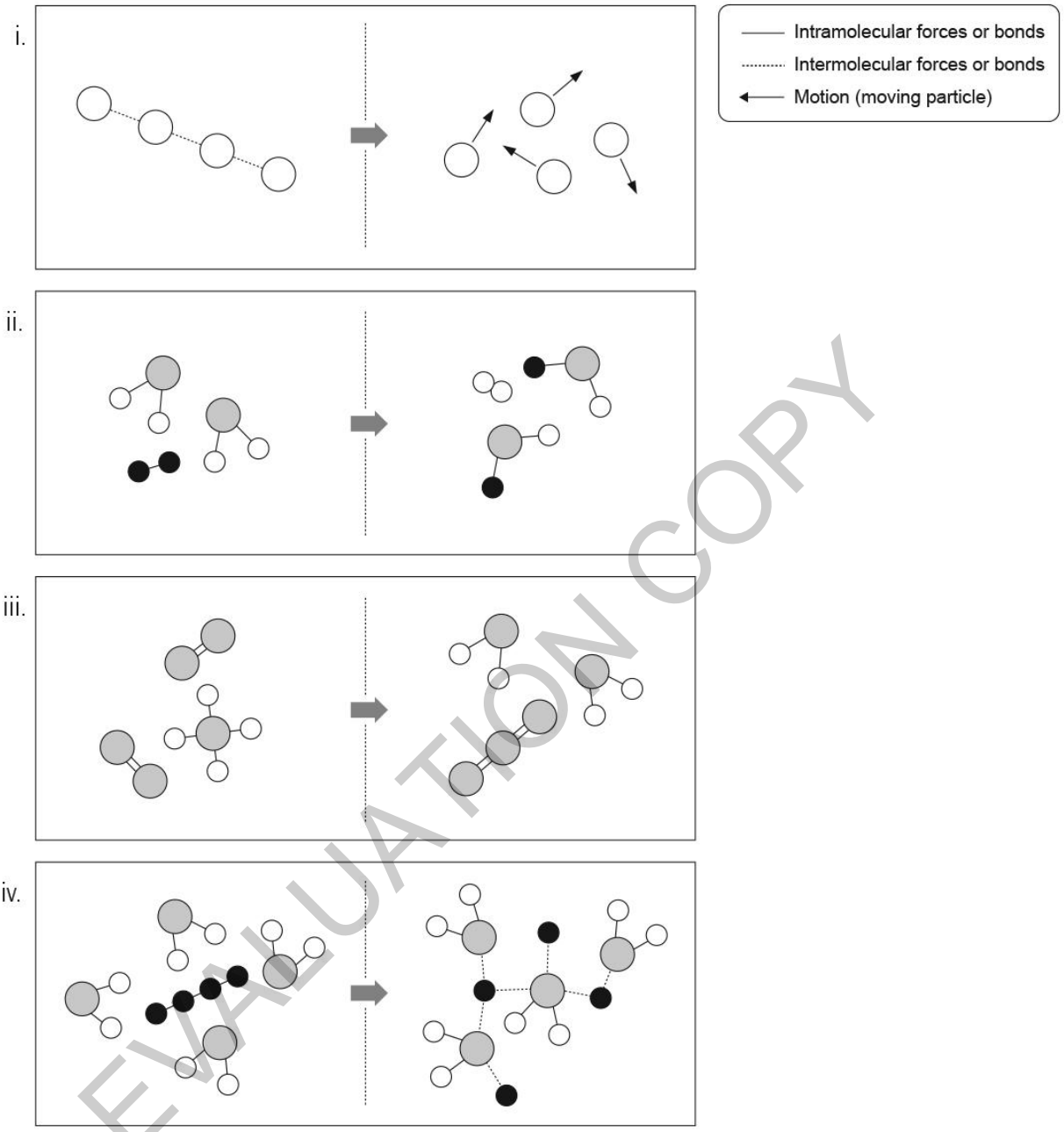
5. Analyze the following particulate-level representations of different processes.



a. Which representations above show a change in both intramolecular bonds and intermolecular forces?

_____

b. Which representations above show a change in just intramolecular bonds? Justify your answer.

_____

c. Which representations above show a change in just intermolecular forces? Justify your answer.

_____

MODEL 1

Building Model 1 – Is it a Chemical Change?

1. Obtain 6 clean 100-mL beakers and label them “A”, “B”, “C”, “D”, “AB”, and “CD”.
2. Pour 100 mL of Unknown 1A into Beaker A.
3. Pour 100 mL of Unknown 1B into Beaker B.
4. Pour 100 mL of Unknown 1C into Beaker C.
5. Pour 100 mL of Unknown 1D into Beaker D.
6. Combine 50 mL of Unknown 1A from Beaker A and 50 mL of Unknown 1B from Beaker B into Beaker AB. Note any visible changes that occur.
7. Combine 50 mL of Unknown 1C from Beaker C and 50 mL of Unknown 1D from Beaker D into Beaker CD. Note any visible changes that occur.
8. Observe Beakers AB and CD. Only one represents a chemical change. Speculate as to which beaker, AB or CD, represents a chemical change. Explain your reasoning.

_____

_____

_____

9. With your lab group, brainstorm how temperature, pH, and conductivity sensors could be used to determine which beaker underwent a chemical change.

_____

_____

_____

10. Start a new experiment on the data collection system.
11. Connect the pH sensor to the data collection system.
12. Calibrate the pH sensor.
13. Connect the temperature sensor to the data collection system.
14. Connect the conductivity sensor to the data collection system.
15. Display a digital readout of temperature, pH, and conductivity on the data collection system.
16. Empty Beakers AB and CD and rinse them thoroughly with distilled water.
17. Record observations of color, temperature, pH, and conductivity of the reactant beakers (A–D) by inserting the sensors into each beaker. Rinse the sensors between measurements with distilled water from a wash bottle. Record the data in the Model 1 Data Table.

18. Use the remaining solutions in Beakers A–D to repeat the reactions carried out above by combining the solutions in Beakers A and B and making measurements, and then combining the solutions in Beakers C and D and making measurements. Record observations of color, temperature, pH, and conductivity for both product Beakers AB and CD immediately after the reactants are mixed by inserting the sensors into each beaker. Rinse the sensors between measurements with distilled water. Record the data in the Model 1 Data Table.

Model 1 – Is it a Chemical Change?

Table 1: Model 1 Data Table—Determining a chemical change

Reactant Beaker	Color	pH	Temperature (°C)	Conductivity (Low/Med/High)
A				
B				
AB				
C				
D				
CD				

For conductivity:
Low: Less than 100 µS/cm
Med: Between 100 µS/cm and 1000 µS/cm
High: Greater than 1000 µS/cm

Analyzing Model 1 – Is it a Chemical Change?

19. Which reaction, the one in Beaker AB or the one in Beaker CD, showed a greater change in temperature, conductivity, and pH?

    Beaker CD showed a greater change in all three measurements.

20. When a large change in temperature is observed during a reaction, what might be occurring on the molecular level in the beaker?

    A large temperature change indicates the breaking or forming of intramolecular bonds.

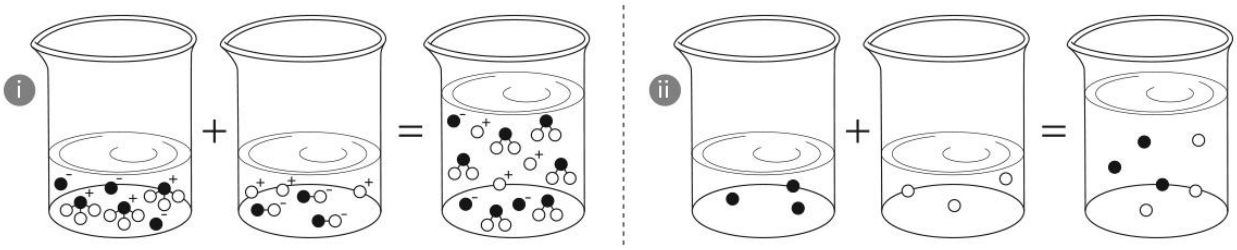
21. When a large change in conductivity is observed during a reaction, what might be occurring on the molecular level in the beaker?

    A large conductivity change indicates that ions are either being formed from neutral species or that ions are combining to form neutral species.

22. When a large change in pH is observed during a reaction, what might be occurring on the molecular level in the beaker?

    A large pH change indicates that H_3O^+ ions are either being formed or being used in a chemical reaction. If the pH moves towards a more neutral reading, the H_3O^+ ions are combining with OH^- ions to make H_2O.

23. Analyze the particulate-level representations below and answer the following questions.



a. Which set of particulate-level representations matches the data for mixing the solution in Beaker A with the solution in Beaker B to produce the products in Beaker AB? Explain your reasoning based on the sensor data.

_____

_____

_____

b. Which set of particulate-level representations matches the data for mixing the solution in Beaker C with the solution in Beaker D to produce the products in Beaker CD? Explain your reasoning based on the sensor data.

_____

_____

_____

24. A change in color can be a clue that chemical change is occurring. Was that the case in Model 1? Justify your answer with data from Model 1.

_____

_____

_____

25. Based on the particulate-level representations and sensor data collected, put a check by all the traits of a chemical change.

_____ a. Substance(s) remain unchanged.

_____ b. Atoms within molecules and compounds rearrange.

_____ c. Chemical properties of products are different than reactant properties.

_____ d. Chemical properties of products remain the same as reactant properties.

_____ e. Bonds are made or broken.

26. With your lab group, create a one-sentence definition of a chemical change.

_____

_____

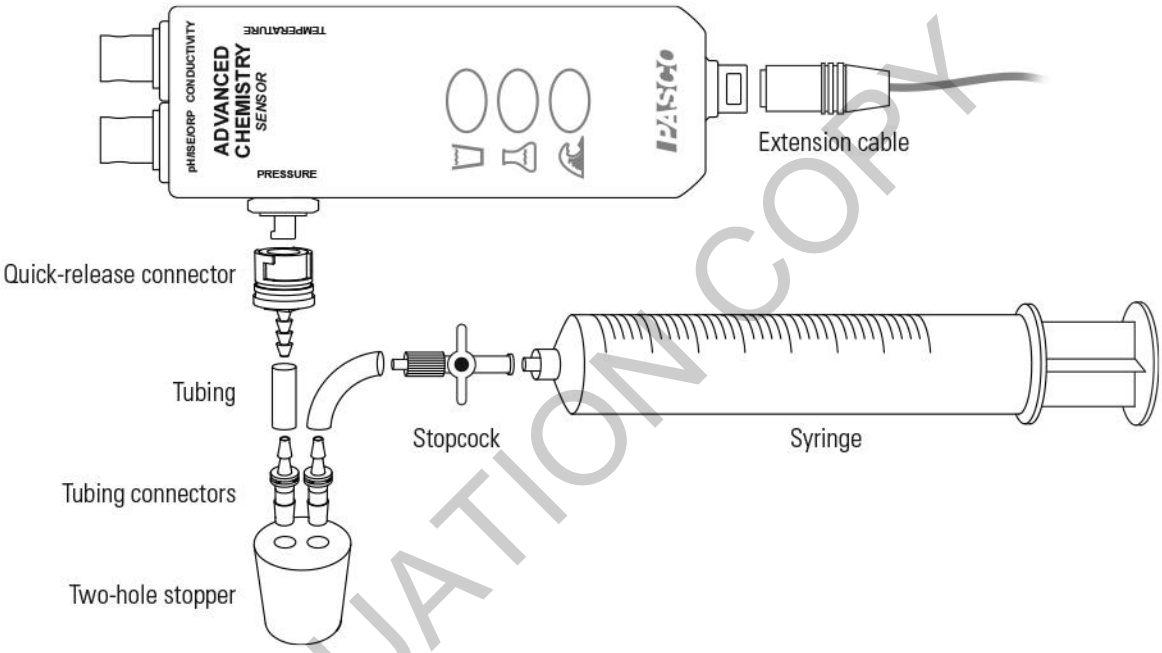
MODEL 2

Building Model 2 – Chemical versus Physical Change

1. Start a new experiment on the data collection system.

2. Connect the absolute pressure sensor to the data collection system using a sensor extension cable.

3. Connect the quick-release connector to the stopper using the tubing connector and the 1- to 2-cm piece of tubing by following the steps below. Use the picture as a guide.



   a. Insert the thicker end of one of the tubing connectors into the hole in the stopper. If this is difficult, add a drop of glycerin.

   b. Connect a 1- to 2-cm piece of tubing to the other, thinner end of the tubing connector.

   c. Insert the barbed end of the quick-release connector into the open end of the 1- to 2-cm piece of tubing. If this is difficult, add a drop of glycerin.

4. Insert the quick-release connector into the port of the absolute pressure sensor and then turn the connector clockwise until the fitting "clicks" onto the sensor (about one-eighth turn).

5. Display a pressure versus time graph on the data collection system.

6. Obtain two test tubes. Label them "A" and "B". Place them into a test tube rack.

7. Connect the syringe to the stopper as shown in the diagram and insert the stopper into Test Tube A. Start collecting data.

8. Using the syringe, obtain a 2 mL sample of Unknown 2A. Open the stopcock, quickly inject the sample, and pull the plunger back to the 2-mL mark.

9. Observe the change in pressure. Record if the pressure increased, decreased, or stayed the same over a 1-minute time interval in the Model 2 Data Table. Note any visible gas formation.

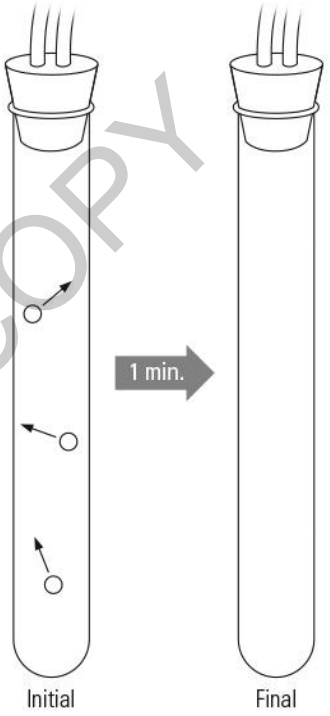
10. Remove the stopper and return the test tube to the test tube rack. Stop collecting data on the data collection system.

11. In the procedure just performed, you removed 2 mL of gas (mostly air) from the test tube after introducing the liquid. Explain why that step was necessary in order to keep the initial gas pressure constant.

    The introduction of 2 mL of liquid reduces the volume occupied by gas in the test tube and increases the pressure. To keep the initial gas pressure constant, a volume of gas equal to that of the introduced liquid needed to be removed.

12. Using the particulate-level representations provided in the Getting Your Brain in Gear questions as a guide, draw gas molecules in the "Final" test tube to represent the pressure change you observed.

13. Explain how the pressure data collected helped you determine what happened in Test Tube A.



14. Take Test Tube B and, with tongs, fill the test tube one quarter full of Unknown 2B. Dry it with a paper towel and immediately place it inside Test Tube B. Be careful not to compress the unknown.

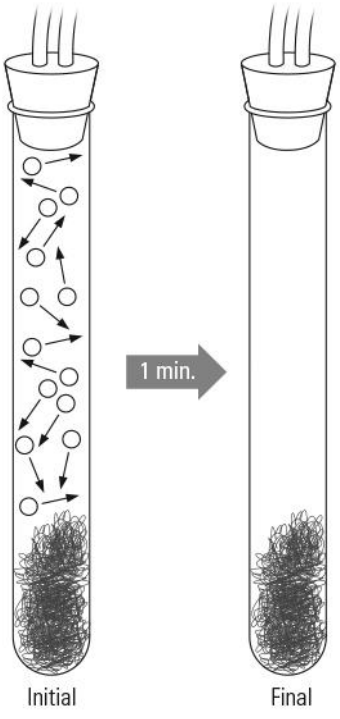
15. Remove the syringe and turn the stopcock to the closed position. Insert the stopper connected to the pressure sensor into the test tube and immediately start collecting data.

16. Observe the change in pressure. Record if the pressure increased, decreased, or stayed the same over a 10-minute time interval in Model 2. Note any visible gas formation and color change.

17. Stop collecting data on the data collection system. Remove the stopper and return the test tube to the test tube rack.

18. Using the particulate-level representations provided in the Getting Your Brain in Gear questions as a guide, draw gas molecules in the "Final" test tube to represent the pressure change you observed.

19. Explain how the pressure data collected helped you determine what happened in Test Tube B.



20. Dispose of the unknowns in the proper waste containers. Clean the beakers and test tubes with soapy water.

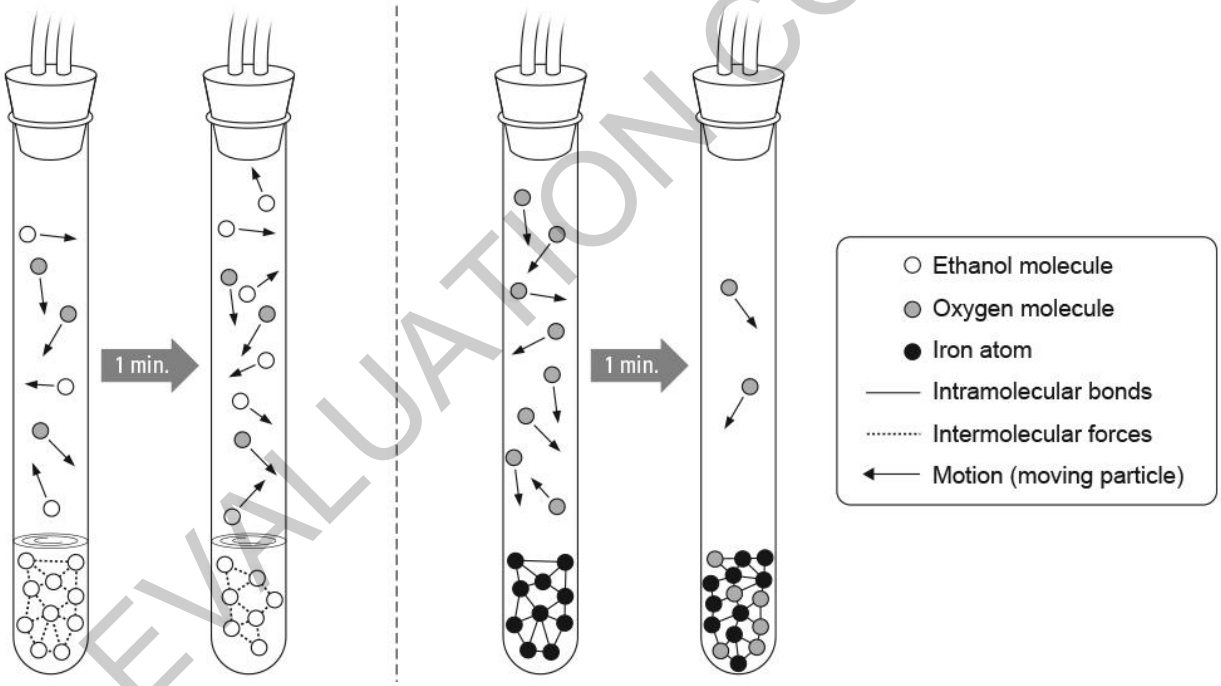
Model 2 – Chemical versus Physical Change

Table 2: Model 2 Data Table—Determining a chemical or physical change

Test Tube	Gas Visible?	Pressure Change (Increase/Decrease/Same)	Changes to Overall Appearance of Substances
A			
B			

Analyzing Model 2 – Chemical versus Physical Change

21. One of the changes observed in Model 2 was a chemical change and the other was a physical change. Use the particulate-level representations below and your data to answer the following questions.



_____ _____

a. Label each diagram as representing either Test Tube A or Test Tube B.

b. Use the chemical change definition your group developed for Model 1 to identify which test tube, A or B, contained the chemical change. Explain why it is a chemical change.

_____

22. An increase or decrease in pressure cannot, by itself, be used to differentiate between a physical or chemical change, but it does provide insight to what is happening with the substances.

    a. Explain how the pressure sensor was important in understanding what is happening inside the two different test tubes?

_____

_____

    b. What other data helped you determine if a physical or chemical change occurred in the two test tubes?

_____

_____

23. Consider the following statements and label them as representative of a chemical or physical change.

_____ a. Forming or breaking intermolecular forces

_____ b. Forming or breaking intramolecular forces or bonds

24. Revisit the particulate-level representations in question #5 of Getting Your Brain in Gear.

    a. Which representations are chemical changes?

_____

    b. Which representations are physical changes?

_____

25. In discussing the results of the reaction in Test Tube B, a student states "The stopper must be leaking, causing a drop in pressure." Explain why a drop in pressure cannot possibly result from a leak in the stopper in this situation.

_____

_____

_____

26. List at least two variables in the Test Tube B reaction that could be studied to determine how they might affect the magnitude of the pressure drop during the reaction.

_____

_____

MODEL 3

Building Model 3 – Ambiguous changes

1. Carry out the reaction your teacher assigns your group.

2. Which change will your lab group complete?

_____

3. Predict what will change in terms of pH, temperature, and conductivity.

_____

_____

4. Predict whether the change will be a chemical or physical change.

_____

5. Obtain a clean and dry 100-mL beaker.

6. Start a new experiment on the data collection system.

7. Connect the pH, conductivity, and temperature sensors.

8. Set up the screen to display temperature, pH, and conductivity.

9. Pour 50 mL of distilled water into the beaker. Record the initial pH, temperature, and conductivity in the Model 3 Data Table.

10. Add a small *pea sized* sample (about 0.5 g) of the other reactant to the beaker. Stir with the stirring rod.

11. Use the sensors to measure the final pH, temperature, and conductivity of the contents of the beaker immediately after the reactants are mixed. Record these in the Model 3 Data Table.

12. When all lab groups are finished with data collection, share data to complete the Model 3 Data Table.

13. Dispose of the contents of the beakers in the proper waste containers. Clean the beakers and test tubes with soapy water. Rinse the sensors with distilled water and properly disconnect them.

Model 3 – Ambiguous changes

Table 3: Model 3 Data Table—Determining the type of change

Reactants	Observations	Condition	pH	Temp (°C)	Conductivity (Low/Med/High)
$C_{12}H_{22}O_{11}$ + H_2O		Initial			
		Final			
NaCl + H_2O		Initial			
		Final			
$NaCH_3COO$ + H_2O		Initial			
		Final			
Ca + H_2O		Initial			
		Final			
NH_4NO_3 + H_2O		Initial			
		Final			

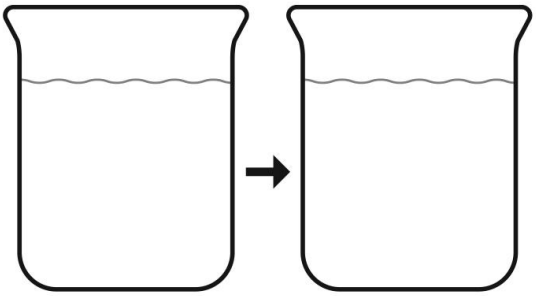
For conductivity:

Low: Less than 100 µS/cm
Med: Between 100 µS/cm and 1000 µS/cm
High: Greater than 1000 µS/cm

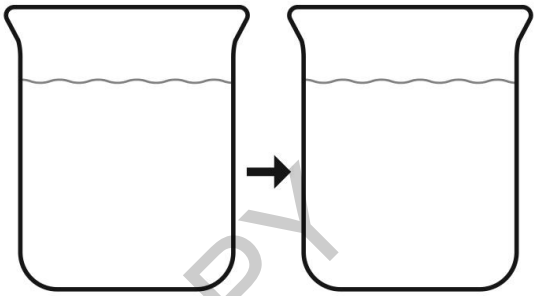
Analyzing Model 3 – Ambiguous changes

14. For the change that you observed, draw a particulate-level representation of the reaction that helps explain the data you collected with the sensors. Explain how the particulate-level representation is consistent with your data.

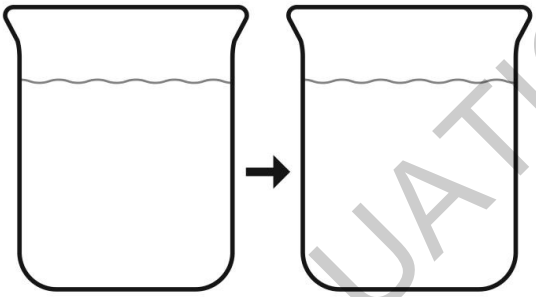
$C_{12}H_{22}O_{11}$ + H_2O



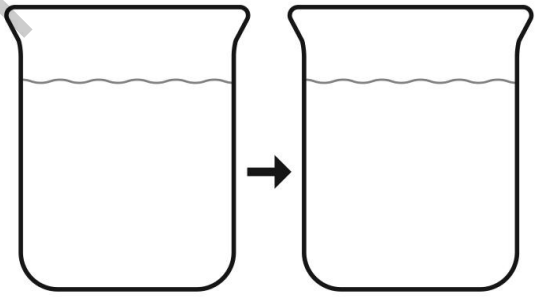
NaCl + H_2O



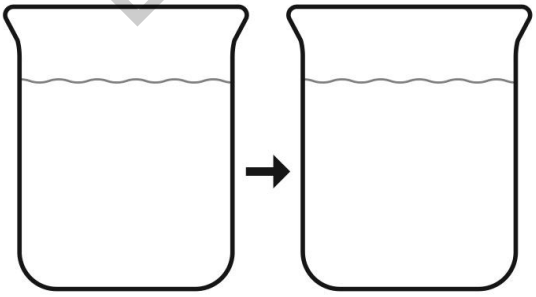
$NaCH_3COO$ + H_2O



Ca + H_2O



NH_4NO_3 + H_2O



15. Determine if each change is a chemical, physical, or ambiguous change. Support your answer with evidence from Model 3. Specify whether intramolecular or intermolecular bonds were affected. Was your prediction correct?

16. Two students were having a disagreement about whether $NaNO_3$ mixed with water results in a physical or chemical change. Student A claims it is a physical change because no new substance is formed and upon evaporation of the water, $NaNO_3$ could be recovered since only intermolecular forces change during dissolution. Student B claims it is a chemical change because the ionic bonds in $NaNO_3$, which are intramolecular, are broken by the water. This forms new ions, Na^+ and NO_3^-, that affect conductivity. What would your group tell Students A and B?

Connecting to Theory

When a process is classified as a chemical change, intramolecular interactions change, producing a new, chemically distinct substance due to the rearrangement of atoms. When a process is classified as a physical change, intermolecular interactions change. No new substances are produced. Atoms within the original molecules do not rearrange. Some processes can be labeled ambiguous changes when both intramolecular and intermolecular interactions change during the process.

Applying Your Knowledge

1. Reflecting on the entire lab, is identifying an unknown change as physical or chemical straightforward? Write a paragraph explaining your thoughts using data collected from this lab.

2. Scientific sensors can be used to understand what is happening on a scale far too small for humans to directly observe. Reflect on your use of technology during this lab. Write a paragraph on how technology can be used to visualize processes that cannot be directly observed. Use external resources to find examples of sensors not used in this lab.

2. LIGHT, COLOR, AND CONCENTRATION

Initial Question

If you've ever added a powdered drink mix to water, you realize that the more concentrated the drink, the deeper the color of the solution. Analytical chemists, particularly in the agricultural and medical fields, routinely use a quantitative approach called *spectroscopy* to determine the concentration of solute in a solution as it relates to the color of the solution.

How can you use electromagnetic waves to determine the concentration of a solution?

Materials and Equipment

Model 1

- Data collection system
- Colorimeter
- Cuvette
- Sensor extension cable
- Pipet with pump or bulb, 10-mL
- White 3 × 5 index card or piece of paper
- Colored pencils
- Scissors
- Distilled water and wash bottle
- Kimwipes or tissues
- One of the following:
  0.10 M Cobalt(II) nitrate ($Co(NO_3)_2$), 30 mL
  0.10 M Nickel(II) nitrate ($Ni(NO_3)_2$), 30 mL
  0.10 M Iron(III) nitrate ($Fe(NO_3)_3$), 30 mL
  0.10 M Zinc nitrate ($Zn(NO_3)_2$), 30 mL

Model 2

- Data collection system
- Colorimeter
- Cuvette
- Sensor extension cable
- Distilled water and wash bottle
- Test tubes (5), large
- Test tube rack
- Pipet with pump or bulb, 10-mL
- Glass stirring rod
- Kimwipes or tissues
- One of the following:
  0.10 M Cobalt(II) nitrate ($Co(NO_3)_2$), 30 mL
  0.10 M Nickel(II) nitrate ($Ni(NO_3)_2$), 30 mL
  0.10 M Iron(III) nitrate ($Fe(NO_3)_3$), 30 mL
  0.10 M Copper(II) sulfate ($CuSO_4$), 30 mL

Applying Your Knowledge

- Data collection system
- Colorimeter
- Sensor extension cable
- Cuvette
- Pipet with pump or bulb, 10-mL
- Distilled water and wash bottle
- Kimwipes or tissues
- 0.10 M Copper(II) nitrate ($Cu(NO_3)_2$), 30 mL
- Copper(II) nitrate ($Cu(NO_3)_2$), unknown concentration, 6 mL

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wash your hands with soap and water after handling the solutions, glassware, and equipment.
- Nickel(II) nitrate, cobalt(II) nitrate, iron(III) nitrate, zinc nitrate and copper(II) sulfate are hazardous to the environment and should not be disposed of down the drain. Make sure you follow your teacher's instructions on how to properly dispose of these solutions.

Getting Your Brain in Gear

1. Which color of light has the higher energy—blue or red?

_____

2. The atomic theory put forth by Bohr was based on the interaction of light with electrons at various energy levels. According to Bohr's theory, what could happen to an electron that was hit by a photon of light?

_____

_____

3. According to Bohr's theory, what must happen for an excited electron to move to a lower energy state?

_____

_____

4. According to Bohr's theory, how is the change in the electron's energy different if it absorbs the energy of red light versus absorbing the energy of blue light?

_____

_____

_____

5. White light passed through a prism comes out as a rainbow. Describe white light in terms of a mixture of photons.

_____

_____

_____

MODEL 1

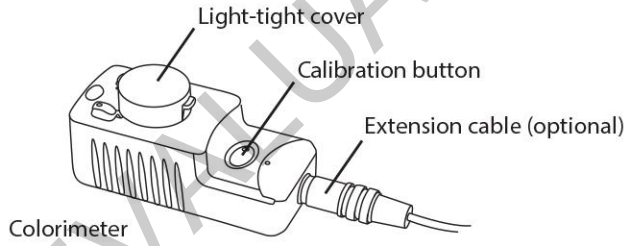
Building Model 1 – Transmittance and Absorbance for Solutions

1. Start a new experiment on the data collection system.
2. Connect the colorimeter to the data collection system using the extension cable.
3. Place a 1 cm × 7 cm piece of white paper in the sample cell compartment of the colorimeter.
4. Press the green button and observe the light as it appears on the paper. You may need to shade the cell compartment from room light with your hand.

5. What colors of light appear on the paper (list at least three)?

_____

6. Record the color of light emitted by the colorimeter above their corresponding wavelengths in the Model 1 Data Table.
7. Obtain a sample of a 0.10 M solution to test in the colorimeter for Model 1. Your instructor will assign you either cobalt(II) nitrate, nickel(II) nitrate, iron(III) nitrate or zinc nitrate.
8. Record the color of your solution in the Model 1 Data Table.
9. Fill a cuvette at least ¾ full with distilled water.
10. Wipe off the sides of the cuvette and only handle it by the top.
11. Calibrate the colorimeter with the distilled water (the water sample is called a "blank").



12. Why is it important to wipe off the sides of the cuvette before placing it into the colorimeter?

_____

_____

13. What is the approximate percent transmittance at each of the four wavelengths?

_____

14. What is the approximate absorbance at each of the four wavelengths?

_____

15. The solutions you are about to test in the colorimeter are aqueous solutions. That is, water is the solvent. Both water and glass can absorb visible light at some wavelengths. With this in mind, explain why the colorimeter is calibrated with a blank solution? (Hint: Using a "blank" in a colorimeter is similar to the "tare" button on a digital balance.)

_____

_____

16. Place ~6 mL of your assigned 0.10 M test solution into the cuvette. Wipe the cuvette and handle it only from the top.

17. Place the cuvette in the colorimeter chamber and close the cover. Record your transmittance and absorbance data in the Model 1 Data Table for each of the four wavelengths.

18. Share your data with other groups to complete Table 1.

Model 1 – Transmittance and Absorbance for Solutions

Table 1: Model 1 Data Table—Light transmittance and absorbance for solutions of different colors

0.1 M Solution	660 nm		565 nm		468 nm		610 nm	
	%T	*A*	*%T*	*A*	*%T*	*A*	*%T*	*A*
$Co(NO_3)_2$ Color: _____								
$Ni(NO_3)_2$ Color: _____								
$Fe(NO_3)_3$ Color: _____								
$Zn(NO_3)_2$ Color: _____								

Analyzing Model 1

19. Consider the words "transmit" and "absorb" as they are used normally.

    a) If a solution has a high transmittance for a certain color of light, what does that mean in terms of photons of light interacting with electrons in the solution?

_____

_____

_____

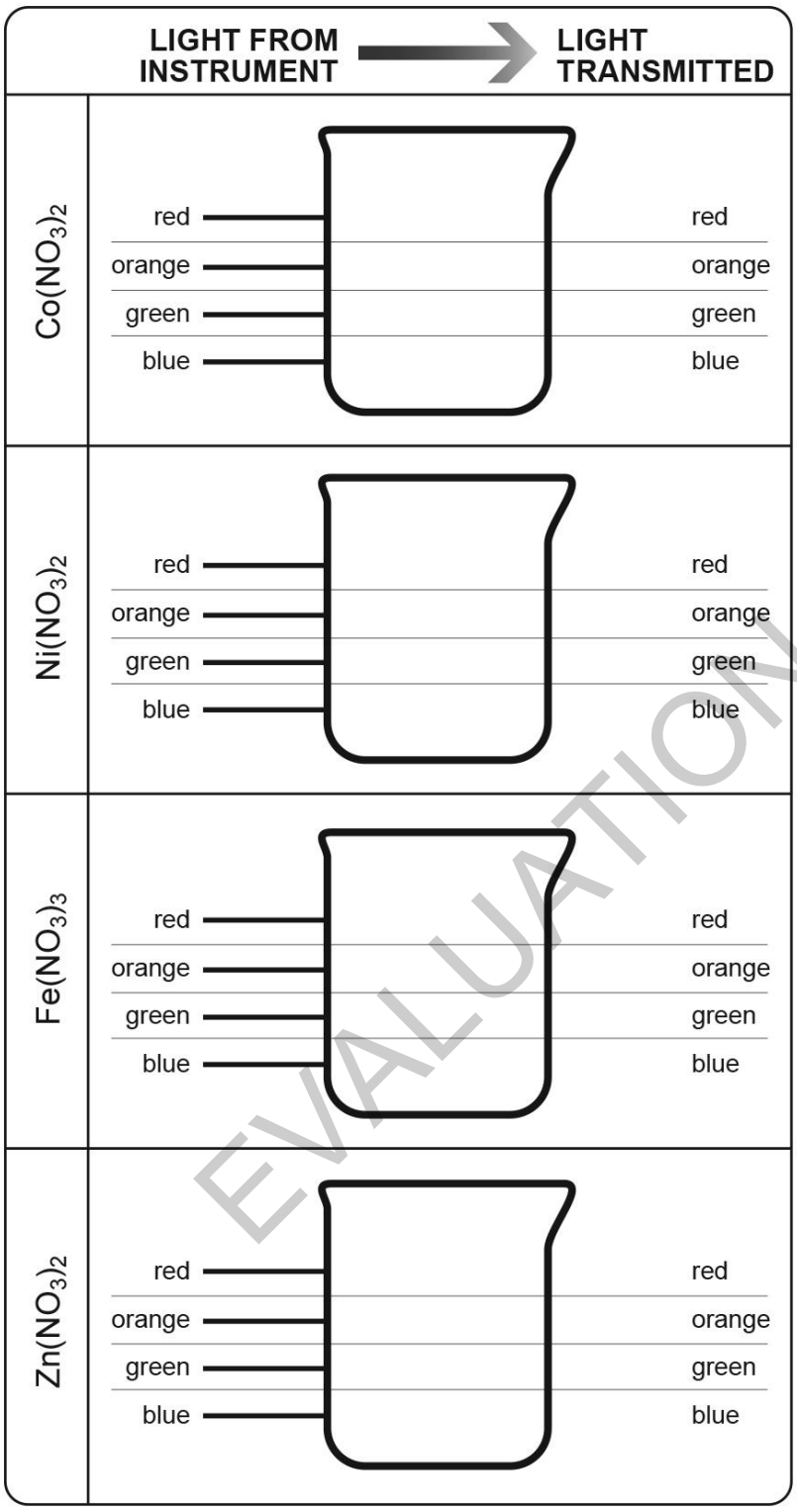
b) When a solution has a high transmittance for a certain color of light, does it also have a high absorbance for that color? Use specific evidence from Model 1 to justify your answer.

c) Explain the relationship you stated above in terms of the interaction of photons of light with electrons in the solution.

20. All of the solutions used in Model 1 were made by dissolving a salt in distilled water. For each solution, list the individual ions present after the salt has completely dissolved.

21. Identify the ions that cause the solutions to have color.

22. Use colored pencils to color the beakers below containing the solutions from Model 1. Assemble the accessory photogate near the edge of the lab table. Point out related information. Point out related information.



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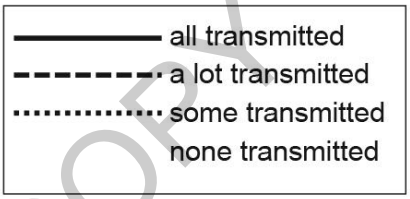
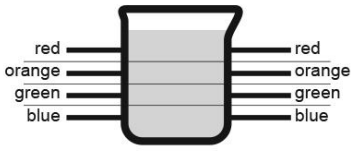


Example

If all lights (red, orange, green, and blue) came from the instrument fully and were transmitted fully through the solution, it would be illustrated like this:



23. In the diagrams above use solid or dotted lines of the appropriate color to represent both the incoming light and the outgoing light for each of the four wavelengths as they traveled through each solution. The diagrams should be consistent with the data collected in Model 1.

24. State the formula and color of the solution which absorbed the most

    a) green light

_____

    b) blue light

_____

    c) red light

_____

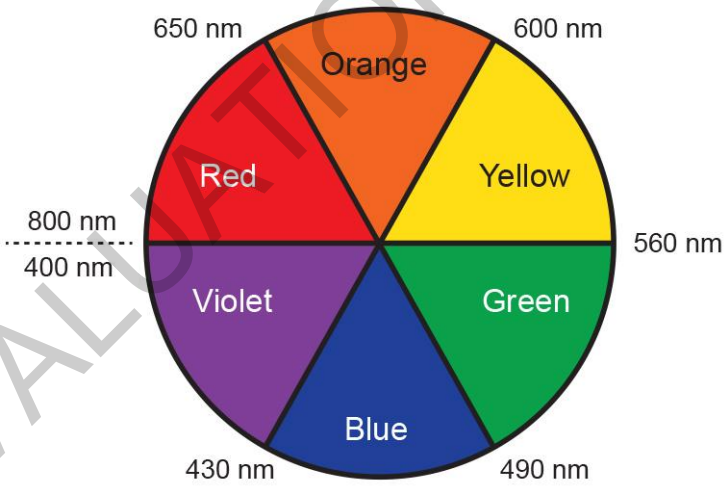
25. Consider the solutions in Model 1. When light is shone through a solution that matches the color of the solution, is it mostly transmitted or absorbed? Justify your answer with data from Model 1.

_____

_____

_____

26. Consider the color wheel below. Red and green are considered complementary colors, as are violet and yellow. When light is shone through a solution that is a complementary color to that of the solution, is it mostly transmitted or absorbed? Justify your answer with data from Model 1.



_____

_____

_____

27. Can wavelengths of visible light be used to analyze the concentration of colorless solutions? Justify your answer with evidence from Model 1.

_____

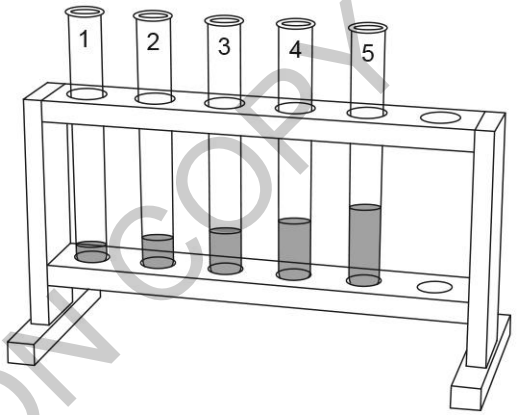
_____

Connecting to Theory

When we look at something white, our eyes are picking up light of every wavelength that is reflecting off of that object. Colored objects absorb one or more wavelengths of light, however, so our eyes only receive part of the visible spectrum. Thus our brain registers the object as having a color. A red object, for example, might absorb blue, yellow and green wavelengths. Our brain receives the reflected violet, red and orange wavelengths and "averages" them together, making us think we have seen red.

MODEL 2

Building Model 2 – Varying Concentration



1. Label five clean, dry test tubes "1" through "5" and place them into a test tube rack.

2. Pipet 2.0, 4.0, 6.0, 8.0 and 10.0 mL of your assigned colored 0.10 M solution into test tubes 1 through 5, respectively. (If you previously used a colorless solution, ask your instructor which colored solution you should use for Model 2.)

3. Wash the pipet and use it to deliver 8.0, 6.0, 4.0, and 2.0 mL of distilled water into test tubes 1 through 4 so that each test tube has 10.0 mL of solution.

4. Why do the test tubes need to be dry? What error would be caused by wet test tubes?

_____

_____

5. Calculate the concentration of the solutions in each test tube, and enter those values in the Model 2 Data Table.

6. Thoroughly mix each solution with a stirring rod.

   NOTE: Clean and dry the stirring rod before stirring a different solution.

7. Configure the data collection system to manually collect the absorbance and transmittance data of all four wavelengths and the solution concentration in a table. Define the concentration as a manually entered data set with units of molarity.

8. Begin with the solution with the lowest concentration. Rinse the cuvette twice with a small portion of the solution and then fill the cuvette two-thirds full.

9. Wipe the cuvette clean and dry and place it into the colorimeter

10. Record the absorbance and transmittance in the Model 2 Data Table for each of the four wavelengths of light.

11. Rinse the cuvette and record data for each of the other four solutions of known concentration.

Model 2 – Varying Concentration

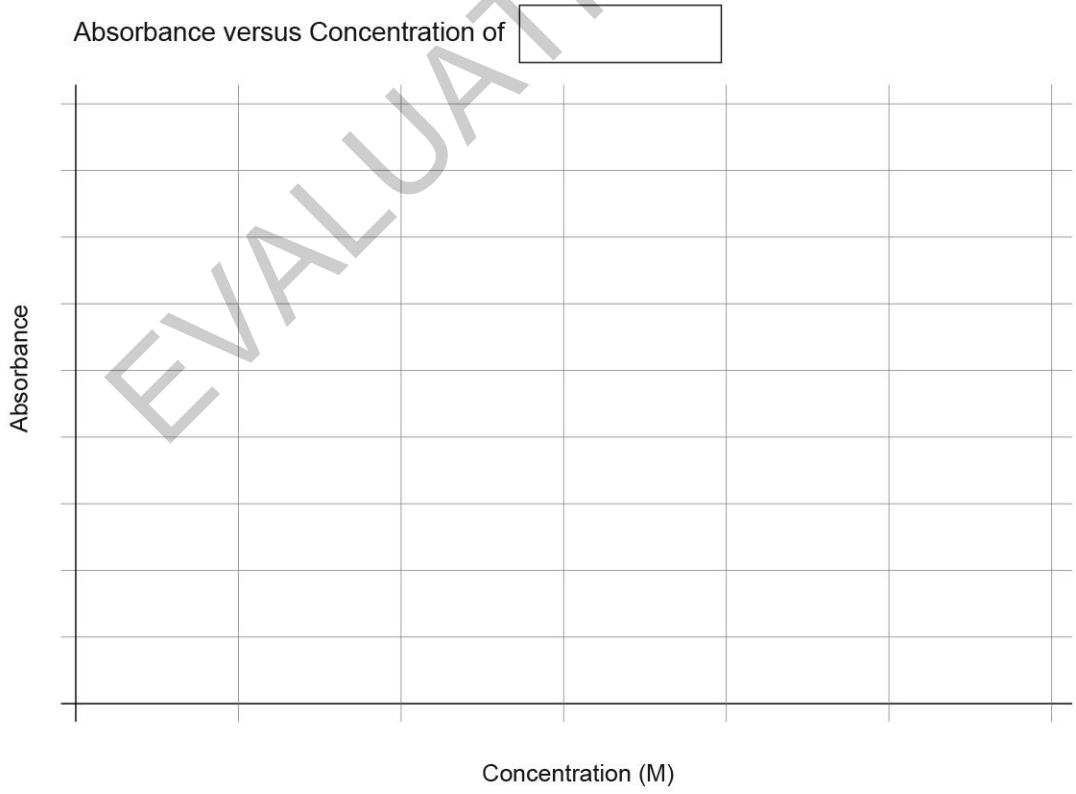
Solution: _____

Table 2: Model 2 Data Table—Detecting the concentration of a solution using light

Test Tube #	Concentration (M)	Red (660 nm)		Green (565 nm)		Blue (468 nm)		Orange (610 nm)	
		%T	*A*	*%T*	*A*	*%T*	*A*	*%T*	*A*
1									
2									
3									
4									
5									

Analyzing Model 2 – Varying Concentration

12. Graph the four sets of absorbance versus concentration data for your solution. Use color pencil (or colored lines) to indicate the wavelength of light used to collect each set of data.



13. Which color of light provides absorbance data with the steepest slope? Which color of light gives data with the shallowest slope?

_____

_____

14. Check with lab groups that tested different colored solutions. Record their answers to the question above regarding the color of light that provides the steepest slope in Table 3.

Table 3: Wavelength displaying the greatest change in absorbance as concentration changes

Parameter	Group Results for:			
	Cobalt(II) nitrate	Nickel(II) nitrate	Iron(III) nitrate	Copper(II) sulfate
Color of solution				
Color of light with steepest slope				
Color of light with shallowest slope				

15. In general, is the absorbance data with the steepest slope obtained from light that matches the color of the solution or from the complementary color?

_____

_____

16. Imagine that your instructor gives you a sample of your solution of unknown concentration.

a. Explain how your absorbance data might be used to find the concentration of that solution.

_____

_____

_____

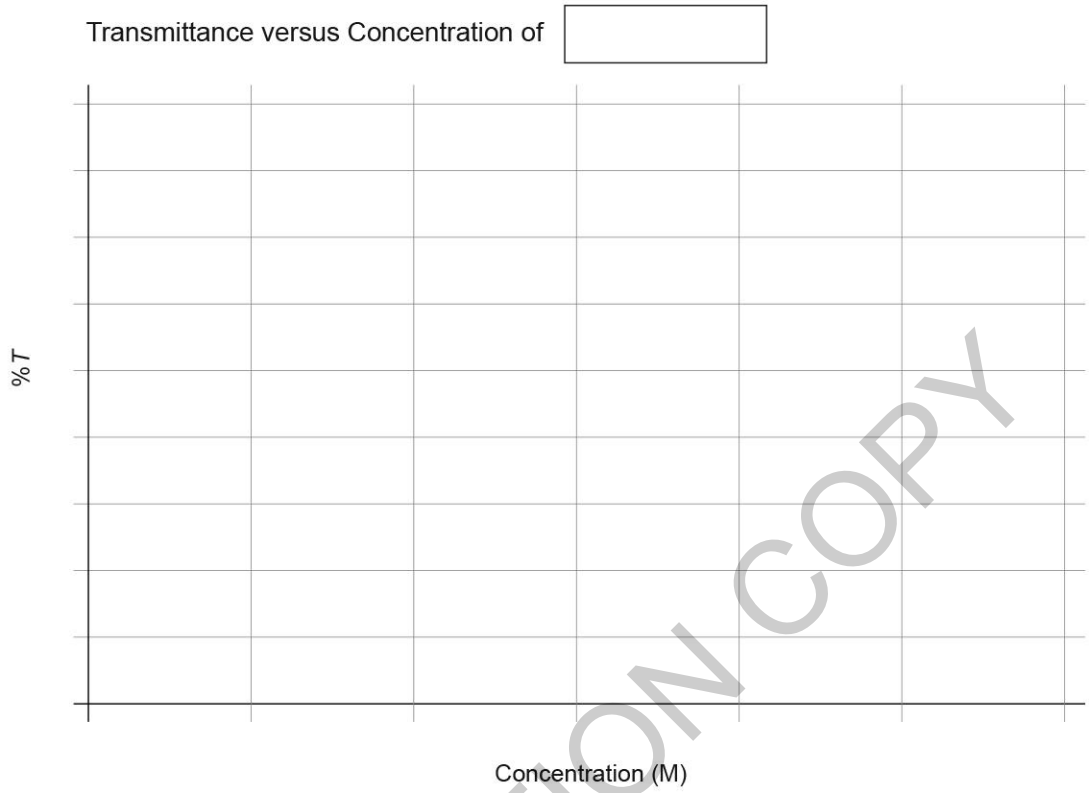
b. Would it be best to use the wavelength of light that gave the steepest slope or the shallowest slope in determining the concentration of your unknown? Explain your reasoning.

_____

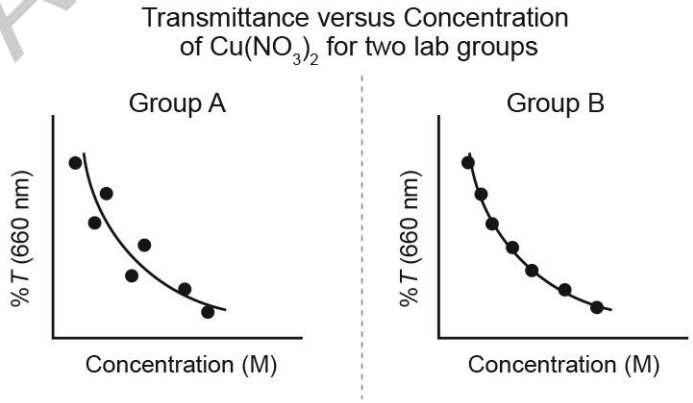
_____

_____

17. Graph the percent transmittance data that corresponds to the absorbance data with the steepest slope. Which set of data, %T or A, would be the easiest to model with a mathematical equation? Justify your answer.



18. Consider the data below collected by two different lab groups for copper(II) nitrate solution at 468 nm on the same colorimeter. (Assume the spectrometer was working properly in both cases.)



a) Discuss how the quality of the data compares between the two groups.

b) Propose at least two reasons why the data might differ between the two groups.

_____

_____

Connecting to Theory

Spectroscopy is the study of the interaction of electromagnetic radiation and matter. In spectroscopy and spectrophotometry, two terms are inescapable: transmittance and absorbance. Transmittance T is defined as the ratio of the intensity of light after it passes through a medium being studied (I) to the intensity of light before it encounters the medium (I_o).

$$T = \frac{I}{I_0}$$

Chemists more commonly refer to the percent transmittance $\%T$, which is simply $\frac{I}{I_0} \times 100$. Because the percent transmittance is exponentially related to concentration of solute, the use of absorbance, which gives a linear relationship, is often preferred.

$$A = -\log T = -\log \frac{I}{I_0}$$; note that $A = -2 \log (\%T)$

If one knows the percent transmittance, one can calculate absorbance and vice versa. Most modern spectrophotometers have both a $\%T$ and an absorbance scale. With a digital instrument, it is simply a matter of changing modes to display either value.

Beer's Law, is one of the most fundamental and widely applied spectroscopic laws. It relates the absorbance of light to the concentration c of the solute, the optical path length b and the molar absorptivity a of a solution.

An operation statement of Beer's Law can be represented as

$$A = abc$$

The molar absorptivity is a constant that depends on the nature of the absorbing solution system and the wavelength of the light passing through it. A plot that shows the dependence of A on wavelength is called a spectrum.

Applying Your Knowledge– Determining the Concentration of an Unknown

Your instructor will provide you with a bottle of 0.10 M copper(II) nitrate and a sample of an unknown concentration of copper(II) nitrate. Propose and carry out a plan to determine the concentration of the copper ion in the unknown. What is the concentration of the unknown?

3. GRAVIMETRIC ANALYSIS OF A PRECIPITATE

Initial Question

Chemists can find the identity of unknown compounds using techniques such as qualitative analysis, chromatography, spectroscopy, and gravimetric analysis. Gravimetric analysis, which uses a balance to determine the mass of a substance, is one of the oldest and most accurate quantitative methods for determining the amount of an analyte in a sample.

Can you determine the amount and identity of an unknown component of a substance?

Materials and Equipment

Model 1

- Beakers (4), glass, 100-mL
- Beral pipets (4)
- Unknown A (alkali metal carbonate), 5.0 g
- 0.10 M Sodium nitrate, ($NaNO_3$), 5 drops
- 0.10 M Potassium chloride, (KCl), 5 drops
- 0.10 M Ammonium nitrate, (NH_4NO_3), 5 drops
- 0.10 M Calcium chloride, ($CaCl_2$), 5 drops
- Stirring rod
- Marking pen (to label beakers)
- Distilled water, 200 mL

Model 2 and Applying Your Knowledge

- Beaker, glass, 100-mL
- Filtration funnel
- Erlenmeyer flask, glass, 250-mL
- Filter paper, Whatman® Ashless, #42
- Watch glass, 100-mm
- Analytical balance, 0.001 g precision, 1 per class
- Stirring rod
- Pencil
- Wash bottle with distilled water
- Drying oven, 1 per class

Model 2

- Unknown A (same unknown as Model 1), 1.00 g
- 0.25 M Calcium chloride ($CaCl_2$), 50 mL[2]
- Distilled water, 100 mL

Applying Your Knowledge

- Unknown B, 2.00 g
- 0.50 M Potassium nitrate (KNO_3), 20 mL
- 0.50 M Lithium chloride (LiCl), 20 mL
- 0.50 M Calcium nitrate ($Ca(NO_3)_2$), 20 mL
- 0.50 M Sodium chloride (NaCl), 20 mL
- Distilled water, as needed

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear your goggles.

Getting Your Brain in Gear

1. In this lab you will be given an unknown alkali metal carbonate. Your lab group will have to determine the identity of that compound through gravimetric analysis. The unknown could be: lithium carbonate, sodium carbonate, potassium carbonate, or cesium carbonate.

   a. Does each of these compounds have the same ratio of metal atoms to carbonate ions? Explain your answer.

_____

_____

_____

   b. What information do you need to find the percent mass of an ion, like carbonate, in a compound?

_____

_____

_____

   c. Using the periodic table, find the percentage of carbonate by mass in each of the carbonates.

   Lithium carbonate (Li_2CO_3): _____

   Sodium carbonate (Na_2CO_3): _____

   Potassium carbonate (K_2CO_3): _____

   Cesium carbonate (Cs_2CO_3): _____

   d. Why is the percentage of carbonate different for each of the compounds listed above while the ratio of carbonate to metal ion is the same?

_____

_____

_____

   e. When identifying an unknown, why is it helpful to know the chemical percent composition?

_____

_____

_____

MODEL 1

Building Model 1 – Precipitating an Unknown

1. Obtain four 100-mL beakers and label them "A," "B," "C," "D."

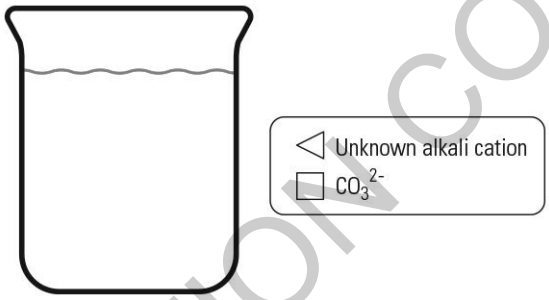
2. Add approximately 50 mL of distilled water to each beaker.

3. Into each of the 100-mL beakers add a *pea size* amount of Unknown A, which is an alkali metal carbonate.

4. Use a stirring rod to mix and dissolve the unknown carbonate.

5. In the beaker below draw the unknown carbonate solution as a particulate-level representation. Use the particulate key as a guide.

   NOTE: Use "M" when referring to the unknown alkali metal.



6. To determine the identity of the unknown, the mass of the unknown and the mass of carbonate in the unknown needs to be obtained. Brainstorm ways to separate the alkali metal ions from the carbonate ions.

_____

_____

_____

7. Into Beaker A add 5 drops of 0.1 M $NaNO_3$.

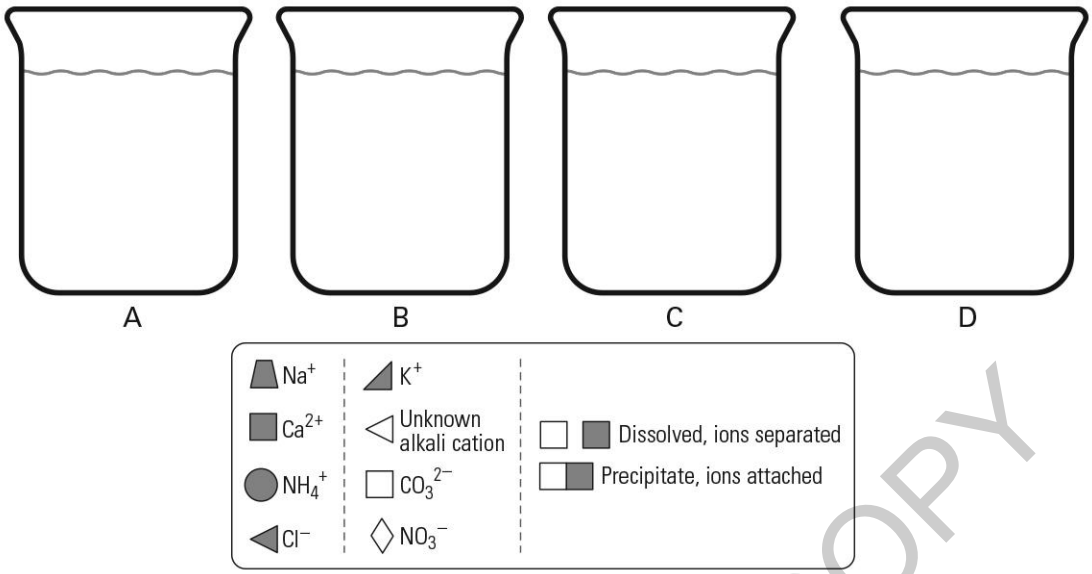
8. Into Beaker B add 5 drops of 0.1 M NH_4NO_3.

9. Into Beaker C add 5 drops of 0.1 M $CaCl_2$.

10. Into Beaker D add 5 drops of 0.1 M KCl.

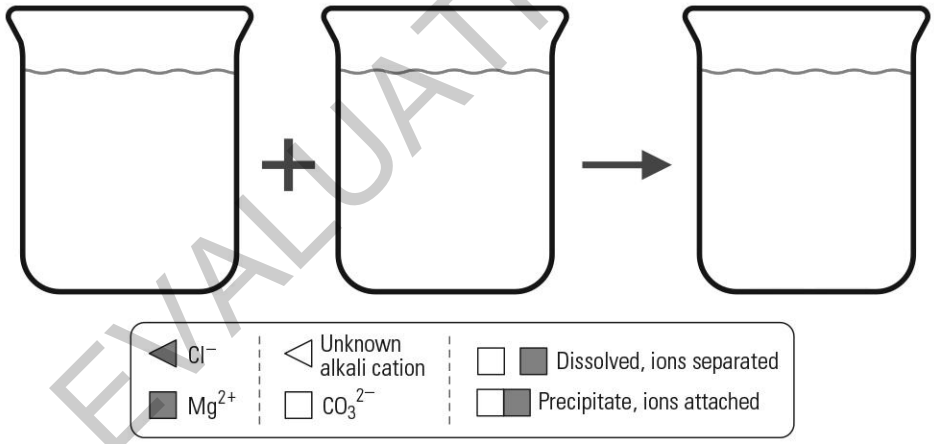
11. In the beakers in Model 1 draw particulate-level pictures of the resulting solutions in Beakers A-D. Use the particulate key as a guide.

Model 1 – Precipitating an Unknown



Analyzing Model 1 – Precipitating an Unknown

12. Draw a particulate-level representation of the reaction that occurred in Beaker C. Start with three molecules of M_2CO_3, where "M" refers to the unknown alkali metal, and three molecules of $CaCl_2$. Use the particulate key as a guide. Please observe the Law of Conservation of Mass in your drawings.



13. Use your drawings of the reaction in Beaker C to describe the pathway the carbonate molecules followed throughout this reaction.

_____

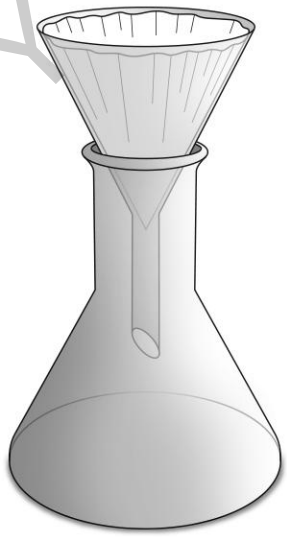
_____

_____

MODEL 2

Building Model 2 – Finding the Mass of Carbonate in an Unknown

1. Place a clean 100-mL beaker on an analytical balance and tare the mass of the beaker.
2. Add approximately 1.00 g of your unknown carbonate into the beaker. Record the exact mass (to three decimal places) in the Model 2 Data Table.
3. Add 20 mL of distilled water and stir with a stirring rod until dissolved.
4. Add 30 ml of 0.25 M $CaCl_2$ to the solution containing the unknown carbonate and stir to dissolve.
5. Assemble a filtration setup as in the diagram to the right using the Erlenmeyer flask and funnel.
6. Write your initials on a piece of filter paper with a pencil. Record the mass (to three decimal places) of the dry filter paper in the Model 2 Data Table. Then fold the filter paper and place it into the funnel.
7. Slowly pour the contents of the beaker with your precipitate into the funnel. Do not overfill the filter paper.
8. Rinse the beaker and stirring rod with deionized water to ensure that all the precipitate is in the funnel.
9. Continue until all of the filtrate has moved through the filter paper into the flask.



10. What type of substance is small enough to pass through the filter paper?

_____

_____

11. What type of substance is large enough to get caught in the filter?

_____

_____

12. How would the amount of your yield be affected if some of the carbonate was not precipitated?

_____

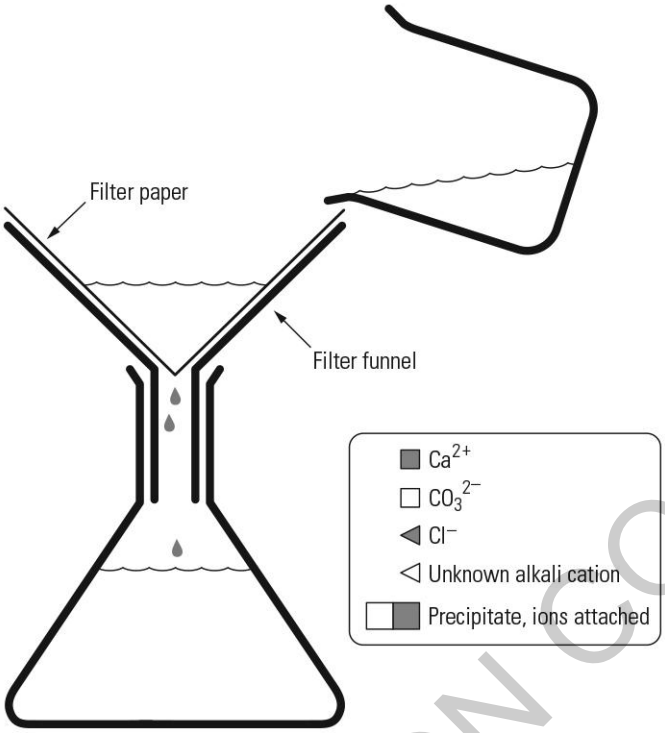
_____

13. Where would the non-precipitated ions be after the filtration is complete?

_____

_____

14. In the filtration setup below, draw particulate-level pictures of the products being filtered. Use the particulate key as a guide.



15. How can you determine if any carbonate ions went through the filter?

_____

_____

_____

16. What action should you take if carbonate ions passed through the filter?

_____

_____

17. After you make sure all the carbonate has been removed from the filtrate, carefully place the wet filter paper with the $CaCO_3$ onto a watch glass and then into a drying oven overnight. This will remove any remaining water to ensure accurate mass measurements.

The Next Day

18. Remove the filter paper from the drying oven and measure its mass using an analytical balance. Record the mass (to three decimal places) in the Model 2 Data Table and determine the mass of the calcium carbonate precipitate.

Model 2 – Finding the Mass of Carbonate in an Unknown

Table 1: Model 2 Data Table – Finding the mass of carbonate in an unknown

Parameter	Mass (g)
Alkali metal carbonate (Unknown A)	
Dry filter paper	
Dry filter paper plus $CaCO_3$	
$CaCO_3$	

Analyzing Model 2 – Finding the Mass of Carbonate in an Unknown

19. Use the periodic table to determine the percentage of carbonate in calcium carbonate.

20. Knowing the percentage of carbonate in $CaCO_3$ and the mass of calcium carbonate, find the mass of carbonate in the unknown alkali metal carbonate (Unknown A).

21. Find the percentage of carbonate in the alkali metal carbonate using the mass of the carbonate from Unknown A in Model 2 and the total mass of the alkali metal carbonate.

22. The possible unknown compounds in this lab include lithium carbonate, sodium carbonate, potassium carbonate, and cesium carbonate. Using the percentages calculated in the Getting Your Brain in Gear section of the lab, identify the unknown and explain why you are confident with the methods of data collection that lead you to this conclusion.

_____

_____

_____

Connecting to Theory

When water quality is tested, a precipitate is intentionally formed. From the color of the precipitate, the identity of the dissolved ions can be determined. Chemists consult the Solubility Rules when they want to force ions to precipitate. The Solubility Rules are designed so that the user can cross reference cations with anions and determine if they will precipitate. Once the precipitate is formed, it can be dried and measured using gravimetric techniques.

Table 2: Abridged Solubility Rules

Ion	Solubility	Exceptions
NO_3^- (Nitrate)	Soluble	None
ClO_4^- (Chlorate)	Soluble	None
Halogens except F	Soluble	Ag^+, Hg_2^{2+}, Pb^{2+}
F^- (Fluoride)	Soluble	Ca^{2+}, Ba^{2+}, Sr^{2+}, Hg_2^{2+}, Pb^{2+}, Ag^+
SO_4^{2-} (Sulfate)	Soluble	Ca^{2+}, Ba^{2+}, Sr^{2+}, Hg^{2+}, Pb^{2+}, Ag^+
CO_3^{2-} (Carbonate)	Insoluble	Alkali Metals and NH_4^+
PO_4^{3-} (Phosphate)	Insoluble	Alkali Metals and NH_4^+
OH^- (Hydroxide)	Insoluble	Alkali Metals and Ca^{2+}, Ba^{2+}, Sr^{2+}
Alkali metals	Soluble	None
NH_4^+ (Ammonium)	Soluble	None

Applying Your Knowledge – Identifying an Unknown

An unknown alkali metal carbonate was discovered in a pharmacy. The pharmacist would like to identify it. If the unknown is lithium carbonate, it can be used as a drug to treat bipolar disorders. All other alkali carbonates: potassium carbonate, cesium carbonate, and sodium carbonate, will not be useful in treating this type of disorder.

Your lab group can use the following chemicals to identify the unknown:

- 2.0 g of unknown alkali metal carbonate
- 20.0 mL of the following solutions 0.5 M KNO_3, 0.5 M LiCl, 0.5 M $Ca(NO_3)_2$, and 0.5 M NaCl.

All other standard laboratory equipment is available. Consult your instructor with special requests. You do not need to use all of the materials provided.

1. Design a procedure to find the identity of the unknown.

_____

_____

_____

2. Create a data table to organize your data.

3. Before you start the lab, have your instructor approve your lab procedure for safety, but not on the accuracy of your proposed procedure.

4. Show the calculations needed to identify the unknown.

5. Did the pharmacist have lithium carbonate or a different compound? How did you come to this conclusion?

_____

_____

_____

6. Discuss the limitations of the laboratory techniques you used and how you can improve the accuracy of your results. You may use diagrams to supplement your explanations.

_____

_____

_____

4. STOICHIOMETRY IN SOLUTIONS

Initial Question

When water is tested, chemists can tell you what impurities are present. If something harmful is found in your drinking water, like lead or cadmium, it is important to know how much is present. Hazardous particles put into your body faster than they can be removed will build up to toxic levels. There are several ways to determine the amount of dissolved particles in a solution. In this lab, you will explore one of them.

How is the amount of a dissolved substance determined?

Materials and Equipment

Model 1, Model 2, and Applying Your Knowledge

- Data collection system
- Conductivity sensor
- Fast-response temperature sensor
- Drop counter
- Drop dispenser:
  Syringe, 60-mL
  Stopcock (2)
  Drop tip
- Beaker, 250-mL
- Beaker, glass, 150-mL
- Graduated cylinder, 50-mL
- Mohr pipet, 25-mL
- Pipet pump
- Magnetic stirrer (stir plate)
- Micro stir bar
- Multi-clamp
- Ring stand
- Three-finger clamp
- Phenolphthalein, 3 drops
- 2.0 M Sodium hydroxide (NaOH), 120 mL
- Distilled water, 110 mL
- Wash bottle
- Materials for drop counter and pH sensor calibration (refer to Appendix A)

Model 1

- 1.0 M Hydrochloric Acid (HCl), 25.0 mL

Model 2

- Hydrochloric Acid (HCl), one of several possible concentrations, 25.0 mL

Applying Your Knowledge

- Monoprotic acid of an unknown concentration, 25.0 mL

Safety

Add these important safety precautions to your normal laboratory procedures:

- This lab uses strong acids and bases. In case of contact with your skin, wash off the solution with a large amount of water.

Getting Your Brain in Gear

1. Identify each of the following substances as an acid or a base.

HCl: _____

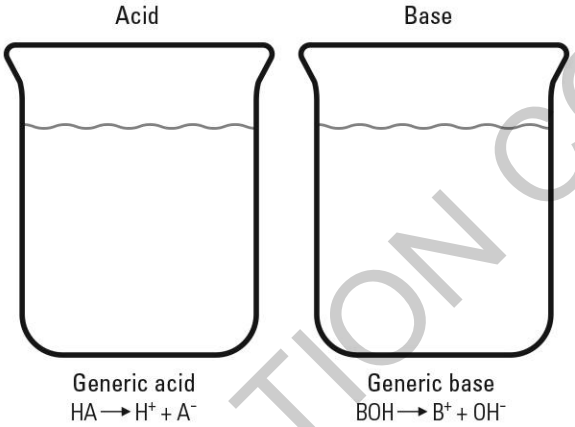
H_2SO_4: _____

KOH: _____

NaOH: _____

HNO_3: _____

2. In the beakers below, draw particle-level representations showing a strong acid and a strong base dissolved in water.



3. Describe the procedure you would use to make 100 mL of 0.85 M HCl from a 2.0 M HCl solution. Assume you have a 100-mL volumetric flask, distilled water and a 50-mL graduated cylinder available.

_____

_____

_____

4. List three pieces of evidence that indicate a chemical reaction has taken place.

_____

_____

_____

MODEL 1

Building Model 1 – Using a Strong Acid and Strong Base

1. Start a new experiment on the data collection system.

2. Connect a conductivity sensor, a fast-response temperature sensor, and a drop counter to the data collection system.

3. Display both temperature and conductivity on the *y*-axis of a graph and fluid volume on the *x*-axis.

4 Use the multi-clamp to attach the drop counter to the ring stand. Use the illustration as a guide.

5. Use the three-finger clamp to attach the drop dispenser to the ring stand.

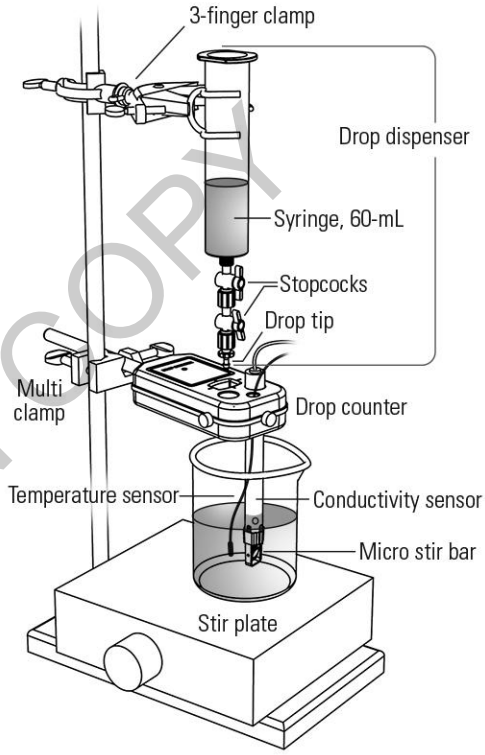
6. Rinse the drop dispenser syringe:

   a. Place a 250-mL beaker under the drop dispenser and open both stopcocks.

   b. Rinse the drop dispenser syringe and stopcock three times with approximately 20 mL of distilled water. This will remove any residue.

   c. Rinse the drop dispenser three times with 20 mL of the 2.0 M NaOH. This removes remaining water that would dilute the NaOH solution.

   d. Discard the rinse solution as directed by your teacher.



7. Calibrate the drop counter using the instructions in Appendix A.

   NOTE: Do not disconnect the drop counter from the data collection system or it will need to be calibrated again.

8. Use the top stopcock to adjust the flow rate to approximately 1 drop per second. Close the bottom stopcock and fill the syringe to the top mark with the 2.0 M NaOH solution.

   NOTE: The top valve controls the flow rate and the bottom valve turns the flow on and off.

9. Assemble the rest of the apparatus, using the steps below and the illustration as a guide.

   a. Position the magnetic stir plate on the base of the ring stand.

   b. Position the drop counter over the magnetic stir plate.

   c. Place the temperature sensor though the small hole in the drop counter.

   d. Place the conductivity sensor, with the micro stir bar attached, through a large hole in the drop counter.

10. Using a Mohr pipet, transfer 25.0 mL of 1.0 M HCl solution to a clean, dry 150-mL beaker. Record the molarity and volume in the Model 1 Data Table.

11. Add 50.0 mL of distilled water to the beaker.

12. Calculate the number of moles of acid added to the beaker.

13. Calculate the molarity of the solution after the 50.0 mL of distilled water is added.

14. Calculate the number of moles of acid after the 50.0 ml of distilled water is added.

15. Does adding distilled water change the molarity or the number of moles of acid? Explain your answer.

_____

_____

_____

16. Put 3 drops of phenolphthalein indicator into the beaker with the HCl solution.

    NOTE: Phenolphthalein is a dye that changes color in the presence of a base.

17. Place the 150-mL beaker with the hydrochloric acid solution under the drop dispenser. The sensors should be immersed in the solution. Turn on the magnetic stirrer at a slow and steady rate.

18. Start recording data.

19. Open the bottom stopcock on the drop dispenser to begin the flow of the 2.0 M NaOH into the HCl solution.

20. In the Model 1 Data Table, record the volume of titrant used when the phenolphthalein indicator changes color.

21. Continue until approximately 20 mL of NaOH solution has been added to the beaker.

22. Stop recording data.

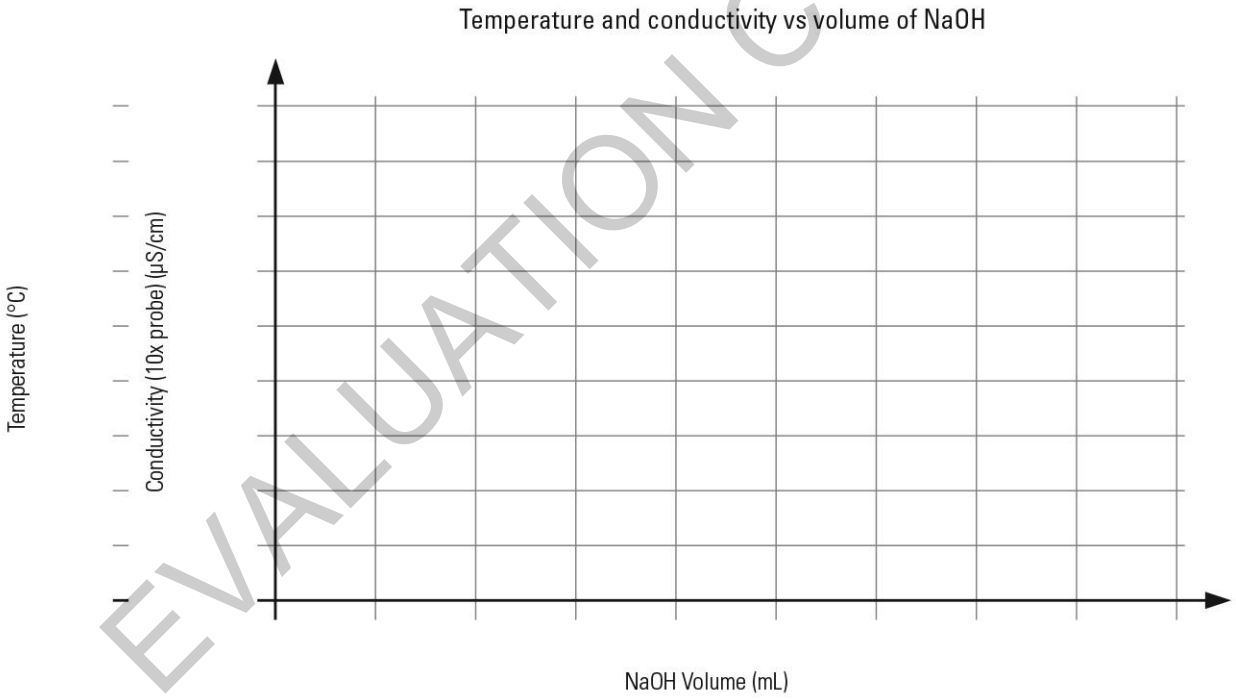
23. Save your experiment and dispose of the used solutions according to your teacher's instructions.

24. Sketch or attach a copy of your graph of Temperature and Conductivity vs Volume of HCl in the space provided in Model 1.

Model 1 – Using a Strong Acid and Strong Base

Table 1: Model 1 Data Table—End point determination

Parameter	Value
Concentration of HCl (M)	
Volume of 1.0 M HCl solution (mL)	
Concentration of NaOH used (M)	
Volume of NaOH added to change the color of the solution (mL)	



Analyzing Model 1 – Using a Strong Acid and Strong Base

25. Write the balanced chemical equation for the reaction in Model 1.

_____

26. The point where the solution changes color is called the *end point*. What was the volume of 2.0 M NaOH required to reach the end point of the reaction? Label this point on the graph.

_____

27. Complete Table 2 with the volume, molarity, and number of moles of acid and base when the end point is reached.

Table 2: Amount of reactants

Solution	Molarity (M)	Volumes (mL)	End Point Amount (mol)
HCl (analyte)			
NaOH (titrant)			

28. In this procedure the color change end point is also the *equivalence point*. What is equal at the equivalence point?

29. Look at your graph in Model 1. Does the temperature plot indicate a clear change at the equivalence point? If yes, describe the shape of the curve at the equivalence point.

30. Write the word "energy" on the appropriate side of the balanced equation. Explain your answer.

_____ $HCl + NaOH \rightarrow NaCl + H_2O$ _____

31. This reaction is very fast. Assume that the reaction reaches completion after each drop of titrant is added.

    a. Once the reaction is past the equivalence point, will excess reactant continue to have an effect on the change in temperature? Explain your response.

    b. Describe the region of the Model 1 graph where NaOH is the limiting reactant in the reaction.

    c. Describe the region of the Model 1 graph where HCl is the limiting reactant in the reaction.

32. Look at your graph in Model 1. Explain, based on the equation and the limiting reactant, why there is a change in the temperature curve around the equivalence point.

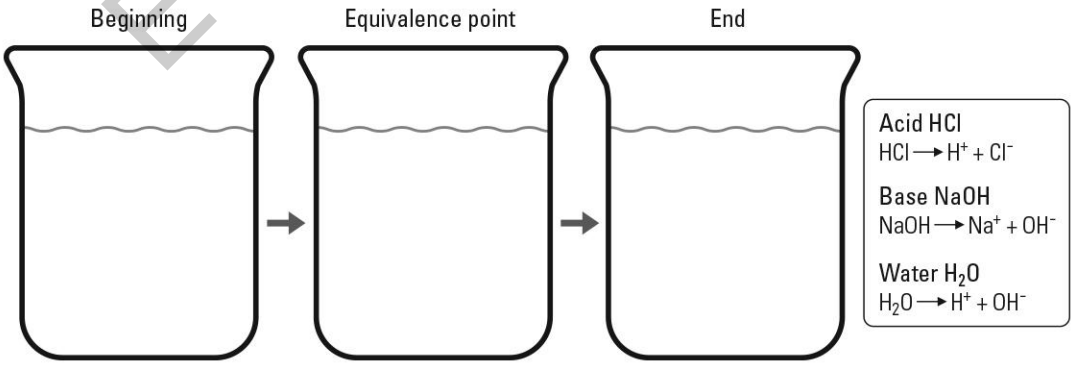
33. The chemical equation for a reaction can be re-written in ionic forms to indicate the actual substances that are reacting. Write both the complete equation and the net ionic equation for the reaction in Model 1.

34. Look at your graph in Model 1. Does the conductivity plot indicate a clear change at the equivalence point? If yes, describe the shape of the curve at the equivalence point.

35. Explain the change in conductivity before the equivalence point, based on the species in the beaker.

36. Explain the change in conductivity after the equivalence point, based on the species in the beaker.

37. Draw a particulate level representation of the substances in the beaker before the experiment, at the equivalence point, and at the end of the experiment.



38. Did the color-change end point occur at the same volume of NaOH as the change in the temperature graph and the conductivity graph? If not, provide some reasons for the discrepancy.

_____

_____

_____

39. Phenolphthalein, a temperature sensor, and a conductivity sensor were all used to determine when the reaction was complete. For the following reactions, which would work best? Explain your reasoning.

    a. A reaction in which a precipitate is formed.

_____

_____

_____

    b. A reaction that is endothermic.

_____

_____

_____

    c. A reaction in which one of the products has a dark color.

_____

_____

_____

MODEL 2

Building Model 2 – Varying Concentration

1. Set up the equipment as you did for Model 1.
2. Start a new experiment on the data collection system, as you did in Model 1.
3. Rinse and fill the drop dispenser with 2.0 M NaOH.
4. If the drop counter has been disconnected from the data collection system since it was last calibrated, calibrate it using the procedure in Appendix A.
5. Your instructor will give you a sample of HCl to react with the 2.0 M NaOH. Record its concentration in Model 2.
6. Using a Mohr pipet, transfer 25.0 mL of the HCl solution into a clean, dry 150-mL beaker. Record the molarity and volume in the Model 2 Data Table.
7. Add 50.0 mL of distilled water to the beaker.

8. Calculate the number of moles of acid added to the beaker.

9. Calculate the molarity of the solution after the 50.0 mL of distilled water is added.

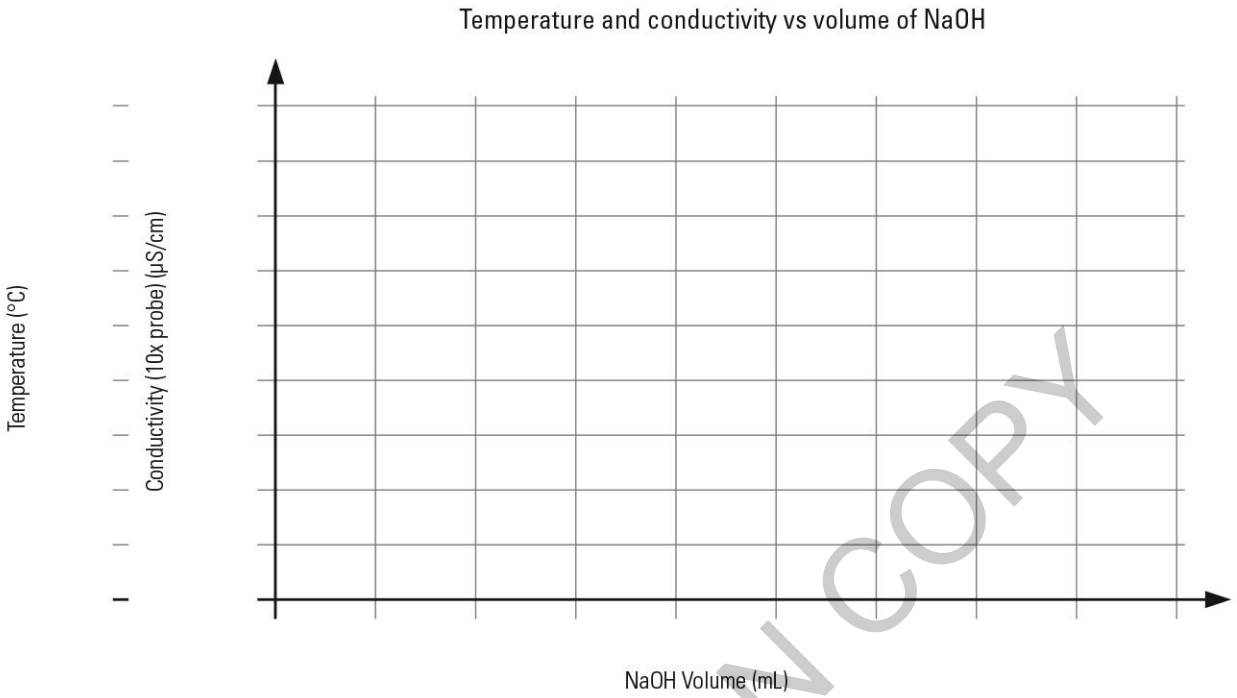
10. Calculate the number of moles of acid after the 50.0 mL of distilled water is added.

11. How many moles of NaOH will be required to reach the equivalence point with your sample of hydrochloric acid?

12. What volume of 2.0 M NaOH will be required to reach the equivalence point with your sample of hydrochloric acid?

13. Put 3 drops of phenolphthalein indicator into the beaker with HCl solution.

14. On the graph below, sketch the expected Temperature and Concentration vs Volume of NaOH curves for your sample of hydrochloric acid. Indicate the point on the graph where you expect the end point to occur.



15. Place the 150-mL beaker with the hydrochloric acid solution under the drop dispenser. Turn on the magnetic stirrer at a slow and steady rate.

16. Start recording data.

17. Turn the drop dispenser stopcock carefully, allowing the titrant (2.0 M NaOH) to drip slowly (1 to 2 drops per second) into the HCl solution.

    NOTE: The top valve controls the flow rate and the bottom valve turns the flow on and off.

18. In the Model 2 Data Table, record the volume when the phenolphthalein indicator changes color.

19. Add NaOH until the equivalence point has been reached and exceeded.

20. Stop recording data.

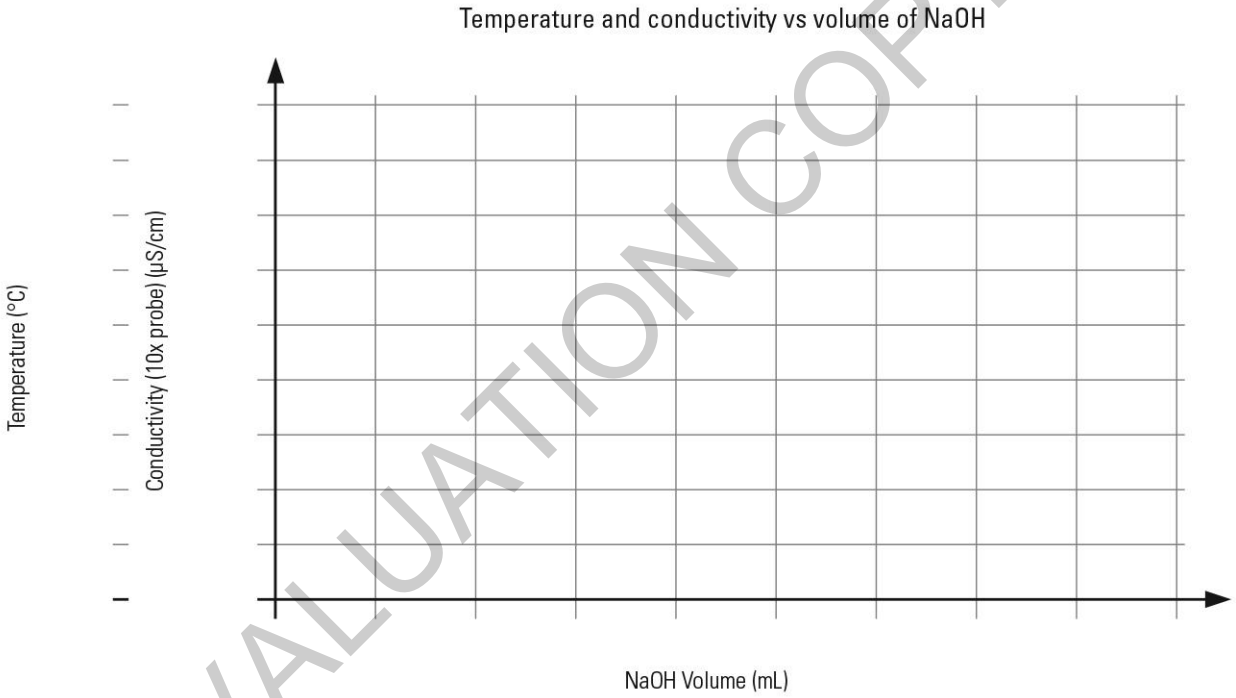
21. Save your experiment and dispose of the used solutions according to your teacher's instructions.

22. Sketch or attach a copy of your graph of temperature and conductivity vs volume of HCl and paste it into Model 2.

Model 2 – Varying Concentration

Table 3: Model 2 Data Table—End point determination

Parameter	Value
Concentration of HCl sample (M)	
Volume of 1.0 M HCl solution (mL)	
Concentration of NaOH used (M)	
Volume of NaOH added to change the color of the solution (mL)	



Analyzing Model 2 – Varying Concentration

23. How did your predicted graph compare to the experimental graph?

_____

_____

_____

24. Compare your graph to those of other students with different concentrations of HCl. What is the same for each of the graphs? What is different?

_____

_____

_____

25. What variable affected the volume of 2.0 M NaOH required to reach the equivalence point?

_____

_____

26. What other variable could affect the volume of 2.0 M NaOH required to reach the equivalence point? Explain.

_____

_____

Connecting to Theory

The technique in this lab is called *titration*. It is a powerful analytical technique that uses a substance with a known concentration to determine the concentration of a solution with an unknown concentration. Titrations are most often used with indicators or with a pH sensor. As you have experienced, other types of measurements can be used.

This technique is most often used to answer the question, "How much of a dissolved substance is in a sample?"

Applying Your Knowledge – Determining an Unknown Concentration

You will be given an unknown concentration of a strong monoprotic acid. Design an experiment to determine the concentration of the acid using 2.0 M NaOH. After your teacher has approved it, carry out your experiment.

Be prepared to make a presentation to the class that includes the following:

1. Your resulting data and graph.

2. Depending on the design of your experiment, provide one or more of the following:

   a. An explanation of how the indicator end point of the titration compared to the indicator end point in Models 1 and 2.

   b. An explanation of how the temperature curve for your reaction compares to the temperature curve of HCl and NaOH in Models 1 and 2.

   c. An explanation of how the conductivity curve for your reaction compares to the conductivity curve of HCl and NaOH in Models 1 and 2.

3. The concentration of the unknown acid with calculations that support your answer.

4. The percent error of your unknown concentration and sources of error. Ask your instructor for the actual concentration of your solution.

$$\%\text{Error} = \frac{\left|\text{Actual concentration} - \text{Your concentration}\right|}{\text{Actual concentration}} \times 100$$

5. POLAR AND NONPOLAR SUBSTANCES

Initial Question

Some things dissolve in water, some do not. If you want to dissolve permanent marker ink, for example, you'll need something oily. Why? What is the difference in the chemical structure of a waterproof ink and one that washes off the paper at the first hint of moisture?

How does the polarity of a compound affect its solubility in different solvents?

Materials and Equipment

Model 1

- Data collection system
- pH sensor
- Beaker (5), 100-mL
- Stirring rod
- Beral pipet
- Mineral oil, 30 mL
- Distilled water, 30 mL
- Colored pencils or camera
- **Set 1 Compounds**

  Copper(II) sulfate ($CuSO_4 \cdot 5H_20$), 0.5 g

  Iron(III) chloride ($FeCl_3$), 0.5 g

  Cobalt(II) chloride ($CoCl_2$), 0.5 g

  Beta-carotene ($C_{40}H_{56}$, carrot pigment), 10 mL

  Capsanthin ($C_{40}H_{56}O_3$, paprika pigment), 10 mL

  Riboflavin ($C_{17}H_{20}N_4O_6$, vitamin B), 10 mL

  Lycopene ($C_{40}H_{56}$, tomato pigment), 10 mL

  Betanin ($C_{24}H_{27}N_2O_{13}$, beet pigment), 10 mL
- **Set 2 Compounds**

  Acetylsalicylic acid ($C_9H_8O_4$), 10 mL

  Stearic acid ($C_{17}H_{35}COOH$), 0.5 g

  Oleic acid ($C_{17}H_{33}COOH$), 10 mL

  Acetic acid (CH_3COOH), 10 mL

  Citric acid ($C_6H_8O_7$), 0.5 g

Model 2

- Beaker (2), 100-mL
- Mineral oil , 20 mL
- Lycopene ($C_{40}H_{56}$, tomato pigment), 10 mL
- Betanin ($C_{24}H_{27}N_2O_{13}$), beet pigment), 10 mL

Safety

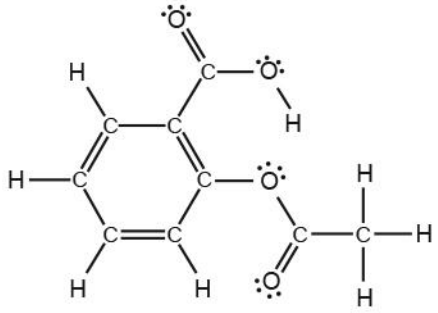
Add these important safety precautions to your normal laboratory procedures:

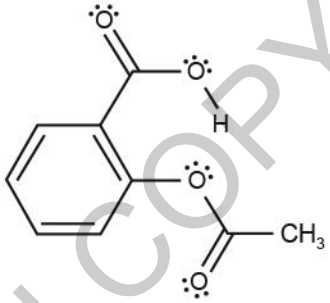
- Many of the solutions used in this lab are alcohol based and are therefore flammable. They should not be used near an open flame or ignition source.
- Even though many of the compounds in this lab are “kitchen” items, treat all materials in this activity as hazardous.

Getting Your Brain in Gear

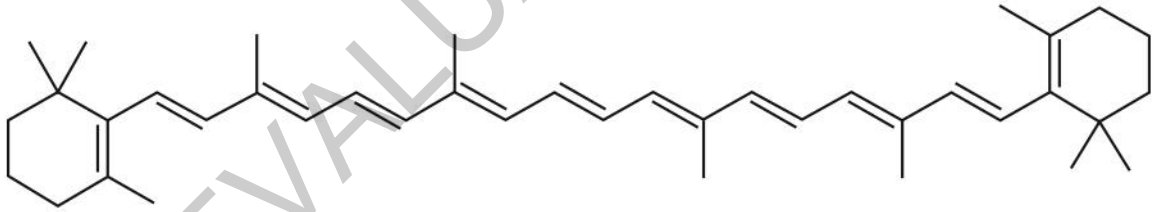
1. What is the difference between a compound and a mixture? Give two examples of each.

2. Some molecules are too large to represent as Lewis dot structures. However, there is a simple "code" chemists often use to draw them. Below is the Lewis dot structure of aspirin, drawn two ways. Determine the rule to turn a Lewis structure into the "skeleton" structure on the right.

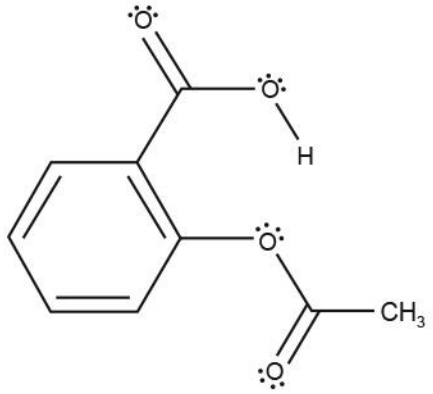




3. How many carbon atoms are in the following molecule?



4. Circle all of the atoms or groups of atoms in the aspirin molecule that could form hydrogen bonds with water.



5. While some acids may dissolve in water, others do not. How would measuring the pH before and after the acid is added to water help determine if the acid dissolves in water?

_____

_____

_____

MODEL 1

Building Model 1 – Dissolving Compounds

1. Your teacher will assign you one compound from the Set 1 Compounds in the Materials and Equipment list. The compound may already be dissolved in a solvent or may be provided as a solid powder. Obtain about 10 mL of your assigned compound if it is a solution or a small scoop (approximately 0.5 g) if it is a solid.

2. In a 100-mL beaker, mix 10 mL of distilled water and 10 mL of mineral oil.

3. The density of water is about 1.00 g/mL and the density of mineral oil is about 0.85 g/mL. In the mixture you just made, which layer is on top and which is on bottom?

_____

_____

4. Add your assigned compound to the oil–water mixture. Stir with a stir rod for about 10 seconds.

5. Allow the mixture to sit for about 5 minutes. Determine which solvent your compound dissolves in best. In the Set 1 Compounds Results section below, use colored pencils or a photograph to record your observations. Label the layers.

6. Dispose of all mixtures in the proper waste containers and wash the beakers thoroughly with soap.

7. Your teacher will now assign you a compound from the Set 2 Compounds in the Materials and Equipment list. Obtain 10 mL of the assigned solution or a small scoop (approximately 0.50 g), if it is a solid.

8. Consider this new substance. Can you use the same method (dissolving the compound in a beaker with water and mineral oil) to test if it will dissolve in oil or water? Why or why not? If not, suggest a method or test that could be performed to determine in which solvent the compound dissolves.

_____

_____

_____

9. In a 100-mL beaker, mix 10 mL of distilled water and 10 mL of mineral oil. Allow this mixture to sit for 10 minutes while you perform the next step. This is the control.

10. In a second 100-mL beaker, mix 10 mL of distilled water, 10 mL of mineral oil and either 10 mL or a small scoop of your assigned compound. Mix with a stirring rod or by swirling the beaker. Allow this to sit for 10 minutes.

11. Connect a pH sensor to the data collection system.

12. For each of the oil–water mixtures, including the control, use a beral pipet to transfer some of the water layer to a clean beaker. Transfer enough to submerge the pH meter into the sample. Measure the pH of the water layer and record the results in the Model 1 Data Table.

    NOTE: Mixing water with oil may make the water slightly more acidic. It is therefore important to measure the pH of the oil–water control to determine the extent of this effect. If the acid dissolves in the water layer, expect a significant change (2 or more pH units) from the control.

13. Determine if the compound dissolved mostly in water or oil and place an "X" in the appropriate column of the Model 1 Data Table.

14. Rinse your pH probe well, first with soapy water and then with distilled water.

15. Rinse all of your glassware well, first with soapy water and then with distilled water.

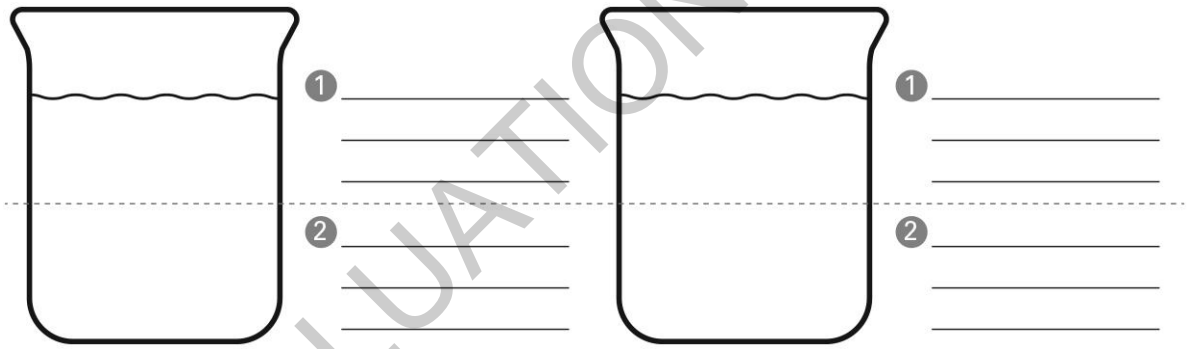
16. Share your data with the class to complete the Model 1 Data Table.

Model 1 – Dissolving Compounds

Set 1 Compounds Results

Assigned compound: _____

OBSERVATIONS



Set 2 Compounds Results

Assigned compound: _____

Table 1: Model 1 Data Table—Properties of various compounds

Compound	pH of Water Layer	Dissolved in Water	Dissolved in Oil
Set 1 Compounds			
Copper(II) sulfate, $CuSO_4$			
Cobalt(II) chloride, $CoCl_2$			
Iron(III) chloride, $FeCl_3$			
Beta-carotene, $C_{40}H_{56}$			
Capsanthin, $C_{40}H_{56}O_3$			
Riboflavin, $C_{17}H_{20}N_4O_6$			
Lycopene, $C_{40}H_{56}$			
Betanin, $C_{24}H_{27}N_2O_{13}$			
Set 2 Compounds			
Acetylsalicylic acid, $C_9H_8O_4$			
Stearic acid, $C_{17}H_{35}COOH$			
Oleic acid, $C_{17}H_{33}COOH$			
Acetic acid, CH_3COOH			
Citric acid, $C_6H_8O_7$			
pH of water in control mixture			

Analyzing Model 1 – Dissolving Compounds

17. Did most of the colored compounds dissolve in both water *and* oil, or did most compounds dissolve in one or the other?

18. Which compounds used in this experiment have ionic bonds? Did these dissolve in water or in oil?

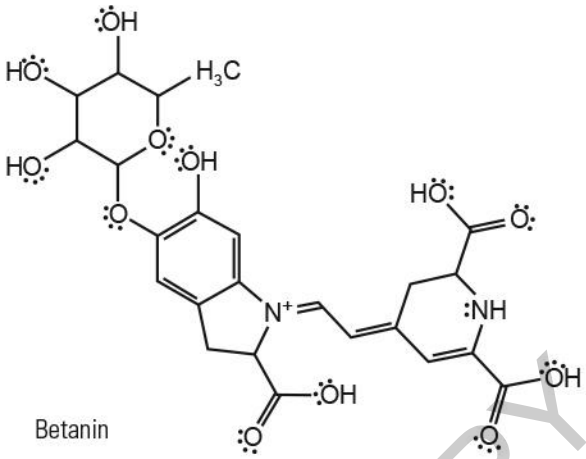
19. Do all of the molecular compounds dissolve in oil? Support your answer with data from the Model 1 Data Table.

20. One way to think about which molecular compounds will dissolve in water and which will dissolve in oil is to determine which molecules are able to form hydrogen bonds with the water molecules.

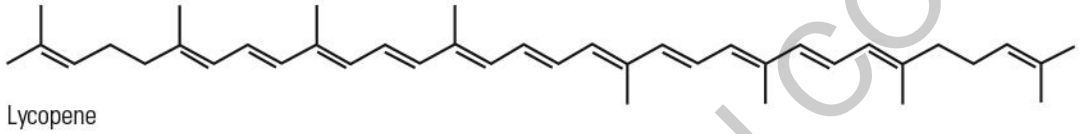
    a. What atoms must be present for a molecule to form a hydrogen bond with water?

Refer to these skeleton structures of four of the Set 1 Compounds:

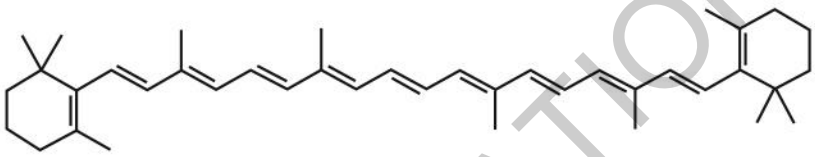
Riboflavin



Betanin



Lycopene



Beta-carotene

b. Can riboflavin form a hydrogen bond with water? If so, circle the places on the molecule that could form a hydrogen bond with water.

_____

_____

_____

c. Can beta-carotene form a hydrogen bond with water? If so, circle the places on the molecule that could form a hydrogen bond with water.

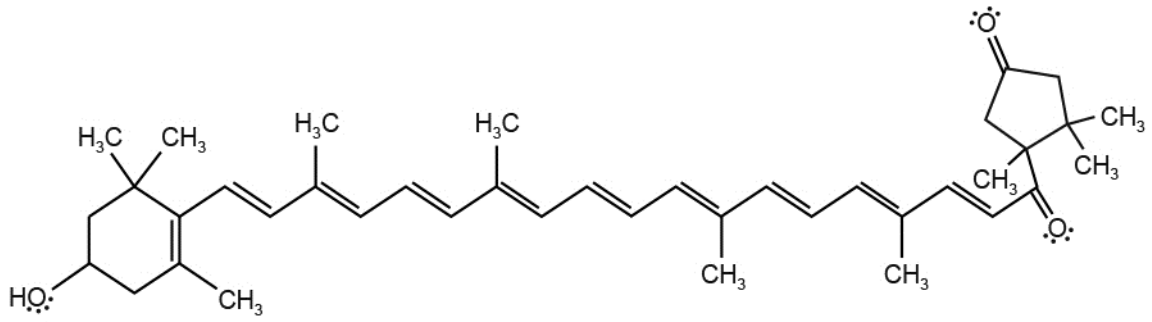
_____

_____

d. Are all of the molecules that dissolved in water able to form hydrogen bonds with water?

_____

21. Below is the molecular structure of capsanthin. Does having three or fewer oxygen atoms in a molecule containing 40 carbon atoms provide enough hydrogen bonding to water to make that molecule soluble in water? Justify your answer using your data.



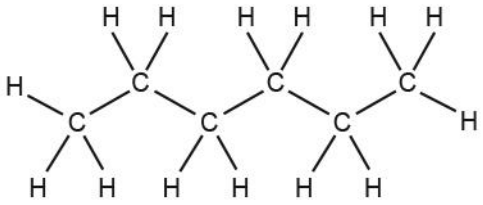
22. A second way to think about which compounds will dissolve in water and which will dissolve in oil is to consider which ones are polar and which are nonpolar. Mineral oil is a mixture of molecules that are carbon chains of various lengths (ranging from 18 to 40 carbons). An example of one molecule is shown here:

a. Is this compound polar or nonpolar? Briefly explain your answer.

b. Is water polar or nonpolar? Briefly explain how you know. Include a drawing.

c. Textbooks often use the phrase "like dissolves like" to explain solubility. What they mean by this is that polar compounds dissolve in polar compounds while nonpolar compounds dissolve in nonpolar compounds. Does your data support this statement? Give examples to support your answer.

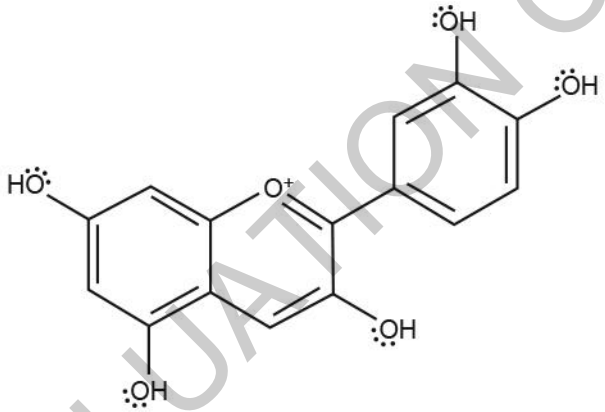
23. a. Hexane is shown below. Is hexane a polar or nonpolar compound?



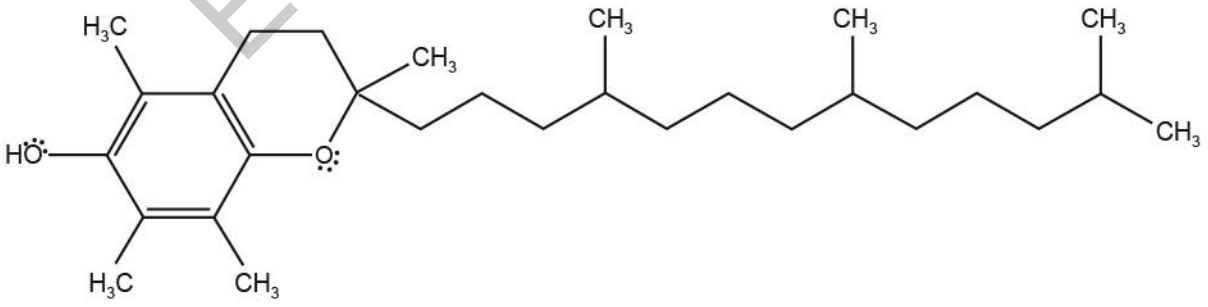
b. Will beta-carotene dissolve in this solvent (hexane)? Briefly explain your answer.

24. Determine if the following compounds will dissolve in oil or water. If the molecule is water soluble, circle the sites where hydrogen bonding with water can occur.

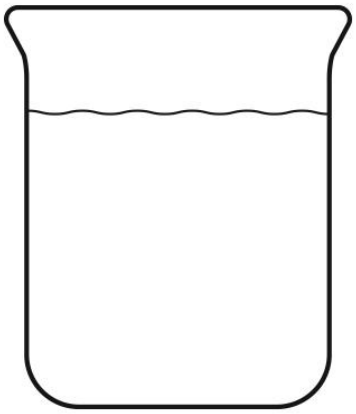
a. Cyanidin (a compound that gives many fruits their red color)



b. Alpha-tocopherol (a form of vitamin E)



25. Suppose lycopene and betanin were both added to an oil–water mixture. Predict where each solute would dissolve best and draw a picture of your prediction.



26. Barium sulfate, $BaSO_4$, is insoluble in water. Does this characteristic follow the "like dissolves like" guideline? Explain your reasoning.

MODEL 2

Building Model 2 – Extraction

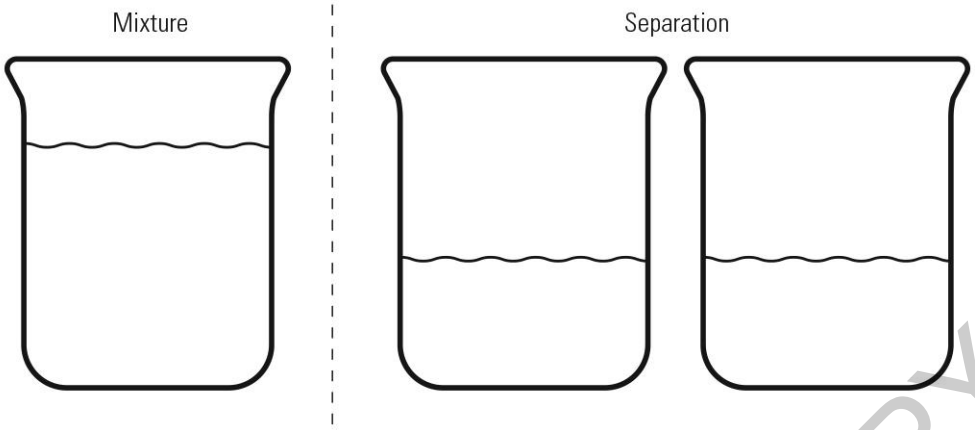
1. Obtain 10 mL each of the lycopene and betanin solutions (the structures of these molecules are depicted in the Analyzing Model 1 section). Record the color of each solution.

2. Mix the two solutions together in a 100-mL beaker, and then add 20 mL of mineral oil. Stir for 10 seconds then let the mixture sit for two to five minutes. Record your observations.

3. Decant the top layer into a separate beaker. Record your observations in Model 2 – Extraction by either drawing a picture (use colored pencils to record the color) or taking a photo.

Model 2 – Extraction

Observations



Analyzing Model 2 – Extraction

4. Explain how you were able to separate the lycopene and betanin in Model 2.

_____

_____

_____

Connecting to Theory

There are many times in chemical research, manufacturing and industry when mixtures of compounds must be separated. Several techniques are used to achieve separation. Many of these techniques make use of the different solubility of the substances in the mixture. The process you performed in this lab is known as *extraction*—for example, one compound moves into the nonpolar solvent layer, the other stays in the polar solvent layer.

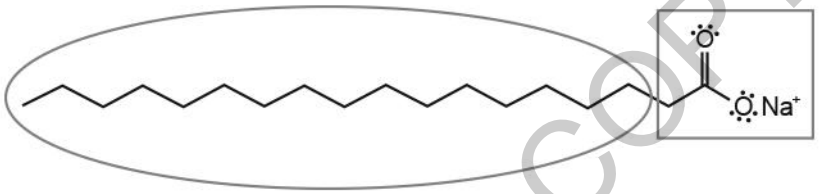
Consider the decaffeination of coffee (extraction of caffeine from coffee beans), which is also accomplished by an extraction method. Coffee beans are soaked in a solvent that dissolves caffeine, but not the other compounds in coffee, such as those that give the coffee its flavor. Over the years, various solvents have been used, including dichloromethane and supercritical CO_2. This process is not 100% efficient; some of the caffeine is not dissolved in the solvent. This is why the coffee is labeled as "decaffeinated" and not "caffeine free."

Chromatography is another commonly-used process that separates the components of a mixture. In this process, a liquid or gas moves over a solid medium (such as paper or silica). Some of the components dissolve better in the mobile phase than others, and so travel farther along the solid medium. Others stick better to the solid. In the end, the components are separated.

Applying Your Knowledge

1. Lycopene, beta-carotene and capsanthin are all converted by your body into vitamin A. Your body is better able to absorb these compounds if the foods they come from (such as tomatoes, carrots, and peppers) are cooked, particularly if they are cooked in a little oil. Why might this be the case?

2. Soap is generally formed from molecules that have long nonpolar "tails" and a "head" that is very soluble in water. Such compounds are called *surfactants*, and an example of one (sodium stearate) is pictured below.



   a. Circle the nonpolar region of this molecule

   b. Put a box around the polar region of this molecule.

   c. What about the structure of the polar region of this molecule will give extremely polar properties?

   d. Using what you have learned in this lab, why do you think surfactant molecules are more effective at dissolving oily compounds from dishes than pure water alone?

3. Consider what you know about "permanent" ink and ink that can be washed off in water. How are the compounds used in those inks different?

6. SOLUBILITY

Initial Question

Most ionic compounds are considered to be soluble or slightly soluble in water. Even compounds considered insoluble will dissolve to some small extent. This small extent can become very important when the dissolved substance is poisonous like lead, thallium, or cadmium. Over time, tiny amounts of these heavy metals can build up in your body and cause severe health problems. By knowing the amount of a dissolved ion in a solution, we can determine any potential health risks.

How can you determine the amount of dissolved ions in a solution?

Materials and Equipment

Model 1

- Data collection system
- Conductivity sensor
- Beakers (3), 150-mL
- Balance (1 per class)
- Stirring rod
- Graduated cylinder, 100-mL
- Unknown A, solid, 1.0 g
- Unknown B, solid, 1.0 g
- Unknown C, solid, 1.0 g[3]
- Distilled water, 300 mL
- Wash bottle with distilled deionized water

Model 2

- Data collection system
- Conductivity sensor
- Magnetic stir bar
- Stir plate
- Ring stand
- Graduated cylinder, 100-mL
- Balance (1 per class)
- Beaker, 150-mL
- Clamp
- Potassium bitartrate ($KHC_4H_4O_6$), solid, 4.2 g
- Distilled water, 100 mL

Model 3

- Erlenmeyer flask, 125-mL
- Mohr pipet, 25-mL
- Pipet bulb
- Beaker (2), 150-mL
- Buret
- Buret clamp
- Funnel
- Quantitative filter paper
- Magnetic stir bar
- Stir plate
- Phenolphthalein, 3 drops
- 0.10 M Sodium hydroxide (NaOH), 80 mL
- Distilled water, 20 mL

Safety

Add these important safety precautions to your normal laboratory procedures:

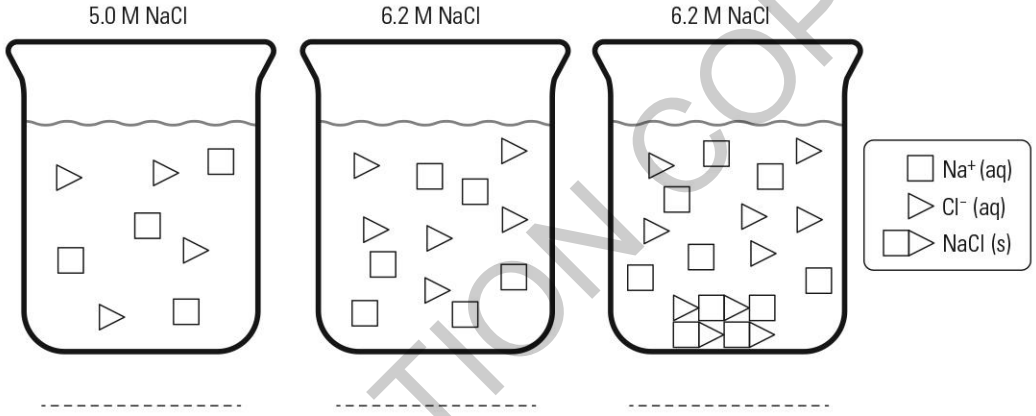
- In addition to goggles and an apron, wear gloves.

Getting Your Brain in Gear

1. Why would the conductivity of a solution change when solute is added?

2. Based on conductivity, how can you distinguish between soluble ionic and molecular solutes when they are dissolved in water?

3. Consider the three beakers below. Label the solutions either saturated or unsaturated. Explain your reasoning.



4. Bitartrate is a polyatomic ion with the formula $HC_4H_4O_6^-$. In a saturated solution of potassium bitartrate, the following equilibrium reaction occurs:

$$KHC_4H_4O_6(s) \rightleftharpoons K^+(aq) + HC_4H_4O_6^-(aq)$$

Describe the chemical processes during the forward and reverse reactions.

MODEL 1

Building Model 1 – Saturated or Unsaturated?

1. Obtain three 150-mL beakers and label them "A," "B," and "C."
2. Pour 100 mL of distilled water into each of the beakers.
3. Connect the conductivity sensor to the data collection system.
4. Insert the conductivity sensor into the water in Beaker A.

   NOTE: Make sure the small hole on the side of the conductivity probe is submerged. Gently tap the conductivity probe to remove any trapped bubbles.
5. Start data collection. Record the conductivity in the Model 1 Data Table.
6. Measure and add 1.0 g of unknown solid A to the beaker.
7. Stir the solution with a glass stirring rod and then record the conductivity and appearance on the Model 1 Data Table.
8. Make a particulate drawing for the unknown in solution in Model 1.
9. Rinse the conductivity probe with distilled deionized water and then repeat the previous steps with unknowns B and C in their respective beakers.

Model 1 – Saturated or Unsaturated?

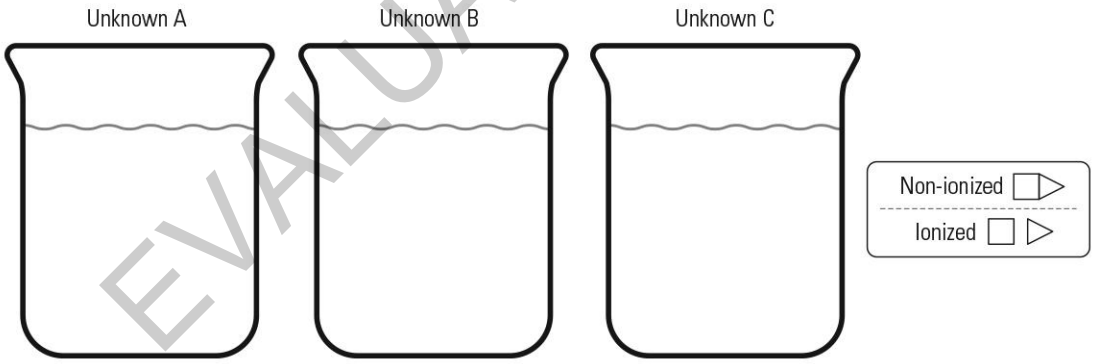


Table 1: Model 1 Data Table—Identifying a saturated solution

Unknown	Appearance	Conductivity (µS/cm)	
		Water	Water Plus Unknown
Unknown A			
Unknown B			
Unknown C			

Analyzing Model 1 – Saturated or Unsaturated?

10. Which of the solutions would you describe as unsaturated? Explain your reasoning.

11. Which of the solutions would you describe as saturated? Explain your reasoning.

12. Which of the unknowns would you describe as ionic? As covalent? Explain your reasoning for each.

13. How could you experimentally verify your answers above?

14. If you are going to use conductivity to help determine the saturation of a solution, what can you say about the substance you use for this study?

MODEL 2

Building Model 2 – Reaching Saturation

1. Connect the conductivity sensor to the data collection system.
2. Pour 100.0 mL of distilled water into a 150-mL beaker.
3. Add a stir bar to the beaker and place the beaker on a magnetic stirrer, placed on the base of the ring stand.
4. Use the ring stand and clamp to hold the conductivity sensor immersed in the water in the beaker and then turn on the magnetic stirrer.

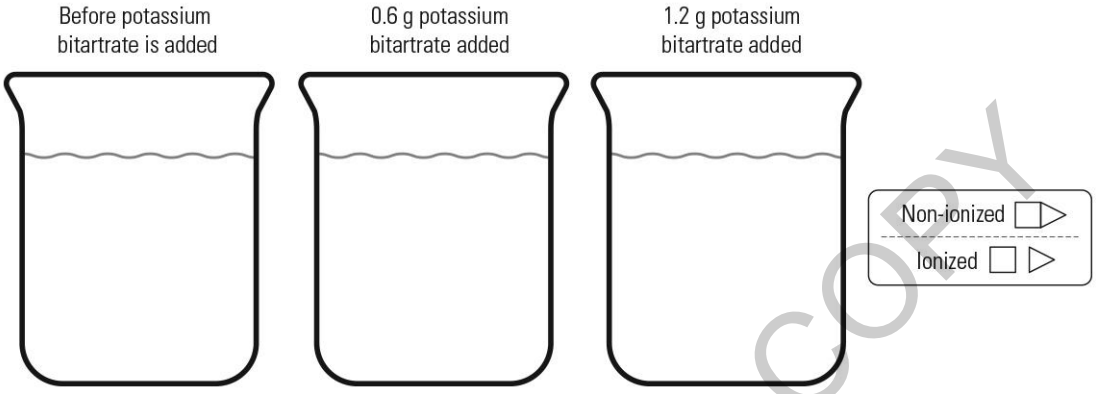
   NOTE: Make sure the small hole on the side of the conductivity sensor is submerged. Gently tap the conductivity probe to remove any trapped bubbles.
5. Start data collection. Record the conductivity and the appearance of the solution in the Model 1 Data Table.
6. While constantly stirring, add 0.2 g of potassium bitartrate to the beaker.

7. After 4 minutes, record the conductivity and appearance in the Model 2 Data Table.

8. With constant stirring, add an additional 0.2 g of potassium bitartrate to the beaker. After 4 minutes, record the conductivity and appearance of the solution.

9. Continue this process of adding 0.2 g of potassium bitartrate to the beaker and stirring for 4 minutes until 1.2 g have been added.

10. Make particulate level drawings of the solutions before potassium bitartrate is added, after 0.6 g are added, and after 1.2 g are added.



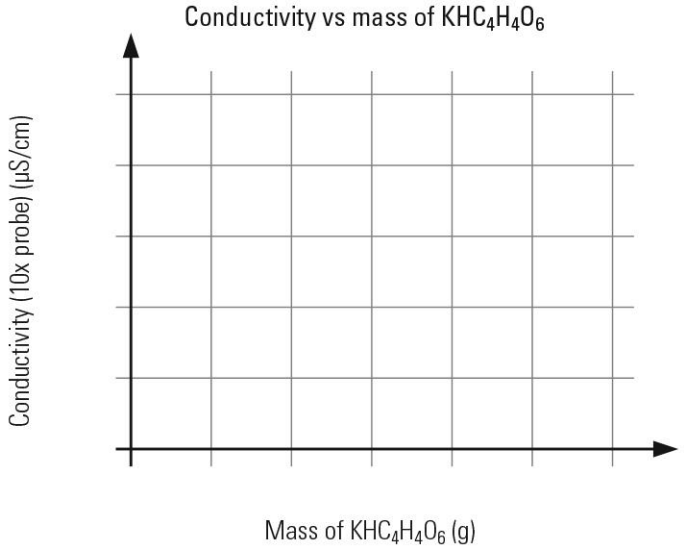
11. Sketch a graph of conductivity on the *y*-axis and total mass of potassium bitartrate added on the *x*-axis.

12. Do not discard the contents in your beaker. Save the solution for Model 3.

Model 2 – Reaching Saturation

Table 2: Model 2 Data Table—Detecting the saturation point

Trial	Total Potassium Bitartrate Added (g)	Conductivity	Appearance	Saturated or Unsaturated?
1				
2				
3				
4				
5				
6				
7				



Analyzing Model 2 – Reaching Saturation

13. In the Model 2 Data Table, describe the solution after each trial as either saturated or unsaturated.

_____

_____

_____

14. What is the approximate mass of $KHC_4H_4O_6$ required to saturate 100 mL of water? Explain your reasoning using at least two instances of data-based evidence.

_____

_____

_____

MODEL 3

Building Model 3 – Quantifying Solubility

1. Use the following steps to remove any solids from the solution you saved from Model 2.

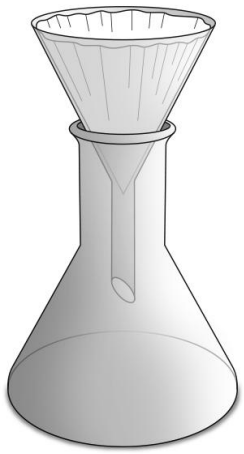
   NOTE: Do not add any water to the filtrate.

   a. Assemble a filtration setup as in the diagram shown at the right, using a 125-mL Erlenmeyer flask, filter paper, and a funnel.

   b. Fold the filter paper and place it into the funnel.

   c. Slowly pour the contents of the beaker into the funnel. Do not over fill the filter paper.

   d. Continue until all of the filtrate has moved through the filter paper into the flask.



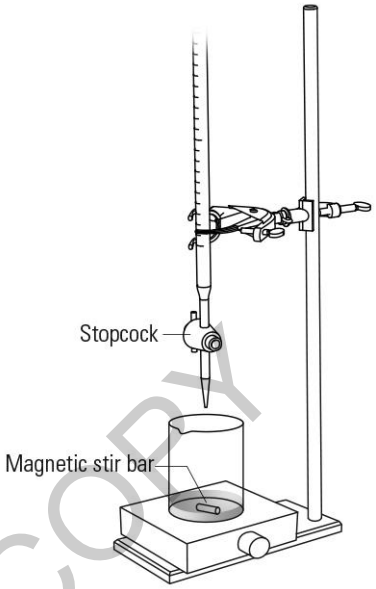
2. Is the filtered solution saturated or unsaturated?

_____

3. Insert the magnetic stir bar into a clean, dry, 150-mL beaker. Then, using a Mohr pipet, deliver 25 mL of the filtered potassium bitartrate solution from the Erlenmeyer flask into the beaker. Save the rest of the solution for a second trial.

4. Add approximately three drops of phenolphthalein indicator to the potassium bitartrate solution in the beaker.

5. Use a ring stand to set up a buret, as shown.



6. Rinse the buret:

   a. Open the stopcock and then place a waste beaker under the buret.

   b. Rinse the buret three times with small amounts of distilled water. This will remove any residue.

   c. Rinse the buret three times with small amounts of 0.10 M NaOH. This will push out any water or other impurities.

7. Close the stopcock. Replace the waste beaker with the 150-mL beaker that contains the 25 mL of potassium bitartrate and phenolphthalein. Dispose of the waste according to your teacher's instructions.

8. Fill the buret with 0.10 M NaOH. Record the initial volume in the Model 3 Data Table.

9. Turn on the magnetic stirrer. Then open the stopcock to achieve a steady drip of approximately one drop per second. Add the 0.10 M NaOH until you get a permanent, faint pink color in the solution, and then close the stopcock.

10. Record the final volume of sodium hydroxide in the Model 3 Data Table.

11. Repeat the previous steps for a second trial using another 25-mL sample of the $KHC_4H_4O_6$ solution. Calculate the volume of titrant added for each trial and determine the average volume.

Model 3 – Quantifying Solubility

Table 3: Model 3 Data Table—Using titration to determine solubility

Parameters	Trial 1	Trial 2	Average
Volume of $KHC_4H_4O_6$ solution (mL)			
Concentration of NaOH used (M)			
Initial titrant volume (mL)			
Final titrant volume (mL)			
Volume of titrant added to reach the endpoint (mL)			

Analyzing Model 3 – Quantifying Solubility

12. Bitartrate is a weak acid and sodium hydroxide reacts with it according to the following net ionic reaction:

$$OH^-(aq) + HC_4H_4O_6^-(aq) \rightleftharpoons H_2O(l) + C_4H_4O_6^{2-}(aq)$$

a. Calculate the average number of moles of OH^- used in the titrations.

b. Calculate the average number of moles of $HC_4H_4O_6^-$ in the 25.0-mL sample of the solution.

c. Calculate the average molarity of the $HC_4H_4O_6^-$ in the solution.

d. Calculate the average mass of the $KHC_4H_4O_6$ dissolved in 100 mL of water.

13. Compare this mass of $KHC_4H_4O_6$ to the approximated mass in Model 2.

Connecting to Theory

The ability of a compound to dissolve in a solvent is its solubility. The solubility of an ionic compound refers to the maximum amount of solute that can dissolve in a given amount of solvent at standard temperature and pressure. The solution of an ionic compound containing the maximum amount of solute is known as a saturated solution and is in a state of equilibrium between dissolved and undissolved solute.

The solubility product constant, K_{sp}, is a temperature-dependent constant that refers to this state. If a salt, M_xA_y, dissociates into cations $[M^{m+}]$ and anions $[A^{a-}]$ the expression for the solubility product will be

$$K_{sp} = [M^{m+}]^x[A^{a-}]^y$$

where "[ ]" indicates the molar concentration of the ion in solution.

For example, the equation below describes the equilibrium of a saturated solution of calcium carbonate in water:

$$CaCO_3(s) \rightleftharpoons Ca^{2+}(aq) + CO_3^{2-}(aq)$$

Calcium carbonate dissolves in the solution in the forward reaction and at the same time calcium carbonate precipitates from the solution in the reverse reaction. When both reactions occur at the same rate, a state of equilibrium is established.

The K_{sp} expression for calcium carbonate would be:

$$K_{sp} = [Ca^{2+}][CO_3^{2-}]$$

Applying Your Knowledge – Determining Solubility Equilibrium

1. Write the K_{sp} expression for potassium bitartrate using the following equilibrium reaction:

$$KHC_4H_4O_6\,(s) \rightleftharpoons K^+(aq) + HC_4H_4O_6^-(aq)$$

2. Based on the formula of potassium bitartrate and the average molarity at saturation of bitartrate from Model 3, what are the molarities of potassium ions and the bitartrate ions in a saturated solution?

   a. Calculate the value of K_{sp} for potassium bitartrate.

3. Copper(II) tartrate, $CuC_4H_4O_6$, dissolves in water according to the following equation

$$CuC_4H_4O_6(s) \rightleftharpoons Cu^{2+}(aq) + C_4H_4O_6^{2-}(aq)$$

The K_{sp} of copper(II) tartrate is 4.0×10^{-4}.

a. What is the K_{sp} expression of copper(II) tartrate?

b. What is the molarity of a saturated solution of copper(II) tartrate?

c. If 0.200 grams of copper(II) tartrate are added to 100 g of water, is the solution saturated?

7. EMPIRICAL FORMULA

Initial Question

A major emphasis of laboratory work for a chemist is determining the composition of a compound. There are many tools, such as chromatographic separation and spectroscopy, that aid the chemist in determining chemical composition. By keeping track of mass and breaking a compound into its component pieces, the pieces can be measured and the composition determined.

How do you discover the formula for an unknown substance?

Materials and Equipment

Model 1

- Hot plate, 1 per group, or an oven for the class
- Crucible and cover
- Crucible tongs
- Unknown copper hydrate, 1.0–1.5 g
- Balance (1–2 per class)

Model 2

- Data collection system
- Colorimeter
- Sensor extension cable
- Graduated cylinder, 25-mL
- Volumetric flask, 100-mL
- Unknown copper hydrate, 1.0–1.5 g
- 0.10 M Copper(II) chloride ($CuCl_2 \cdot 2H_2O$), 60 mL
- Distilled water, 25 mL

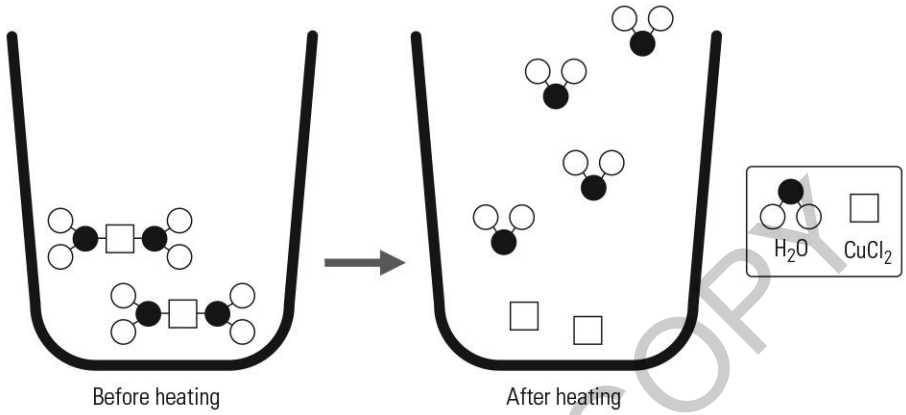
Safety

Add these important safety precautions to your normal laboratory procedures:

- Do not look into a hot crucible. Hot material may be ejected.
- Do not touch chemicals with your hands.

Getting Your Brain in Gear

1. In this lab, you will be heating a hydrate to remove the water. Label the appropriate molecules in the before-heating and after-heating diagrams below with "Hydrate," "Anhydrous salt," and "Water."



2. Write a mathematical equation that would show the relationship between the mass of the hydrate, the mass of water lost, and the mass of the anhydrous salt.

3. There are two possible ionic compounds that can be formed by copper and chlorine. Write their chemical formulas.

_____

4. Recall that copper ions have a blue to green color in solution. Propose a lab technique that could be used to determine the concentration of copper ion in a solution prepared with your hydrate sample.

_____

_____

MODEL 1

Building Model 1 – Percentage of Water

1. Clean and dry a small ceramic crucible and cover.

2. Measure the mass of the crucible and cover. Record this in the Model 1 Data Table.

3. Measure between 1.0 and 1.5 grams of the unknown in the crucible (the cover should be on the balance, as well). Record the total mass of the sample, crucible, and cover in the Model 1 Data Table.

4. In this lab procedure, you obtain the mass of the unknown in the crucible. Explain why this method is preferred over finding the mass of the unknown in a weighing container and then pouring the sample into the crucible.

_____

_____

_____

5. Set up a hot plate to heat the uncovered crucible. Use a medium setting.

   NOTE: Heating the hydrate too hot (>300 °C) will result in the production of poisonous chlorine gas.

6. As water is released from the sample, the color will change from blue to brown. Use crucible tongs to gently shake the crucible occasionally to expose the blue hydrate in the middle. Continue heating until the blue color is gone; this will take ten to fifteen minutes. Work on the problem below while you wait.

7. In Model 2 you will use a spectrophotometric technique to determine the percentage of copper ion in your sample. To do this, you will need standard solutions of 0.10 M, 0.08 M, 0.06 M and 0.04 M copper ion. You will be given a stock solution of 0.10 M copper ion. Perform the calculations and write a procedure for how you will make at least 20.0 mL of each of the standard solutions.

_____

_____

_____

8. Once all the crystals are brown, remove the crucible from the hot plate with crucible tongs. Let the sample cool with the cover in place. After cooling for five minutes, find and record the total mass of the sample, crucible, and cover.

   NOTE: You cannot measure the mass of a hot object on the balance.

9. Why is it necessary to heat the sample with the cover removed?

10. Why is it necessary to let the substance dry with the cover on?

11. To ensure that all the water has been removed, reheat the crucible with the unknown for five minutes (uncovered). Let the sample cool on the desk (covered) and then obtain the mass as you did previously. Continue to heat in five-minute intervals until all of the water has been removed from the hydrate sample.

12. How will you know if you have heated the hydrate sufficiently to remove all of the water?

13. Transfer the brown anhydrous sample from your crucible to the solid waste jar in the hood. Rinse and dry the crucible.

Model 1 – Percentage of Water

Table 1: Model 1 Data Table—Determine the percentage of water in the hydrate

Parameters	Mass (g)
Crucible and cover	
Hydrate sample, crucible and cover	
After 1st heating	
After 2nd heating	
After 3rd heating (if necessary)	

Analyzing Model 1 – Percentage of Water

14. Calculate the mass of water lost from the hydrate.

15. Calculate the percentage of water in the original sample.

16. Complete Table 2 using data from your classmates to compare different sized samples of hydrate. Compute the average percentage of water in the sample.

Table 2: Compare class results for the percentage of water in the hydrate

Mass of Hydrate Sample (g)	Mass of Water Lost (g)	Percentage of Water in Hydrate (%)

Average percentage of water in the hydrate: _____

17. Consider the class data above.

a. How does the mass of water lost relate to the mass of the hydrate sample?

_____

_____

b. How does the percentage of water lost relate to the mass of the hydrate sample?

_____

_____

18. Explain how the class data above supports the Law of Definite Proportions.

_____

_____

_____

MODEL 2

Building Model 2 – Moles of Copper

1. Add a 1.0 to 1.5 gram sample of hydrate to a 100.0 mL volumetric flask and fill it to the mark with distilled water.

Mass of copper hydrate sample: _____

2. For obtaining a graph exhibiting Beer's Law, prepare the four copper ion standards (0.10 M, 0.08 M, 0.06 M, 0.04 M) as you described in the Building Model 1 section.

3. What color is the copper ion when dissolved in water?

_____

4. Which wavelength of light do you anticipate will give the highest absorbance reading on the colorimeter?

_____

5. What color of light does that wavelength correspond to?

_____

6. You will be using the linear regression of the line to determine the number of moles of copper ion present in your sample. Would it be better to fit the absorbance or transmittance data? Explain your reasoning.

_____

_____

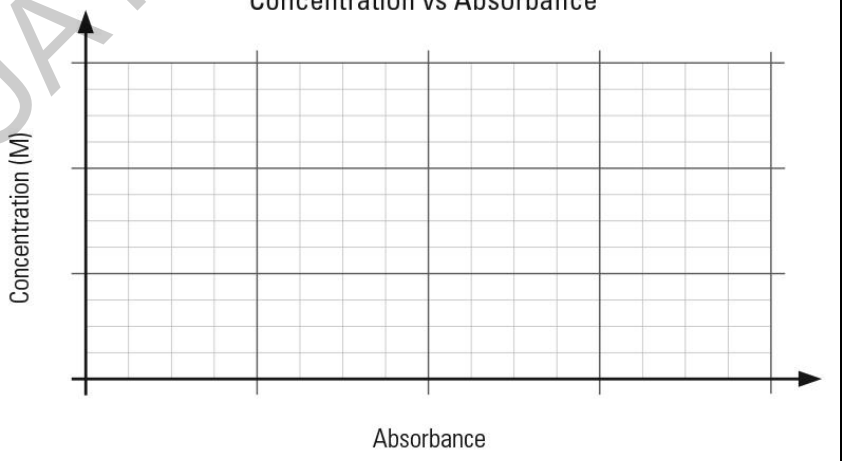
7. Calibrate the colorimeter.

8. Record the absorbance in the Model 2 Data Table for each standard solution, sketch or attach a copy of your graph of concentration versus absorbance, and use the linear regression of the line to acquire and record the equation for the line.

9. Record the absorbance in the Model 2 Data Table for your unknown hydrate solution.

Model 2 – Moles of Copper

Table 3: Model 2 Data Table—Using a standard curve to determine the concentration of the unknown

Copper Ion Concentration	Absorbance	Graph
0.04 M		
0.06 M		
0.08 M		
0.10 M		
Unknown		Equation for the line:

Analyzing Model 2 – Moles of Copper

10. Use the equation obtained from the absorbance data from the copper ion standards to find the concentration of copper ion in the solution made with your hydrate sample.

11. Determine the number of moles of copper in the unknown.

12. Calculate the number of moles of water in the unknown using the percentage of water determined in Model 1.

13. Calculate the ratio of the number of moles of water to that of copper in your hydrate. Reduce the ratio to whole numbers.

14. Complete Table 4 using data from your classmates to compare the results when using different sized samples of hydrate.

Table 4: Compare class results for the ratio of the number of moles of water to those of copper

Mass of Hydrate Sample (g)	Moles of Water (mol)	Moles of Copper Ion (mol)	Moles H_2O : Moles Cu

15. Consider the class data above. How does the ratio of moles of water to moles of copper relate to the mass of the hydrate sample?

_____

_____

16. Explain how the class data above supports the Law of Definite Proportions.

_____

_____

17. Determine the mass of chlorine present in your hydrate sample. (Hint: The hydrate contains only copper atoms, chlorine atoms and water molecules.)

18. Calculate the ratio of the number of moles of copper to the number of moles of chlorine in your hydrate. Reduce the ratio to whole numbers.

19. The formula for your hydrate has the form $Cu_xCl_y \cdot zH_2O$. Determine x, y and z in the formula from your answers above and identify your hydrate sample.

Connecting to Theory

John Dalton was an Englishman, a teacher, and an exceptional theoretical chemist. He developed and wrote many postulates of the modern atomic theory at the turn of the 19th century (circa 1803). He was influenced by the experiments of two Frenchmen, Antoine Lavoisier and Joseph Louis Proust.

A fundamental component of the modern atomic theory is that the mole ratios of elements in a compound will be small whole numbers (the Law of Definite Proportions). The whole-number mole ratio is commonly referred to as the *empirical formula* of a compound.

One of the challenges in finding the proper chemical formula for a compound is the possibility of more than one plausible mole ratio for the elements in that compound. Dalton called this the Law of Multiple Proportions. For example, when testing a compound that contained iron and sulfur, the plausible chemical formula could be FeS or Fe_2S_3. However, once the mass of iron and the mass of sulfur present in a given mass of the compound are determined, the true chemical formula of the compound can be established.

Applying Your Knowledge

1. The student has a combination of iron and oxygen.

   a) What are the possible formulas for the compound?
   FeO and Fe_2O_3

   b) The student obtained the following information regarding the compound. Based on this information, which compound is it?

Item	
Total mass of sample	1.50 g
Grams of iron	1.05 g
Grams of oxygen	0.45 g

8. MEASURING VITAMIN C—A REDOX TITRATION

Initial Question

Vitamin C, also called *L-ascorbic acid*, is found in many foods. Most people expect orange juice to be the best source of vitamin C but other berries have a higher vitamin C content and juice drinks like Hi-C® have a great deal of added vitamin C. In these cases, it is difficult to perform a traditional acid–base titration because there may be more than one acid present. How can we accurately measure the vitamin C content present in foods?

What foods have the highest levels of vitamin C?

Materials and Equipment

Model 1

- Data collection system
- Oxidation reduction potential (ORP) probe
- Beaker (5 for the entire class), 250-mL
- Beaker, 150-mL
- 0.25 % Iodine (I_2) solution, 50 mL for entire class
- 0.01 M L-Ascorbic acid ($C_6H_8O_6$), 50 mL for the entire class
- 3% Hydrogen peroxide (H_2O_2), 50 mL for entire class
- 0.01 M Potassium permanganate ($KMnO_4$), 50 mL for the entire class
- 1.0 M Sodium chloride (NaCl), 50 mL for the entire class
- Distilled water, 50 mL

Model 2 and Applying Your Knowledge

- Data collection system
- Oxidation reduction potential (ORP) probe
- Drop counter
- Drop dispenser:
  Syringe, 60-mL
  Stopcock (2)
  Drop tip
- Multiclamp
- Three-finger clamp
- Ring stand
- Beaker, 150-mL
- Magnetic stir plate and micro stir bar
- Analytical balance
- Materials for drop counter and pH sensor calibration (refer to Appendix A)

Model 2

- 0.25 % Iodine (I_2) solution, 70 mL[1]
  L-Ascorbic acid ($C_6H_8O_6$), 0.040–0.060 g
- Distilled water, 75 mL

Applying Your Knowledge

- 0.25 % Iodine (I_2) solution, as needed
- Foods or juices for vitamin C analysis
- Juicer
- Knife (for slicing fruit)

Safety

Add these important safety precautions to your normal laboratory procedures:

- $KMnO_4$ is a strong oxidizer and should be treated as particularly hazardous. If the solution comes in contact with your skin, rinse immediately with a large amount of running water.

Getting Your Brain in Gear

1. Without consulting your textbook or the Internet, give your best definition of the word "titration."

_____

_____

_____

2. The equation for the reaction between elemental iodine and vitamin C, $C_6H_8O_6$, is

$$I_2(aq) + C_6H_8O_6 \rightarrow 2HI + C_6H_6O_6$$

   a. What are the oxidation states of iodine on both sides of the equation?

_____

_____

   b. Is I_2 oxidized or reduced in this reaction?

_____

   c. Write the half-reaction for I_2 in this oxidation–reduction (or redox) reaction.

_____

   d. Given your answer to part b, is vitamin C oxidized or reduced during this reaction? Briefly explain your answer.

_____

_____

_____

MODEL 1

Building Model 1 – Measuring the Oxidation Reduction Potential of a Solution

1. Connect the oxidation reduction potential probe (ORP) to your data collection system.

2. The ORP probe measures ISE voltage. Monitor live ISE voltage data without recording.

3. Use the ORP probe to measure the oxidation reduction potential following solutions: $KMnO_4$, H_2O_2, vitamin C, NaCl and distilled H_2O. Rinse the probe with distilled water between each measurement. Record the potential in the Model 1 Data Table.

Model 1 – Measuring the Oxidation Reduction Potential of a Solution

Table 1: Model 1 Data Table—Oxidation reduction potential of various solutions

Solution	Oxidation–Reduction Potential (ISE, mV)	Oxidizer (Strong/Not Strong)
I_2 (aq)		
Vitamin C(aq)		
H_2O_2 (aq)		
$KMnO_4$		
NaCl(aq)		
Distilled H_2O		

Analyzing Model 1 – Measuring the Oxidation Reduction Potential of a Solution

4. What solutions in the Model 1 Data Table would you group together as having high oxidation reduction potentials and which would you group together as having low potentials?

_____

_____

5. Potassium permanganate, $KMnO_4$, and hydrogen peroxide, H_2O_2, are both strong oxidizers. This means that they often cause other compounds to be oxidized while they are reduced. Strong oxidizers are highly reactive with other compounds, must not be ingested, and must be stored carefully. Vitamin C and water are not strong oxidizers.

   a. You should see a pattern between the oxidation reduction potential and oxidation strength of the solutions mentioned. Using this pattern, indicate in the Model 1 Data Table whether each solution is a strong oxidizer "s" or not a strong oxidizer "ns".

      NOTE: Strong oxidizers are greater than 250 mV.

b. Based on this information, what is the ORP probe actually measuring?

_____

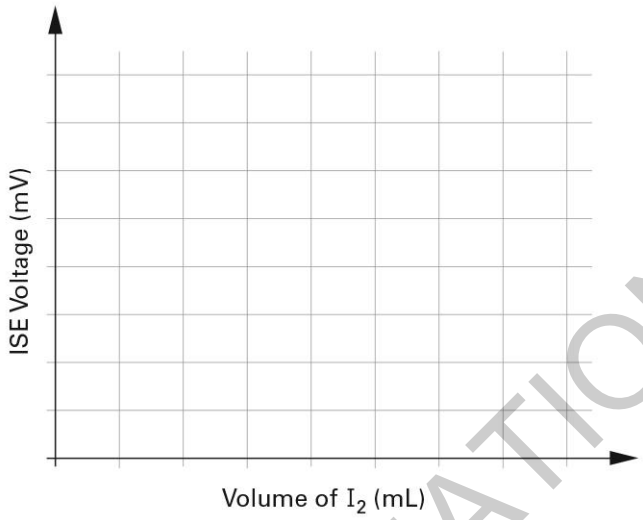
_____

6. Is aqueous sodium chloride a strong oxidizer? Does this make sense with what you know about NaCl?

_____

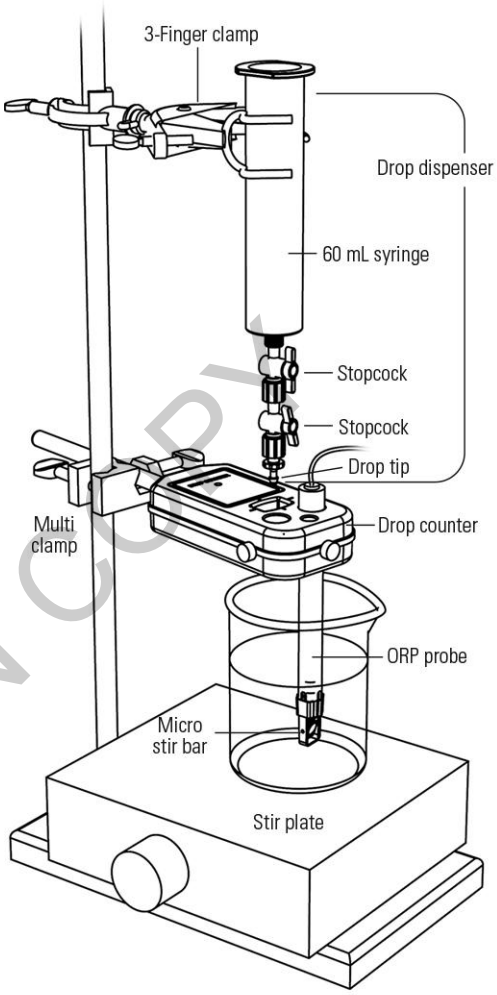
_____

7. Model 2 involves adding iodine, I_2, solution to the vitamin C solution until all of the vitamin C is consumed. On the blank graph below, sketch your prediction for the shape of the graph of ISE voltage versus the volume of iodine added to the vitamin C solution.



MODEL 2

Building Model 2 – Reacting Vitamin C with Iodine



1. Obtain about 60 mL of iodine solution in a beaker.

2. Obtain a drop dispenser and a drop counter. Set up the drop counter as shown in the diagram.

3. Connect the drop counter to the data collection system.

4. Display ISE voltage on the *y*-axis of a graph and fluid volume on the *x*-axis.

5. Rinse the drop dispenser three times with 2 to 3 mL of distilled water and then rinse it three times with 2 to 3 mL of I_2 solution.

6. Fill the drop dispenser with the I_2 solution.

7. Set the flow rate of the drop dispenser and calibrate the drop counter as described in Appendix A.

   NOTE: Do not disconnect the drop counter from the data collection system or it will need to be calibrated again.

8. Obtain between 0.040 and 0.060 g of L-ascorbic acid, vitamin C, and dissolve it in about 75 mL of distilled water in a 150-mL beaker. Record the exact mass of L-ascorbic acid in the Model 2 Data Table below.

   NOTE: If you are using vitamin C tablets rather than L-ascorbic acid, make sure to convert the mass of the tablet measured to the mass of vitamin C, as vitamin C tablets contain binders and other inert ingredients which will not interfere with the titration but do add mass.

9. Obtain a stir plate and stir bar. Add the stir bar to the beaker containing the vitamin C solution. Turn on the magnetic stirrer at a slow and steady rate.

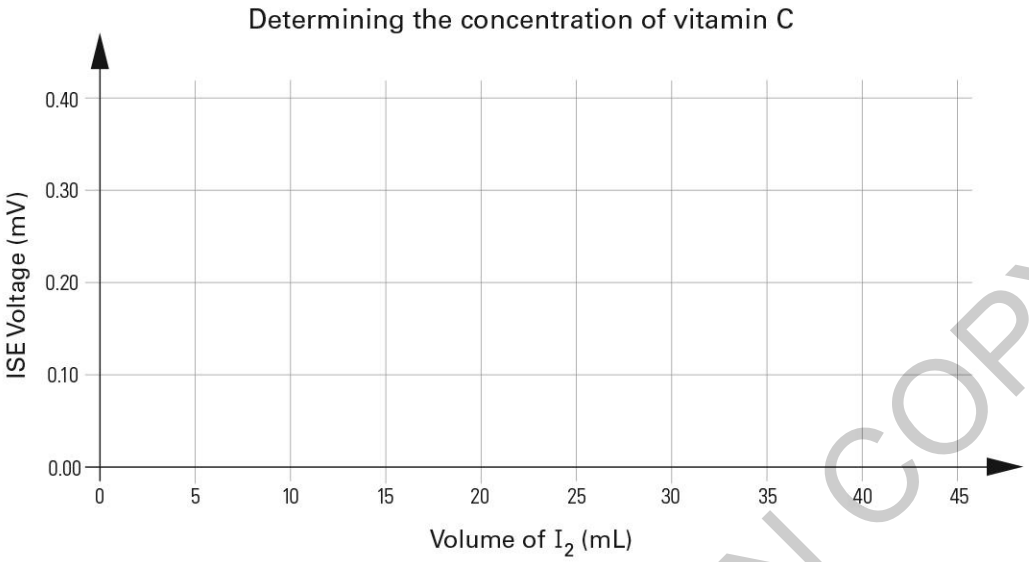
10. Start recording data. Turn the drop dispenser stopcock carefully, allowing the I_2 solution to drip slowly at a rate of 1 to 2 drops per second into the vitamin C solution.

    NOTE: The top valve controls the flow rate and the bottom valve turns the flow on and off.

11. Sketch or attach a copy of the graph of ISE voltage versus volume of $KMnO_4$ in the Model 2 data section.

Model 2 – Reacting Vitamin C with Iodine

Mass of vitamin C: _____



Analyzing Model 2 – Reacting Vitamin C with Iodine

12. a. Does your observed graph match your predicted graph? Explain any differences.

_____

_____

_____

b. What type of graph does your data resemble?

_____

_____

13. As you have probably guessed by now, the experiment you just conducted was a titration.

a. Does this experiment fall under the definition of "titration" you gave in the "Getting Your Brain in Gear" question?

_____

b. Revise your definition of titration based on your experience in lab. Avoid using any reference to color changes or the equipment you use.

_____

_____

_____

14. At what volume of I_2 is all of the vitamin C consumed? How does the graph indicate this?

_____

_____

15. Using the measured mass of vitamin C, calculate the following:

    a. The number of moles of iodine necessary to react completely with the vitamin C.

    b. The molarity of the iodine solution.

16. Collect the molarity of I_2 from other groups.

Table 2: Compare class results of the molarity of the iodine solution

Group	I_2 Concentration (M)
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	

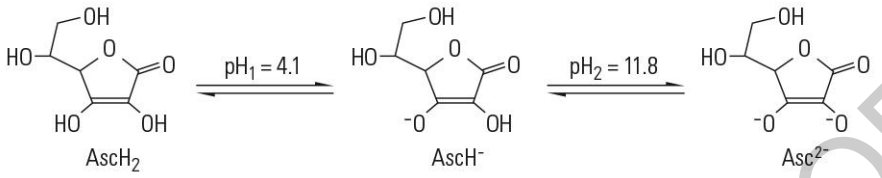
    a. Calculate the standard deviation.

b. Remove molarities that are outside of the standard deviation and then calculate the average concentration. You will use this value for the calculations for the Applying Your Knowledge experiment. This process of determining the concentration of a solution to be used in a later experiment is called *standardization*.

Average molarity of the I_2 standard solution : _____

Connecting to Theory

Vitamin C functions as an anti-oxidant in humans. This means that it causes reduction to occur in other substances. However it only displays weak anti-oxidant abilities, and like weak acids and bases, the oxidation reduction potential of vitamin C is reversible. The anti-oxidant reversibility is a function of pH.



The illustration is a simplified version of the pathway the ascorbate ion undergoes. Eight forms of the ion have been categorized. But as you can see, there are two major changes, one at pH of 4.1 and one at pH 11.8. The middle figure is dominant at pH 7.4. The ability of vitamin C to cause reduction makes it an ideal candidate for ORP titration.

Applying Your Knowledge – Determining the Concentration of Vitamin C in Juice

1. Design an experiment that uses the standardized iodine solution from Model 2. Create a hypothesis you will test related to the vitamin C content of available materials.

2. Once you know what materials are available, answer the following questions *before* beginning the experiment.

   a. What hypothesis would you like to test?

_____

_____

_____

   b. What data will you need to collect?

_____

_____

_____

   c. What conditions will need to be held constant between your two titrations?

_____

_____

_____

3. Outline the procedure of your experiment.

4. Carry out the experiment to test your hypothesis. Record your data. Modify the data table as needed.

Molarity of I_2: 0.0119 M

Table 3: Data Table

5. Provide calculations for your experiment that either prove or disprove your hypothesis.

6. Compare your experiment to others in class. How could your experiment have been improved?

7. Vitamin C is an acid. Why was it necessary in this lab to use the ORP probe rather than the pH sensor?

_____

_____

_____

9. FACTORS THAT AFFECT REACTION RATE

Initial Question

In some cases we want reactions to proceed quickly, for example, for air bag deployment or certain processes used in manufacturing. In other cases, we want reactions to proceed slowly, such as the corrosion of car parts or aging. Scientists have discovered many factors, or variables, that can be manipulated to change the rate of a reaction. In this investigation, you explore one factor that may alter the rate of a reaction and share what you've found with your classmates.

How can we speed up or slow down a chemical reaction?

Materials and Equipment

Model 1 and Model 2

- Data collection system
- Temperature sensor
- Pressure sensor
- Quick-release connector
- Tubing, 1- to 2-cm
- Tubing connectors
- Two-hole stopper to fit flask
- Erlenmeyer flask, 125-mL
- Graduated cylinder, 50-mL
- Syringe, 60-mL
- Mortar and pestle

Model 1

- Calcium carbonate ($CaCO_3$), solid, 0.2 g
- 3.0 M Hydrochloric acid (HCl), 1 mL
- Distilled water, 50 mL

Model 2

- Equipment and amounts depend on the variable:
- Beaker for ice bath
- Beaker (4), 50-mL
- Graduated cylinder, 10-mL
- Magnetic stir bar
- Stir plate
- Hot plate
- Calcium carbonate ($CaCO_3$)
- 3.0 M Hydrochloric acid (HCl)
- Ice
- Distilled water

Safety

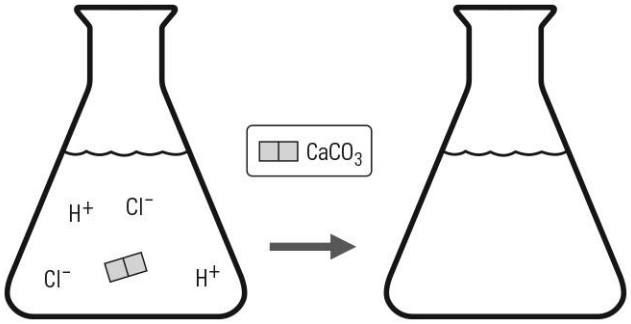
Add these important safety precautions to your normal laboratory procedures:

- Treat all unknowns as a hazardous, toxic, and harmful material.
- All unknowns will need to be disposed of in the proper waste container.
- Hydrochloric acid is highly corrosive; it will damage human tissue and clothing. If you get hydrochloric acid on your skin, flush the area with large amounts of water.

Getting Your Brain in Gear

1. In this lab, you will be mixing calcium carbonate solid with a solution of hydrochloric acid. Write a balanced equation for the reaction that will occur. Include phase notation.

2. Draw a particle-level representation diagram of the balanced equation.



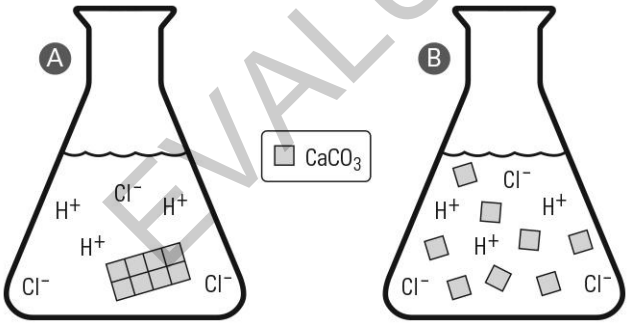
3. Gas pressure is defined as a collision of gas particles. Do the reactants or the products have more gas pressure?

_____

4. What particles are colliding to make the reaction progress?

_____

5. Which of the following would have more collisions? Justify your answer.



_____

_____

_____

MODEL 1

Building Model 1 – The Change in Pressure during a Reaction

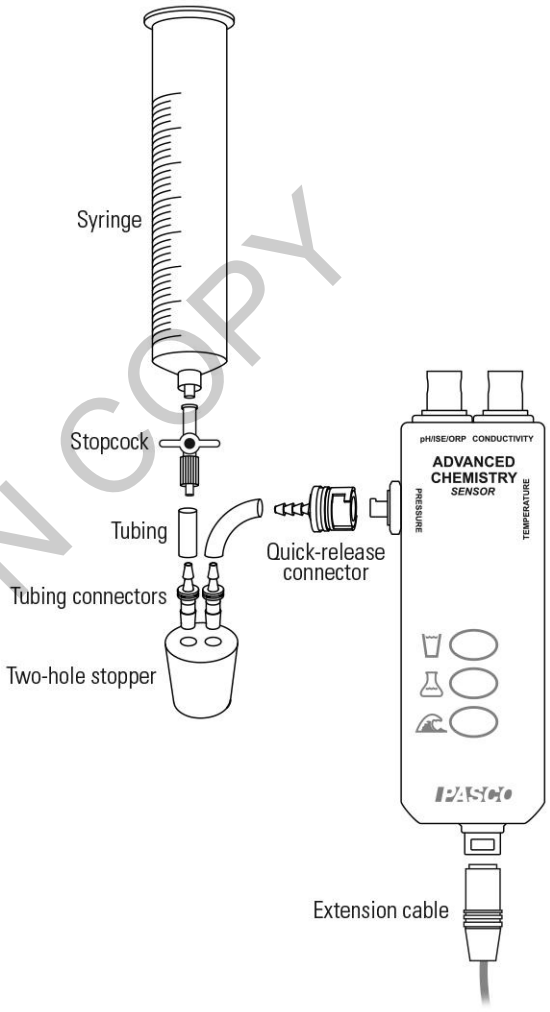
1. Prepare the reaction apparatus by completing the following steps.

   a. Connect the pressure sensor to the two-hole stopper: place the barbed connector of the pressure sensor tightly into the rubber stopper and connect it to the pressure port of the sensor with a piece of tubing.

   b. Connect the syringe to the stopcock connected to the other hole of the two-hole stopper. Close the stopcock.

   c. Place the two-hole stopper tightly into the 125-mL Erlenmeyer flask.

   d. Check for leaks in the system by opening the stopcock, pulling up on the syringe, and holding for 10 seconds. Then release the plunger of the syringe. It should return to its original position if there are no leaks.



2. Connect the pressure sensor and temperature sensor to the data collection system and start a new experiment. Display the pressure on the *y*-axis of a graph and time on the *x*-axis

3. Break off a small piece of white chalk (which is primarily calcium carbonate) and use the mortar and pestle to crush it into a fine powder. Measure approximately 0.2 g of the chalk powder. Record the mass in the Model 1 Data Table. Transfer the calcium carbonate sample to the 125-mL Erlenmeyer flask quantitatively.

4. Add 50 mL of distilled water to the Erlenmeyer flask, reinsert the stopper into the flask, and check again for leaks.

5. Close the stopcock and remove the syringe. Remove the plunger and place 1.0 mL of 3.0 M hydrochloric acid (HCl) into the syringe, keeping the syringe horizontal so the solution doesn't spill out. Replace the plunger and return the syringe to the reaction apparatus by twisting it gently back onto the stopcock.

   NOTE: Because of the short tubing, the syringe sits vertically above the flask.

6. Begin data collection. Record the pressure in the Erlenmeyer flask for 10 seconds.

7. At the ten second mark open the stopcock. If the contents of the syringe do not completely empty into the reaction flask, apply gentle pressure to the plunger. Once this transfer has occurred, quickly close the stopcock once again.

8. Gently swirl the flask while collecting data for at least 5 minutes.

9. Record the room temperature in the Model 1 Data Table after converting it to Kelvin.

10. Which of the following gases are in the flask in quantities greater than or equal to at least ~1% before the HCl is introduced?

Nitrogen	Oxygen	Argon	Chlorine
Carbon dioxide	Water vapor	Hydrogen	Carbon monoxide

_____

11. Which of the gases are in the flask after the reaction has occurred?

_____

12. Explain why the pressure is increasing in the flask during the reaction. Support your answer with concepts from the kinetic molecular theory.

_____

_____

_____

13. Use the time versus pressure graph to determine the pressure in the flask at 10 seconds and at 3 minutes. Record these values in the Model 1 Data Table.

Model 1 – The Change in Pressure during a Reaction

Table 1: Model 1 Data Table—Reaction measurements and results

Parameter	Value
Volume of reaction vessel (mL)	
Mass of chalk ($CaCO_3$) (g)	
Volume of 3.0 M HCl (mL)	
Pressure of gas at 10 sec (kPa)	
Pressure of gas at 3 minutes (kPa)	
Room temperature	

Analyzing Model 1 – The Change in Pressure during a Reaction

14. Calculate the partial pressure of carbon dioxide in the flask at 3 minutes. Assume there was no carbon dioxide in the flask before the reaction.

15. Calculate the number of moles of carbon dioxide in the flask at 3 minutes using the Ideal Gas Law.

    NOTE: Some of the flask volume was occupied by liquid and solid. Assume the volume of the gas is the same as the Erlenmeyer flask 125 mL, or 0.125 L.

16. Calculate the rate of reaction with respect to the production of carbon dioxide for the trial in Model 1.

17. Compare your rate to that of other groups. Is there appreciable difference in the rates? What should be done if a lab group has data that is very different from the rest of the class?

_____

_____

MODEL 2

Building Model 2 – Factors That Affect Rate

1. List at least five variables that could be tested with the same reaction system as Model 1 to determine if they affect the rate of the reaction. Be prepared to share your list with the class.

_____

_____

_____

2. Your instructor will assign a variable for you to test using the reaction system in Model 1. Develop a procedure for a controlled experiment to test that variable. You will need at least four trials. Record your procedure below and design the Model 2 Data Table.

   List the variable(s) in each category for the lab procedure you develop:

   Independent: _____

   Dependent: _____

   Controlled: _____

Procedure:

3. Calculate the rate of reaction for each trial. Use the calculations you performed in Model 1 as an example.

4. In the Model 2 data section, sketch or attach a copy of your graph that shows the relationship between the rate of reaction and your independent variable. Be prepared to share your findings with the class.

Model 2 – Factors That Affect Rate

Model 2 Data Table:

Analyzing Model 2 – Factors That Affect Rate

5. As your classmates summarize their findings, fill in the following relationships. The first blank is for the independent variable. The second blank should be "increased," "decreased," or "stayed the same."

Observations:

A: As _____ increased, the rate of reaction _____

B: As _____ increased, the rate of reaction _____

C: As _____ increased, the rate of reaction _____

D: As _____ increased, the rate of reaction _____

E: As _____ increased, the rate of reaction _____

F: As _____ increased, the rate of reaction _____

G: As _____ increased, the rate of reaction _____

Connecting to Theory

A reaction mechanism is a series of chemical reactions that illustrate the actual pathway reactants undergo to become products. This usually involves several steps. When the steps are combined, reactants that appear on opposite sides of the arrows cancel, resulting in the net ionic equation. For example,

1. $CaCO_3(s) + H^+ + Cl^- \rightleftharpoons Ca^{2+} + HCO_3^- + Cl^-$
2. $HCO_3^- + H^+ + Cl^- \rightleftharpoons CO_2(g) + H_2O + Cl^-$

Net ionic equation: $CaCO_3(s) + 2H^+ \rightleftharpoons CO_2(g) + H_2O + Ca^{2+}$

One of the steps usually takes significantly more time to complete than the others. The slower step is known as the *rate determining* step. It is so slow compared to the others that we consider it to take all of the reaction time and the other steps to take no time at all.

The order of the reaction is determined by the slow step. If step 1 in this example is the rate determining step, then the reaction is first order with respect to both $CaCO_3$ and HCl, represented as $H^+ + Cl^-$, because one $CaCO_3$ molecule is reacting with one HCl molecule. However if step 2 is the rate determining step, the reaction is zero order with respect to $CaCO_3$ because it does not appear in that step and first order with respect to HCl because one HCl molecule is present.

This reaction is convenient for laboratory use but difficult to use when writing a rate law because $CaCO_3$ is a solid. The rate law is in the form: Rate = $k[a]^m[b]^n$, where "k" is the rate constant, "a" and "b" are the reacting species and "m" and "n" are the respective reaction orders. The brackets refer to the concentration of the reactant.

Since $CaCO_3$ is a solid, it cannot have a concentration. The value for $CaCO_3$ does not appear in the rate law. It becomes incorporated into the rate constant.

Applying Your Knowledge – Analyzing Model 2

The reactants in a reaction mechanism must collide before they can become products. Chemists use the Collision Theory to explain observations related to reaction rate and to predict how certain variables might alter the rate of a reaction. The Collision Theory states:

- For a reaction to occur, reactant particles must collide.
- For a reaction to occur, the particles in the collision must have sufficient energy to overcome the activation energy for the reaction.
- For a reaction to occur, the particles in the collision must be oriented correctly.

1. If a collision between reactant particles is required for a reaction, what should happen to the rate of reaction if the number of collisions per second is increased?

_____

_____

2. Which of the variables tested in this lab would affect the number of collisions per second between reactant particles?

_____

_____

_____

3. Refer to Model 2. Do the observations made in the lab support or refute your answer to the previous question? List specific examples and discuss any discrepancies.

4. If the particles in a reaction have sufficient energy for a collision to be successful, what should happen to the rate of reaction if the average kinetic energy of the system is increased?

5. Which of the variables tested in this lab would affect the average kinetic energy of the system?

6. Do the observations made in Model 2 support or refute your answer to the previous question? List specific examples and discuss any discrepancies.

7. Were there any variables tested in Model 2 that affected the rate and were not discussed in previous questions? If yes, propose how the variable tested relates to the collision theory and therefore affects the rate of reaction.

10. MEASURING THE SPEED OF A REACTION

Initial Question

You have seen instructions on bottles of medicine instructing you, for example, to take "two capsules every four hours." How do scientists come up with how often to take a medication? The answer is that they have done experiments that quantify how quickly the medicine is metabolized by the body. In other words, they develop equations that predict how long it will be before the concentration drops too low to have an effect on your symptoms. Such problems require scientists to make quantitative predictions, that is, to find an equation for the reaction.

How do you determine the speed of a reaction?

Materials and Equipment

Model 1

- Data collection system
- Colorimeter
- Cuvette
- Test tubes (2), 20- to 25-mL
- Volumetric pipets (2), 10-mL
- Beaker, 50-mL
- 5.0×10^{-3} M Crystal violet ($C_{25}H_{30}N_3Cl$), 10 mL
- 0.2 M Sodium hydroxide (NaOH), 10 mL
- Distilled water for calibration, about 10 mL
- Kimwipes®

Model 2

- Data collection system
- Colorimeter
- Cuvette
- Temperature sensor
- Beakers (2), 50-mL
- Beakers (2), 400-mL
- Volumetric pipets (2), 10-mL
- 0.2 M Sodium hydroxide (NaOH), 40 mL
- 5.0×10^{-3} M Crystal violet ($C_{25}H_{30}N_3Cl$), 40 mL
- Hot plate
- Ice
- Distilled water for calibration, about 10 mL
- Kimwipes®

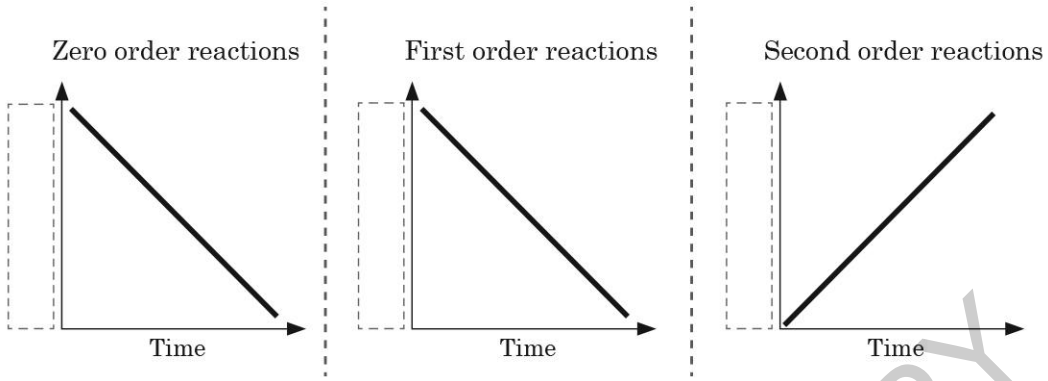
Safety

Add these important safety precautions to your normal laboratory procedures:

- Sodium hydroxide is caustic and should be handled with special care. In case of contact with your skin, wash off the sodium hydroxide with a large amount of water.
- Crystal violet will stain skin and clothing, so be cautious in handling.

Getting Your Brain in Gear

1. Fill in the *y*-axis label that will result in a linear relationship for each order of reaction.



2. The compound *crystal violet* has a purple color in an aqueous solution. When it reacts with sodium hydroxide, crystal violet fades to colorless.

$$\underset{\text{(Purple)}}{C_{25}H_{30}N_3Cl(aq)} + OH^-(aq) \rightarrow \underset{\text{(Colorless)}}{(C_{25}H_{30}N_3Cl)OH^-(aq)}$$

   a. What sensor could we use to measure the concentration of the crystal violet over time?

_____

   b. The reaction requires much more sodium hydroxide than crystal violet to react in a reasonable amount of time. The sodium hydroxide solution to be used is about 50,000 times more concentrated than the crystal violet solution. Even if all of the crystal violet is consumed, will the sodium hydroxide concentration change much?

_____

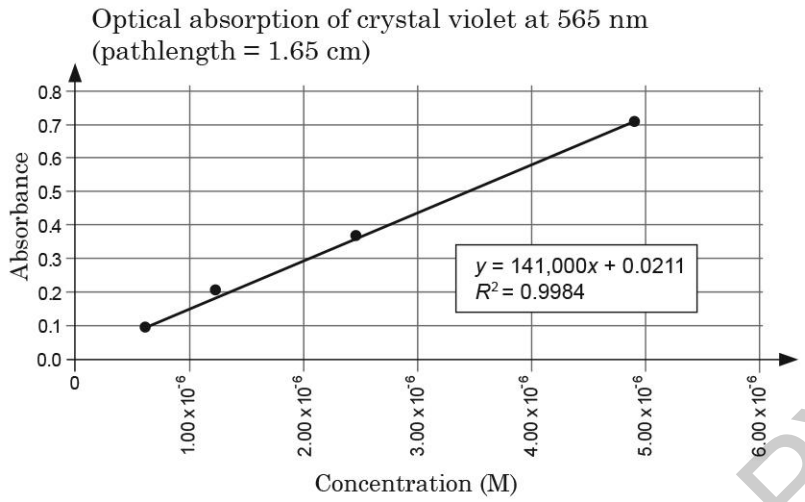
_____

   c. If the sodium hydroxide concentration does not change much, what will the reaction order with respect to sodium hydroxide be?

_____

_____

3. The crystal violet compound is, as the name suggests, a dark blue-purple color in solution. Its absorbance at 565 nm is shown below as a function of concentration.



a. Why was 565 nm (green) light chosen to measure the absorbance?

_____

_____

b. Just using the graph, if you measure the absorbance of a solution to be 0.3, what is the concentration of crystal violet?

_____

c. Use the line of best fit to write an equation relating concentration and absorbance.

NOTE: The equation of the line of best fit is shown in the graph.

d. Solve this equation for the concentration.

e. If the absorbance was found to be 0.95, what is the concentration of crystal violet?

MODEL 1

Building Model 1 – Collecting Kinetics Data

1. Connect the colorimeter to the data collection system.

2. Rinse a cuvette with distilled water and wipe any marks or fingerprints off the outside.

3. To calibrate the colorimeter, fill a cuvette 3/4 full with distilled water and place this in the colorimeter. Push the green oval button on the colorimeter. The button will light up green for several seconds. When the light goes off, make sure that all of the transmittance values have changed to 100% and the absorbance values have changed to 0.00. Repeat the process if needed.

   NOTE: This step tells the colorimeter to record this solution as having zero absorbance. You do not need to repeat this step unless the data collection interface turns off before you collect your data.

4. Obtain two 10 mL volumetric pipets. Pipet 10.00 mL of the crystal violet solution into a test tube and 10.00 mL of 0.20 M NaOH solution into a second test tube.

5. Read this entire step completely before you carry it out.

   a. Pour the crystal violet and sodium hydroxide solutions into a 50-mL beaker and swirl for 5 seconds or until the solution appears homogeneous.

   b. Fill the cuvette about 3/4 full with this solution and cap it. Place it in the colorimeter and start data collection. Collect the data for 3 minutes.

6. Sketch the absorbance versus time data on the Model 1 Graph.

NOTE: You will be using the equipment and the reaction data to make additional calculations, so don't put it away yet.

Model 1 – Collecting Kinetics Data

Model 1 Graph for the crystal violet and sodium hydroxide reaction

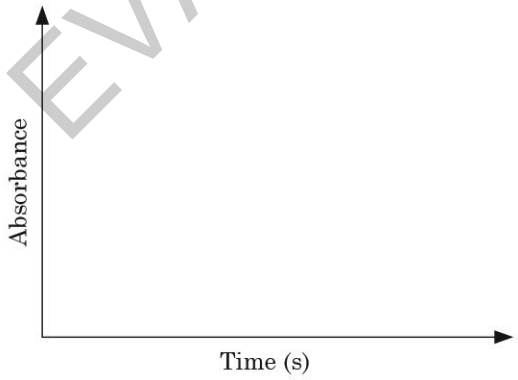


Table 1: Model 1 Data Table—Determining the order of reaction

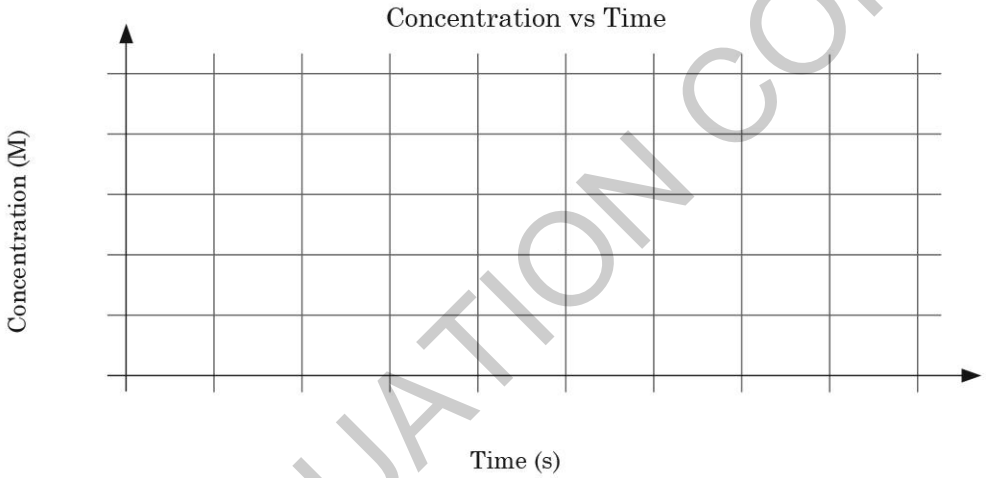
Time (s)	Absorbance Green (565 nm)	Concentration (M) (*a*)	ln(Concentration) (*b*)	1/Concentration (*c*)
0				
10				
20				
30				
40				
50				
60				
70				
80				
90				
100				
110				
120				
130				
140				
150				
160				
170				
180				

Analyzing Model 1 – Collecting Kinetics Data

7. Using the Calculated Data menu on your data collection system, calculate the concentration of crystal violet from the green absorbance. Remember, you must input this as an equation, "concentration = … "

   NOTE: If you are not sure which equation to use, look back at your answer to the Getting Your Brain in Gear questions that relates the concentration of crystal violet to absorbance.

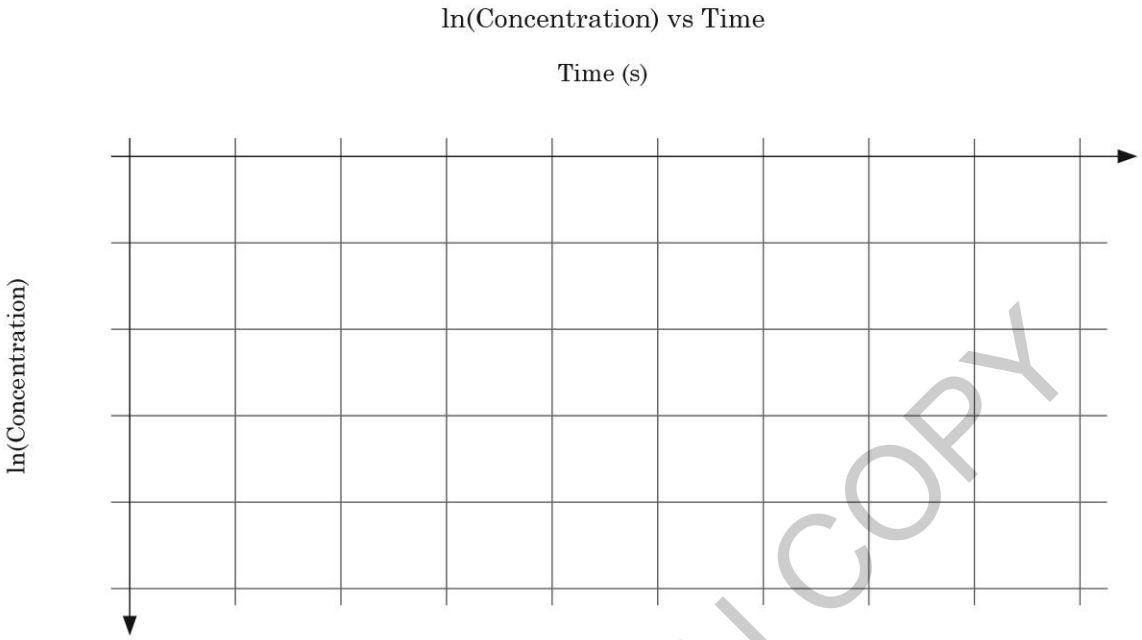
8. Sketch or attach a copy of your graph of concentration (call this *a*) versus time and record or attach the values in the Model 1 Data Table. Can you, by visual inspection alone, determine the order of the reaction? Why or why not?



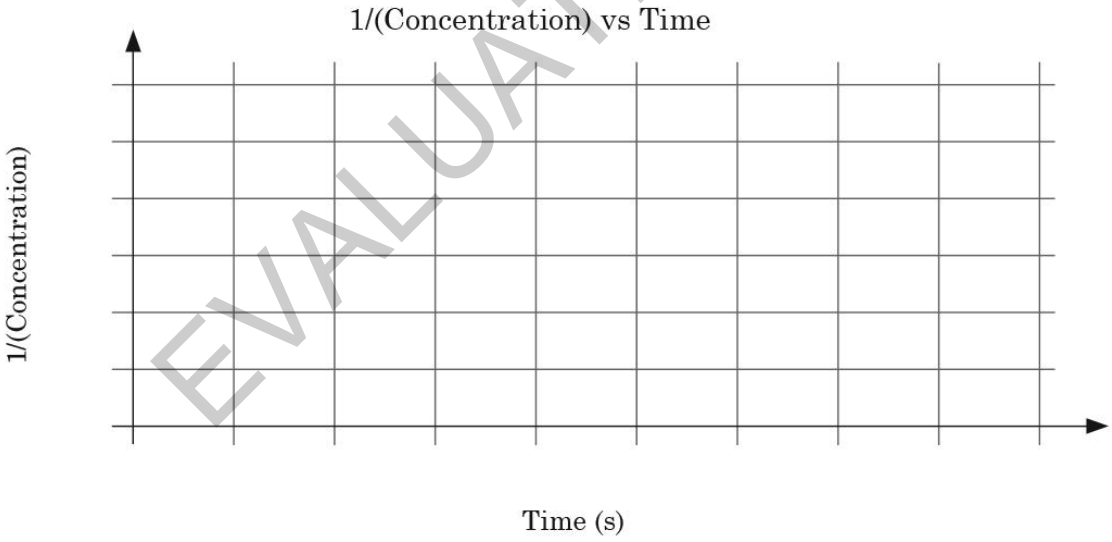
9. Using the Calculated Data menu, calculate the natural log (ln) of the concentration (call this *b*) and the inverse of the concentration (1/Concentration). Call this *c*. Record or attach the values for *b* and *c* in the Model 1 Data Table.

10. Graph the ln(concentration) versus time. Does this appear to be a straight line?

NOTE: Add a line of best fit and use the R^2 *value (coefficient of determination) to determine which curve is the most linear, indicated by the value closest to one.*



11. Graph the inverse of the concentration versus time. Does this appear to be a straight line?



12. Based on the line of best fit, what is the value of the rate constant k for this reaction?

13. Based on your answer to the previous question, write the integrated rate law for the crystal violet (CV) + sodium hydroxide reaction.

14. Based on your equation and the value of k, at what time after the reaction started would the concentration drop from the initial concentration of 5.0×10^{-6} M to 5.0×10^{-7} M?

15. How does temperature affect the rate of a reaction? Does the temperature of the experiment appear in the integrated rate law?

_____

_____

MODEL 2

Building Model 2 – Testing the Effect of Temperature on the Rate Constant

In this model, create an experiment in which you determine if the rate law and rate constant are affected by the temperature.

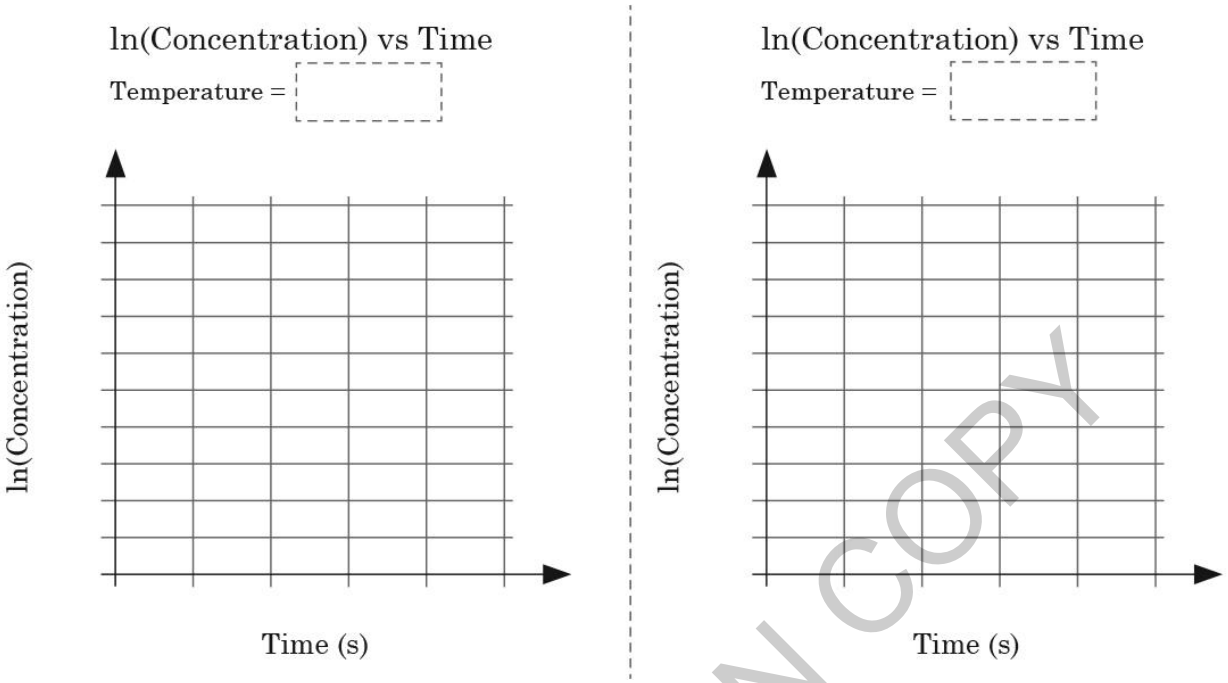
A few things to think about: What are appropriate (and safe) temperatures to use? Will using temperatures 10 °C apart be sufficient to tell if there is an effect? Will your data be more definitive if you choose a larger temperature range or a shorter range? How will you raise or lower the temperature of your solution from room temperature? How will you know the temperature of your solutions?

Conduct measurements using at least two different temperatures.

Collect and analyze the data on the data collection system. When you finish, draw sketches of your most linear graphs that show how the rate law and rate constant are affected by temperature.

Model 2 – Testing the Effect of Temperature on the Rate Constant

Model 2 Graphs of reactions carried out at different temperatures



Analyzing Model 2

1. Which temperature caused the fastest reaction?

_____

2. Which temperature produced the greatest slope?

_____

3. What is the rate law constant for each temperature?

_____

_____

4. Is the rate constant affected by temperature?

_____

_____

Connecting to Theory

Svante Arrhenius suggested that chemical reactions need a certain amount of energy to get started. This energy is required to break bonds and align particles so that they are in the proper orientation for new bonds to form in the products. This energy is called the *activation energy* and is symbolized as E_a.

He realized that to calculate the Activation Energy, the reaction would have to be performed at two different temperatures, T. It would also require two rate constants, k_1 *and* k_2 that corresponds to the temperatures. His equation is listed below.

$$\ln\left(\frac{k_2}{k_1}\right) = \left(\frac{E_a}{R}\right)\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

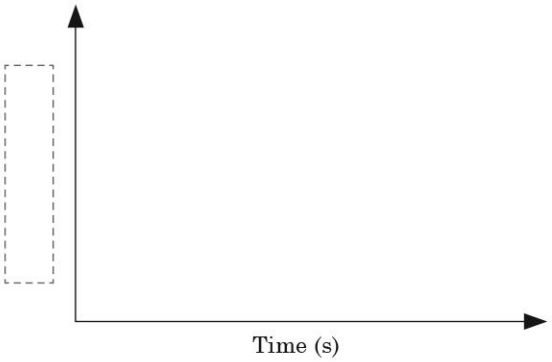
The R in the equation is the gas constant, $8.31\frac{\text{J}}{\text{K mol}}$. Calculate the activation energy from your data in Model 2.

Applying Your Knowledge

Consider the redox reaction between potassium permanganate and sodium oxalate. The net ionic reaction is

$$2MnO_4^-(aq) + 5C_2O_4^-(aq) + 16H^+(aq) \rightarrow 2Mn^{2+}(aq) + 8H_2O(l) + 10CO_2(g)$$

This reaction is used to titrate for oxalate, but for that purpose it is conducted at 60 °C, where it reacts very quickly. At room temperature the reaction is slow and the kinetics can be measured. However, the potassium permanganate is too dark at the relevant concentrations to measure the reaction progression with colorimetry. Suggest what sensor (or sensors) you might use instead to measure this reaction. What might the data you collect from that sensor look like?



11. ENERGY IN CHEMICAL REACTIONS

Initial Question

The First Law of Thermodynamics states that energy is neither lost nor gained in a chemical process. This is paraphrased as "energy is conserved." Reactions that release energy are known as exothermic reactions. Reactions that absorb energy are endothermic reactions.

The amount of heat energy involved in a process is referred to as *enthalpy*. Although the amount of enthalpy cannot be measured directly, scientists can determine how much it changes. In this lab, you will use the First Law of Thermodynamics to determine the change of energy in various reactions and combine the results to determine the enthalpy change of a related reaction.

How do you find the change of enthalpy in chemical reactions?

Materials and Equipment

Calorimeter for Model 1, Model 2, Model 3, and Applying Your Knowledge

- Data collection system
- Stainless steel temperature sensor
- Polystyrene cup, 8 oz
- Ring stand
- Beaker, 250-mL
- Clamp, utility
- Graduated cylinder, 50-mL or 100-mL
- 10 cm × 10 cm cardboard lid

Model 1

- Ammonium nitrate (NH_4NO_3), solid[1]
- Distilled water[1]

[1]The mass and volume needed depend on the reaction assigned to your group.

Model 2

- 1.0 M Sodium hydroxide (NaOH), 100 mL
- 1.0 M Hydrochloric acid (HCl), 100 mL
- Distilled water, 100.0 mL

Model 3

- 1.0 M Sodium hydroxide (NaOH), 100 mL[1]
- 1.0 M Hydrochloric acid (HCl), 100 mL[1]
- Sodium hydroxide (NaOH), 4.0 g

[1]The solution and volume needed depend on the reaction assigned to your group.

Applying Your Knowledge

- 2.0 M Hydrochloric acid (HCl), 100 mL
- Magnesium ribbon (Mg), about 0.5 g

Safety

Add these important safety precautions to your normal laboratory procedures:

- Do not touch the solid NaOH and handle its resulting solution with care. NaOH is caustic and will cause skin burns and burn holes in clothing.
- When NaOH or HCl solutions come in contact with your skin or eyes, rinse immediately with a large amount of running water.

Getting Your Brain in Gear

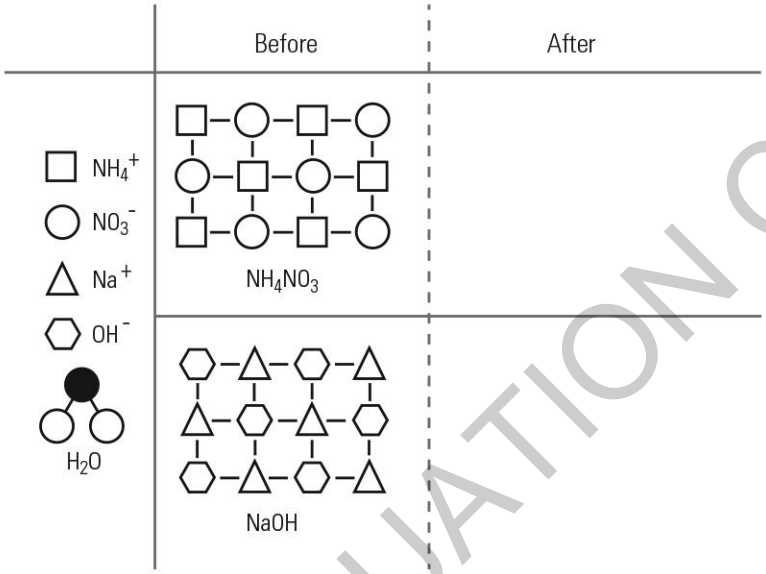
1. A coffee cup calorimeter will be used to measure the heat of reaction (enthalpy of reaction) of several different reactions. The coffee cup minimizes, but does not eliminate, heat transfer with the surroundings. If the temperature of the room was 22.00 °C on the day of the experiment, what transfer of heat will take place between the solution and room, based on the temperature of the solution?

_____

_____

2. Samples of solid ammonium nitrate and sodium hydroxide are depicted below.

   a. Draw the changes that take place when the following compounds dissolve in water.



   b) Describe the changes to the intramolecular forces holding the components together when each salt is dissolved in water.

_____

_____

_____

3. The reaction below is exothermic. What must be true about the total energy in the bonds of the reactants as compared to the total energy of the bonds in water? The formula for the *heat of reaction* is $\Delta H_{rxn} = \Sigma\Delta H_{products} - \Sigma\Delta H_{reactants}$.

$$2H_2\,(g) + O_2\,(g) \rightarrow 2H_2O\,(l) \qquad \Delta H = -285.8\ kJ$$

_____

_____

4. In science, there is no such thing as negative energy but when we calculate the heat energy absorbed or released by a chemical reaction using the equation $q = mc\Delta T$, the temperature change is calculated as $T_{final} - T_{initial}$. When a chemical reaction causes a solution to cool, the change in temperature is negative ($T_{final} < T_{initial}$) and the resulting value of q is negative. q is assigned an artificial negative sign to force a relationship with ΔH. What is the relationship between the algebraic sign of q and the algebraic sign of ΔH?

_____

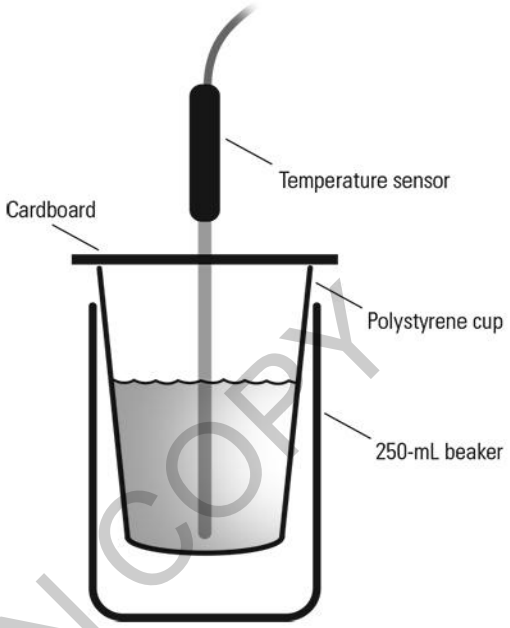
_____

_____

MODEL 1

Building Model 1 – Dissolution of NH_4NO_3

1. Start a new experiment on the data collection system.
2. Connect a temperature sensor to the data collection system.
3. Create a graph display of temperature (°C) versus time (s).
4. Place the polystyrene cup in the 250-mL beaker.
5. Mount the temperature sensor on the ring stand and set it into the cup so it is about half an inch from the bottom.



6. How will placing the cup in a beaker help improve the accuracy of temperature measurements?

_____

_____

_____

7. Check with your teacher to determine which reaction you will carry out.

Table 1: Reactant volumes for Model 1 reactions

Reaction	Mass of NH_4NO_3 (g)	Volume of Water (mL)
A	2.00	50.0
B	2.00	100.0
C	4.00	50.0
D	4.00	100.0
E	6.00	50.0
F	6.00	100.0

8. Rinse the graduated cylinder with deionized water.
9. Measure the amount of water specified in Table 1 for your reaction. Record the volume in the Model 1 Data Table and then pour the water into the calorimeter.
10. Measure the solid reactant and record the mass to at least the nearest 0.01 g in the Model 1 Data Table.
11. Start recording data.
12. When the temperature readings stabilize, carefully transfer the solid reactant into the calorimeter. Swirl the calorimeter gently to stir.
13. When the temperature readings stabilize again, stop recording data.

14. Dispose of the solution properly, wash the cup and graduated cylinder, and rinse them with deionized water.

15. Repeat the procedure to verify your result.

16. Determine the temperature change for each data run and record it in the Model 1 Data Table.

17. Save your experiment and clean up according to your teacher's instructions. Then exchange data with your classmates and enter it into the Model 1 Data Table.

Model 1 – Dissolution of NH_4NO_3

Table 2: Model 1 Data Table—Determining the heat of reaction for the dissolution of NH_4NO_3

Reaction		Mass of NH_4NO_3 (g)	Volume of Water (mL)	ΔT (°C)	Heat *q* Gained or Lost, (kJ)	Number of Moles of NH_4NO_3 (mol)	ΔH_{rxn} (kJ/mol)	Average ΔH_{rxn} (kJ/mol)
A	Run 1							
	Run 2							
B	Run 1							
	Run 2							
C	Run 1							
	Run 2							
D	Run 1							
	Run 2							
E	Run 1							
	Run 2							
F	Run 1							
	Run 2							

Analyzing Model 1 – Dissolution of NH_4NO_3

18. Describe what happened to the temperature of the solution as you increased the mass of ammonium nitrate and used the same quantity of water (Reactions A, C, and E, or B, D, and F).

_____

_____

19. For each reaction, use the specific heat capacity of water to determine the heat of reaction, as follows:

    a. Calculate the heat gained by or lost to the solution using the equation $q = mc\Delta T$ where m is the mass of water plus the mass of the solute and for simplicity assume the mass of 1.00 mL of water is 1.00 g, c is the specific heat capacity of water, 4.184 J/g °C, and $\Delta T_{water} = T_{final} - T_{initial}$. Record your answer, in kilojoules, in the Model 1 Data Table.

    b. Using the mass of ammonium nitrate, calculate the number of moles of ammonium nitrate present in each reaction.

    c. Using the number of moles of ammonium nitrate and the heat released or absorbed, calculate the heat of reaction [$\Delta H = -(q$/mole of product)] for the dissolution of one mole of ammonium nitrate.

20. Will energy appear as a reactant or a product in the following equation? Write the word "energy" on the appropriate side. Explain your reasoning.

$$NH_4NO_3(s) + \text{water} \rightarrow NH_4^+(aq) + NO_3^-(aq)$$

_____

_____

21. Considering the ratios of solute to solvent in Model 1, do large ratios of solute-to-solvent or small ratios of solute-to-solvent cause the greatest temperature changes? Use experimental results to support your answer.

22. Compare the heat q and heat of reaction ΔH. What are the main differences between the two quantities?

23. Identify and explain any trends in the heat of reaction for Model 1.

24. Consider an additional reaction for Model 1 using 10 g of ammonium nitrate in 50.0 mL of water.

    a. How would this mass and volume affect the change in temperature compared to the other trials?

    b. Speculate on the quantity of heat q that would have been gained or lost by the solution in this reaction.

    c. What effect would this have had on your calculation of the heat of reaction for Model 1?

Model 2

Building Model 2 – Limiting Reactants

1. Set up the calorimeter as you did for Model 1.

2. Check with your teacher to determine which reaction you will carry out.

3. What is the relationship between the amount of HCl and the amount of NaOH for the five reactions in Table 3?

Table 3: Model 2 reactions using different ratios of reactant volumes

Ratio	Reactant 1 1.0 M HCl (aq) (mL)	Reactant 2 1.0 M NaOH (aq) (mL)
1	10.0	50.0
2	20.0	40.0
3	30.0	30.0
4	40.0	20.0
5	50.0	10.0

_____

_____

4. For your assigned reaction, measure the specified volume of Reactant 1. Record the value in the Model 2 Data Table and pour Reactant 1 into the calorimeter.

5. Rinse the graduated cylinder. Measure Reactant 2 and record the volume in the Model 2 Data Table.

6. Start recording data.

7. When the temperature readings stabilize, pour Reactant 2 into the calorimeter. Swirl the calorimeter gently to stir.

8. When the temperature readings stabilize again, stop recording data.

9. Dispose of the solution properly, wash the cup and graduated cylinder, and rinse them with deionized water.

10. Conduct the experiment again to obtain a second run.

11. Determine the initial and maximum temperature for each data run. Record the values in Model 2 Data Table.

12. Save your experiment and clean up according to your teacher's instructions. Then exchange data with your classmates and enter it into the Model 2 Data Table so you have the results for each reaction ratio.

Model 2– Limiting Reactants

Table 4a: Model 2 Data Table – Limiting Reactants: Measurements

Reaction		Volume (mL)		Temperature (°C)	
Ratio	Run	1.0 M HCl (aq)	1.0 M NaOH (aq)	Initial	Final
1	Run 1				
	Run 2				
2	Run 1				
	Run 2				
3	Run 1				
	Run 2				
4	Run 1				
	Run 2				
5	Run 1				
	Run 2				

Table 4b: Model 2 Data Table – Limiting Reactants: Calculation of the heat of reaction

Reaction		Temperature Change Δ*T* (°C)	Heat *q* (kJ)	Number of Moles		Heat of Reaction Δ*H* (kJ/mol)	Average Heat of Reaction Δ*H* (kJ/mol)
Ratio	Run			HCl	NaOH		
1	Run 1						
	Run 2						
2	Run 1						
	Run 2						
3	Run 1						
	Run 2						
4	Run 1						
	Run 2						
5	Run 1						
	Run 2						

Analyzing Model 2– Limiting Reactants

13. a. What is the equation for this reaction?

_____

b. Calculate the heat *q* absorbed or released by the solution. Record your results in the Model 2 Data Table.

c. Circle the limiting reagent (the one with the least number of moles) in Table 3, copied below, for each reaction.

Ratio	Reactant 1 1.0 M HCl (aq) (mL)	Reactant 2 1.0 M NaOH (aq) (mL)
1	10.0	50.0
2	20.0	40.0
3	30.0	30.0
4	40.0	20.0
5	50.0	10.0

d. What will happen to the reaction when you run out of limiting reactant?

_____

e. Which should you use, the number of moles of the limiting reactant or the number of moles of the excess reagent, when calculating the molar heat of reaction (kJ per mole of product)? Explain your answer.

_____

_____

_____

14. Calculate the heat of reaction ΔH as you did in Model 1, using the following steps. Record all results in the Model 2 Data Table.

a. Calculate the number of moles of HCl and NaOH used in each reaction. How many moles of product are formed?

b. Calculate the heat of reaction ΔH.

15. Describe the changes in the heat q with respect to the ratios of reactants present.

16. Compare your results with the results of other students with respect to the trends and values of the heat q and the molar heat of reaction, ΔH.

17. Which ratio had the least amount of leftover reactants? Explain, citing data from the experiment.

18. How did the amount used of each reactant affect the heat of reaction ΔH? Why do you think this is?

MODEL 3

Building Model 3 – Additive Nature of Reactions

1. Set up the calorimeter as you did for the previous models.

2. Check with your teacher to determine which reaction you will carry out.

Table 5: Reactions and reactants for Model 3

Rxn #	Reactions	Reactant 1	Reactant 2
1	$NaOH(s) \rightarrow NaOH(aq)$	100.0 mL water	4.00 g NaOH
2	$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$	100.0 mL 1.0 M HCl(aq)	100.0 mL 1.0 M NaOH(aq)
3	$NaOH(s) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$	100.0 mL 1.0 M HCl(aq)	4.00 g NaOH

3. Rinse a graduated cylinder with deionized water and obtain Reactant 1 based on your assigned reaction.

4. Why is it important to rinse the graduated cylinder with deionized water between each use?

_____

_____

5. Carefully transfer the contents of the graduated cylinder into the calorimeter.

6. Obtain Reactant 2.

   NOTE: Since solid sodium hydroxide readily picks up moisture from the air, obtain its mass and proceed to the next step without delay.

7. Start recording data.

8. When the temperature readings stabilize, add Reactant 2 to the calorimeter.

9. Swirl gently to stir. When the temperature readings stabilize again, stop recording data.

10. Why is it important to wait for the readings to stabilize before adding Reactant 2?

_____

_____

11. Dispose of the solutions according to your teacher's instructions, wash the cup and graduated cylinder, and rinse them with deionized water.

12. Conduct the experiment again to obtain a second run.

13. Determine the initial and maximum temperature for each data run. Record the values in the appropriate Model 3 Data Table.

14. Clean up according to your teacher's instructions. Then exchange data with your classmates and enter it into the Model 3 Data Table so you have the results for each reaction.

Model 3 – Additive Nature of Reactions

Table 6a: Model 3 Data Table—Reaction 1

Parameters	Reaction 1 $NaOH(s) \rightleftharpoons Na^+(aq) + OH^-(aq)$	
	Run 1	Run 2
Initial temperature (°C)		
Final temperature (°C)		
Mass of solid NaOH (g)		
Volume of water (mL)		
Mass of solution (g)		
Change of temperature (°C)		
Heat q (kJ)		
Number of moles of NaOH (mol)		
Molar heat of reaction ΔH (kJ/mol)		
Average molar heat of reaction ΔH (kJ/mol)		

Table 6b: Model 3 Data Table—Reaction 2

Parameters	Reaction 2 $NaOH(aq) + HCl(aq) \rightleftharpoons NaCl(aq) + H_2O(l)$	
	Run 1	Run 2
Initial temperature (°C)		
Final temperature (°C)		
Volume of 1.0 M NaOH (mL)		
Volume of 1.0 M HCl (mL)		
Mass of solution (g)		
Change of temperature (°C)		
Heat q (kJ)		
Number of moles of NaOH (mol)		
Number of moles of HCl (mol)		
Molar heat of reaction ΔH (kJ/mol)		
Average molar heat of reaction ΔH (kJ/mol)		

Table 6c: Model 3 Data Table—Reaction 3

Parameters	Reaction 3 $NaOH(s) + HCl(aq) \rightleftharpoons NaCl(aq) + H_2O(l)$	
	Run 1	Run 2
Initial temperature (°C)		
Final temperature (°C)		
Mass of solid NaOH (g)		
Volume of 1.0 M HCl (mL)		
Mass of solution (g)		
Change of temperature (°C)		
Heat q (kJ)		
Number of moles of NaOH (mol)		
Number of moles of HCl (mol)		
Molar heat of reaction ΔH (kJ/mol)		
Average molar heat of reaction ΔH (kJ/mol)		

Analyzing Model 3 – Additive Nature of Reactions

15. Calculate the change of temperature due to the reaction you carried out. Record your results in the corresponding Model 3 Data Table.

16. Calculate the heat q as you did in Model 1 and Model 2. Record your results in the corresponding Model 3 data table.

17. Calculate the number of moles of the reactants in each reaction. Record the results in the corresponding Model 3 Data Table. What is the limiting reagent for each reaction?

    NOTE: For Reaction 2, remember that the units of molarity are moles/liter and the answer should be in moles.

18. Compare your results to the results of other students. Note similarities and differences with respect to the heat q and the molar heat of reaction ΔH.

    _____

    _____

19. Determine the number of moles of product that will be created. Then calculate the molar change of heat ΔH for each reaction (kJ per mole of product) and indicate if the reaction was endothermic or exothermic. Record your results in Model 2 data table.

20. Write the net ionic equation for each of the three reactions.

    Net ionic equation for Reaction 1: _____

    Net ionic equation for Reaction 2: _____

    Net ionic equation for Reaction 3: _____

21. Demonstrate the relationship between the three ionic equations by combining them so the addition of the first two reactions equals the third. In the space below, algebraically add the ions from two of the reactions to equal the third reaction.

22. By citing the heats of reaction you obtained, mathematically verify that you added the correct two reactions together.

23. The previous two questions outline fundamental points of *Hess's Law*—the additive nature of heats of reactions. Describe Hess's Law.

_____

_____

_____

24. How would the numerical value for ΔH_{rxn} change if the calorimeter was made of a conducting material and absorbs a significant amount of energy?

_____

_____

_____

25. How would the numerical value of ΔH_{rxn} change if your lab partner put too much of the limiting reagent in the calorimeter?

_____

_____

_____

Connecting to Theory

Thermochemistry studies are based on measuring the heat released or absorbed in a chemical process. The First Law of Thermodynamics states that energy is conserved in a process; therefore, any energy released or absorbed as heat can be measured by its direct effect on the environment. When a reaction is carried out in an aqueous solution, the energy given off or taken in by the process is transferred to or from the water although a small percentage may be lost to the calorimeter.

For example, if a reaction releases heat, an exothermic reaction, then the temperature of the water will increase. On the other hand, an endothermic reaction will absorb heat from the water, thus causing a decrease in the temperature of the water. This allows for a simple calculation of the heat of the reaction by first measuring the temperature change for the water, and then using the following equation to calculate the heat q absorbed or released by the dilute solution:

$$q = mc\Delta T$$

where m is the mass of the solution (assume the mass of 1.00 mL of solution is 1.00 g), c is the specific heat capacity of water: 4.184 J/g °C, and $\Delta T = T_{final} - T_{initial}$ of the solution. When the solutions used are dilute, they are assumed to have the same thermal properties as water.

In the Model 3 experiment, a polystyrene-cup calorimeter was used to measure the heat released by three different reactions. One of the reactions can be expressed as the combination of the other two reactions. Therefore, the heat of reaction of the one reaction should be equal to the sum of the heats of reaction of the other two. This concept is sometimes referred to as Hess's Law, or the additivity of heats of reaction.

Applying Your Knowledge – Applying Hess's Law

The following reaction cannot be performed directly:

$$Mg + ½O_2 \rightleftharpoons MgO$$

To calculate the energy of formation for magnesium oxide, Hess's Law must be applied. A pathway that can be used is:

$$Mg + 2HCl \rightleftharpoons MgCl_2 + H_2 \qquad \Delta H_1 = ?$$

$$MgCl_2 + H_2O \rightleftharpoons MgO + 2HCl \qquad \Delta H_2 = 133 \text{ kJ/mol}$$

$$H_2 + ½O_2 \rightleftharpoons H_2O \qquad \Delta H_3 = -286 \text{ kJ/mol}$$

$$Mg + ½O_2 \rightleftharpoons MgO \qquad \Delta H_4 = ?$$

Design an experiment using approximately 0.5 g of magnesium ribbon and 2.0 M HCl to determine ΔH_1. Be sure to record the actual amounts you used in the data table. Show your process of determining the limiting reactant. Then use Hess's law to determine the energy required to form one mole of MgO. Make sure the magnesium dissolves fully.

Table 7: Determination of ΔH_1

Parameters	Reaction 1 $Mg + 2HCl \rightleftharpoons MgCl_2 + H_2$	
	Run 1	Run2

The molar heat of reaction for the formation of MgO is _____ (ΔH_4).

Compare your results to known values and calculate the percent error. The following website may be helpful: http://bilbo.chm.uri.edu/CHM112/tables/thermtable.htm.

12. CHEMICAL EQUILIBRIUM

Initial Question

In 1901, Henry Louis Le Châtelier combined explosive hydrogen gas with nitrogen gas in an attempt to form ammonia. His efforts met with disastrous results—he almost killed his assistant. Although he abandoned the synthesis of ammonia, he had a fine career that led him to discover the principle of chemical equilibrium, now known as Le Châtelier's Principle. This principle is used by chemical engineers to create processes that make the maximum amount of products.

How can a chemical reaction be manipulated to maximize yield (without blowing up your assistant)?

Materials and Equipment

Model 1

- Data collection system
- Colorimeter
- Extension cable
- Cuvettes (3)
- Beakers (3), 50-mL
- Mohr pipet, 10-mL
- Pipet bulb
- 0.0080 M Iron(III) nitrate ($Fe(NO_3)_3$), 3.0 mL
- 0.0010 M Potassium thiocyanate (KSCN), 3.0 mL
- Kimwipes®

Model 2

- Test tube rack
- Distilled water, 2 mL
- Plastic pipets (3)
- Test tubes (3), 19 × 150 mm (medium)
- Gloves
- Marking pen
- Cobalt(II) chloride ($CoCl_2$), 1.5 g
- 0.10 M Silver nitrate ($AgNO_3$), 2 mL
- 6.0 M Hydrochloric acid (HCl), 2 mL
- Scoop
- Glass stirring rod

Model 3

- Data collection system
- Fast-response temperature sensor
- Beakers(2), 250-mL
- Hot plate
- Cobalt solution from Model 2
- Water for water baths
- Ice

Applying Your Knowledge

- Data collection system
- Colorimeter
- Extension cable
- Cuvettes
- Mohr pipet, 10-mL
- Pipet bulb
- Equipment and amounts depend on the procedure:
  Test tube, 19 × 150 mm (medium)
  Beakers, 50-mL
  Graduated cylinder, 10-mL
  0.0010 M Potassium thiocyanate (KSCN)
  0.0080 M Iron(III) nitrate ($Fe(NO_3)_3$)
- Kimwipes®

Safety

Add these important safety precautions to your normal laboratory procedures:

- Hydrochloric acid is corrosive. If you come in contact with it, flush the area with plenty of water. It can cause severe tissue burns.
- Cobalt solutions are moderately toxic and are body tissue irritants. If you come in contact with it, flush the area with plenty of water.
- Silver nitrate will stain skin and clothing. Wear gloves when you work with it. If you do come in contact with it, flush the area with plenty of water.

Getting Your Brain in Gear

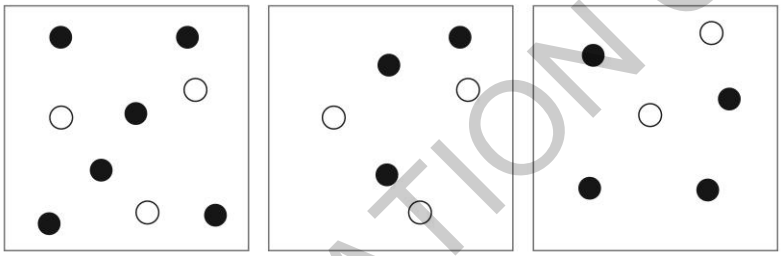
1. Consider the following equilibrium system:

$$A(aq) \rightleftharpoons B(aq)$$

a. Write the equilibrium expression for this system.

b. If the value of K_c is 2, what is the ratio of the [A] to the [B]?

c. Which picture(s) represent the system at equilibrium?



d. Is there a single set of data for [A] and [B] that satisfies the equilibrium state?

2. Consider the following system:

$$Co(H_2O)_6^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons 6H_2O(l) + CoCl_4^{2-}(aq)$$

Pink Blue

a. Write the equilibrium expression for this system.

b. The reaction quotient Q expresses the relative ratio of products to reactants at a given instant. Write the reaction quotient expression for this system.

3. How is an equilibrium constant different from a reaction quotient?

_____

_____

_____

4. When does the value of $Q = K_c$?

_____

_____

5. Explain the following statement: At constant temperature, there is only one equilibrium constant for a system but many different equilibrium states or positions. Provide three examples of product and reactant concentrations that will give $K_c = 20$.

_____

_____

_____

6. Label the following reactions as either endothermic or exothermic:

heat + A ⇌ B _____

A ⇌ B + heat _____

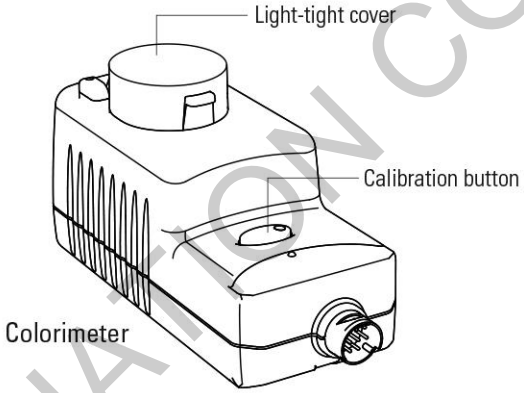
MODEL 1

Building Model 1 – K_c as a Constant

When iron(III) nitrate ($Fe(NO_3)_3$) and potassium thiocyanate (KSCN) solutions react, the following equilibrium is created:

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftharpoons FeSCN^{2+}(aq)$$

1. Start a new experiment on the data collection system.
2. Connect the colorimeter to the data collection system using the extension cable.
3. Fill a cuvette at least ¾ full with distilled water.
4. Wipe off the sides of the cuvette with a lint free tissue and only handle it by the top.
5. Calibrate the colorimeter with the distilled water. The water sample is called a *blank*.



6. Place 3.0 mL of 0.0080 M iron(III) nitrate and 3 mL of 0.00100 M potassium thiocyanate into separate 50-mL beakers. Record the molarity, volume, and color of the solutions in the Model 1 Data Table—Before reacting.
7. Pour the solutions into a third 50-mL beaker and swirl gently to mix thoroughly. Then pour the solution into a cuvette. Record the color of the equilibrium mixture in the Model 1 Data Table—After reacting.
8. Select "Blue (468 nm) Absorb" for the colorimeter.
9. Place the cuvette into the colorimeter, close the top, and start data collection.
10. Once the reading stops fluctuating, record the absorbance in the Model 1 Data Table.
11. Clean up all solutions and equipment according to your instructor's instructions.

Model 1 – K_c as a Constant

Table 1: Model 1 Data Table—Before reacting

Parameter	Iron(III) nitrate	Potassium thiocyanate
Concentration		
Volume		
Color		

Table 2: Model 1 Data Table—After reacting

Parameter	Equilibrium Mixture
Color	
Absorbance	

Analyzing Model 1 – K_c as a Constant

12. Consider the equilibrium system in Model 1. When the two solutions were mixed in the beaker, which of the following calculations represent the initial concentration of Fe^{3+} ions in the mixture? Circle your answer.

$$3.00\ \text{mL} \times 0.0080\ \text{M} = 2.40 \times 10^{-5}\ \text{M Fe}^{3+} \quad \text{OR} \quad \frac{3.00\ \text{mL} \times 0.0080\ \text{M}}{6.0\ \text{mL (total volume of solution)}} = 0.0040\ \text{M Fe}^{3+}$$

13. What is the initial concentration of SCN^- ions in the mixture?

14. Complete the following ICE table and equilibrium expression for this equilibrium system using the volumes and concentrations of the reactants in Model 1.

Table 3: ICE table for calculating equilibrium concentrations

Condition	Fe^{3+}	+ SCN^-	⇌	$FeSCN^{2+}$
I (Initial concentration)				
C (Change)				
E (Equilibrium concentration)				

15. If K_c is not known, describe how you could use a spectrophotometer or a colorimeter to find x or $[FeSCN^{2+}]_{eq}$ in the lab.

    NOTE: This procedure is in the Light, Color, and Concentration lab.

16. Determine the equilibrium constant. Assume (path length × molar absorptivity) for this system is 5900 M^{-1}.

17. How does the value of your equilibrium constant compare to the values of the other groups in your class?

    Table 4: Compare class results

Group	Equilibrium Constant
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	

18. Is your data similar to that of your classmates? What should you do if your sample deviates by a significant amount?

    NOTE: Often the equilibrium constant is considered constant when it varies within a power of ten.

MODEL 2

Building Model 2 – Adding Stress to an Equilibrium System

1. Obtain a test tube, test tube rack and marking pen.

2. Label the test tube "K" and place it in the test tube rack.

3. Add approximately 0.5 g of cobalt chloride hexahydrate into the test tube. Then add 10 drops of distilled water using a pipet and mix the solution with a glass stirring rod. This solution will remain untouched during the lab and represents the original condition of the cobalt system:

$$Co(H_2O)_6^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons 6H_2O(l) + CoCl_4^{2-}(aq)$$

Pink Blue

4. Repeat the previous step for two more test tubes and label them "A" and "B". Record your initial observations for all of the solutions in the Model 2 Data Table.

   NOTE: Hold the test tubes over a white background to make your observations easier.

5. HCl will be added to test tubes A and B. Will this addition increase or decrease the concentration of chloride ions in the equilibrium system? Explain.

_____

_____

_____

6. While wearing gloves, carefully add 6.0 M HCl, drop-wise, to test tube A until a noticeable change has occurred. Then add the 6.0 M HCl, drop-wise, to test tube B. Record your observations in the Model 2 Data Table.

7. $AgNO_3$ will be added to test tube B and a precipitate should form. What reaction will occur to produce this precipitate? Write the net ionic reaction.

8. Should the formation of a precipitate increase or decrease the concentration of chloride ions in the equilibrium system? Explain.

_____

_____

_____

9. While wearing gloves, add 0.1 M $AgNO_3$ drop-wise to test tube B until a color change is produced. You should notice a precipitate on the bottom of the test tube. Record your observations in the Model 2 Data Table.

   NOTE: Don't discard the solutions. You will use the solution in test tube A in Model 3.

Model 2 – Adding Stress to an Equilibrium System

Table 5: Model 2 Data Table—Results of adding stress

Test Tube	Color of the Solution		
	Initial Observations	After Addition of HCl	After Addition of $AgNO_3$
K			
A			
B			

Analyzing Model 2 – Adding Stress to an Equilibrium System

10. In all test tubes, what color is the solution prior to the addition of the HCl or $AgNO_3$?

11. Considering the appearance of the solution prior to the addition of HCl or $AgNO_3$, are there more products or reactants present at equilibrium? Explain your reasoning.

12. After adding HCl, what observation indicated that the reaction shifted to re-establish equilibrium?

13. From the appearance of the solution in test tubes A and B after the addition of HCl, are there more products or reactants present at this re-established equilibrium position? Explain your reasoning.

14. Upon the addition of HCl, is the value of the reaction quotient Q greater than, less than or equal to value of K_c? Write the reaction quotient and use it to explain your answer.

15. Based on the observations in Model 2, does the reaction shift to the left, increasing the concentration of the reactants or to the right, increasing the concentration of products upon the addition of HCl?

16. Have the concentrations of $Co(H_2O)_6^{2+}$ and $CoCl_4^{2-}$ increased or decreased after hydrochloric acid is added?

17. The addition of silver nitrate to the equilibrium system created a change to the system by removing Cl^- ions through a precipitation reaction. How does the new concentration of Cl^- in test tube B compare to the Cl^- concentration in test tube A?

    The concentration of Cl^- in test tube B, after Ag^+ is added, is _____ the concentration of Cl^- in test tube A.
    <, >, or =

18. Upon the addition of $AgNO_3$, is the value of the reaction quotient greater than, less than or equal to value of K_c? Write the reaction quotient and use it to explain your answer.

19. Based on the observations in Model 2, does the reaction shift to the left (more reactants) or right (more products) upon the addition of $AgNO_3$?

20. Did the concentrations of $Co(H_2O)_6^{2+}$ and $CoCl_4^{2-}$ increase or decrease after silver nitrate was added?

21. Model 2 dealt with the following equilibrium system:

$$Co(H_2O)_6^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons 6H_2O(l) + CoCl_4^{2-}(aq)$$

Pink Blue

a. Complete the table to indicate how experimental stresses due to changing the amounts of substances in the solution shifted the equilibrium.

Table 6: Stress results due to changing reactant amounts

Stress	Resulting Color	Direction of Shift	Q vs K_c (<, >, =)
Removal of Cl^-			Q _____ K_c
Addition of Cl^-			Q _____ K_c

b. Predict how the following stresses in the amounts of substances would shift the equilibrium in the solution.

Table 7: Stress result predictions

Stresses That Could Cause This Shift	Resulting Color	Direction of Shift	Q vs K_c (<, >, =)
Removal of $Co(H_2O)_6^{2+}$			Q _____ K_c
Addition of $Co(H_2O)_6^{2+}$			Q _____ K_c
Removal of $CoCl_4^{2-}$			Q _____ K_c
Addition of $CoCl_4^{2-}$			Q _____ K_c

22. The solutions in test tube K, test tube A (after the addition of HCl) and test tube B (after the addition of $AgNO_3$) are all at equilibrium. Which of the following must be true about the solutions in the three test tubes? Circle the correct answer.

i. They have the same amounts of reactants and products, same value of K_c, same color of equilibrium mixture.

ii. They have different amounts of reactants and products, different values of K_c, different color of equilibrium mixture.

iii. They have the same amounts of reactants and products, same value of K_c, different color of equilibrium mixture.

iv. They have different amounts of reactants and products, same value of K_c, different color of equilibrium mixture.

MODEL 3

Building Model 3 – Endothermic or Exothermic

1. Connect a temperate sensor to your data collection system.

2. Set up a warm water bath using a hot plate and a 250-mL beaker, and a cold water bath using ice water and a 250-mL beaker.

3. What lab observation will confirm that the reaction studied in Model 2 is endothermic? Why?

_____

_____

_____

4. What lab observation will confirm that the reaction is exothermic? Why?

_____

_____

_____

5. Place test tube A into the hot water bath for three minutes and then into the cold water bath for three minutes. Record your observation for each situation in the Model 3 Data Table.

6. Clean up all solutions and equipment according to your instructor's instructions.

Model 3 – Endothermic or Exothermic

Table 8: Model 3 Data Table—Results of hot and cold stress

Condition	Resulting Color
After 3 minutes in hot water	
After 3 minutes in ice water	

Analyzing Model 3 – Endothermic or Exothermic

7. Is the cobalt equilibrium system endothermic or exothermic? Why? Provide evidence from your lab that supports your claim.

   The reaction is endothermic because the solution turned blue in a hot water bath. The heat caused the reaction to shift towards the products.

8. Add energy to the appropriate side of the equation below.

_____ $Co(H_2O)_6^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons 6H_2O(l) + CoCl_4^{2-}(aq)$ _____

Connecting to Theory

Within five years of Henry Louis Le Châtelier abandoning his search for the synthesis of ammonia, Fritz Haber was able to create ammonia from hydrogen and nitrogen gas. The Haber process is used in industry to manufacture ammonia, a key component in fertilizer. Ammonia-based fertilizer is responsible for sustaining one-third of the earth's population, so this is a very important process. Ammonia is produced through the following catalyzed reaction:

$$N_2(g) + 3H_2\,(g) \rightleftharpoons 2NH_3\,(g) + \text{heat}$$

Under normal conditions, the yield of ammonia is only 10–20%. This is not enough to keep up with global demand of ammonia.

Le Châtelier's principle is often used to manipulate the outcomes of reversible reactions to maximize yield. If a system in dynamic equilibrium is subjected to a stress such as changes in concentration, temperature, volume, and partial pressures, the concentration of products and reactants change to reestablish the equilibrium constant, K_c . Quantitatively, the direction the reaction shifts to re-establish equilibrium can be determined by comparing the value of Q to the value of K_c.

Applying Your Knowledge – Determining a Constant Equilibrium Constant

1. With your group, design an experiment using the iron(III) thiocyanate equilibrium system to show that K_c remains constant when temperature is constant, within experimental error, despite different stresses added to the system. Record your procedure below.

   While designing your lab, keep the following items in mind:

   - Change only one variable when creating a stress to the system.
   - Calibrate the colorimeter prior to use.
   - Excess SCN^- produces colored side products; keep SCN^- as the limiting reactant at 0.0010 M.
   - Keep all iron solutions at low concentrations (0.0080 M or lower) so as to not overload the colorimeter.
   - You may dilute solutions more using distilled water.
   - Minimize fingerprints.
   - If using a colorimeter, use blue, 468 nm, to measure absorbance.
   - If using a colorimeter, assume (path length × molar absorptivity) for this system is 5900 M^{-1}.
   - Create any data tables needed to organize data.
   - Obtain your instructor's initials before you perform the lab.

Procedure:

Instructor Initials: _____

Data Table(s):

Calculations:

2. Does K_c remain constant after stresses are added to the equilibrium? Why? Provide evidence from your lab that supports your claim.

_____

_____

_____

13. SHAPE OF TITRATION CURVES

Initial Question

A titration curve has a distinctive shape that often catches students by surprise. The shape of this curve changes predictably when weak acids are substituted for strong acids. Other parameters can also cause it to change. Once you have an understanding of the fundamental shape, a great deal of information can be derived from a titration curve.

What factors influence the shape of a titration curve?

Materials and Equipment

Models 1, 2, and Applying Your Knowledge

- Data collection system
- pH sensor
- Drop counter
- Drop dispenser:
  Syringe, 60-mL
  Stopcock (2)
  Drop tip
- Beaker, glass, 150-mL
- Beaker, 250-mL
- Mohr pipet, 25-mL
- Pipet pump
- Magnetic stirrer (stir plate)
- Micro stir bar
- Multi clamp
- Ring stand
- Three-finger clamp
- Distilled water
- Wash bottle
- Materials for drop counter and pH sensor calibration (refer to Appendix A)

Model 1

- 0.10 M Sodium hydroxide (NaOH), 260 mL
- 0.10 M Hydrochloric acid (HCl), 20 mL
- Phenolphthalein indicator solution, 2 drops

Model 2

- 0.10 M Sodium hydroxide (NaOH), 260 mL
- 0.10 M Hydrochloric acid (HCl), 20 mL
- 0.05 M Hydrochloric acid (HCl), 20 mL
- 0.025 M Hydrochloric acid (HCl), 20 mL
- 0.10 M Acetic acid (CH_3COOH), 20 mL
- 0.10 M Potassium hydrogen tartrate ($KC_4H_5O_6$), 20 mL

Applying Your Knowledge

- 0.10 M Sodium hydroxide (NaOH), 260 mL[1]
- Unknown acid of unknown concentration, 15 mL[1]

Safety

Add these important safety precautions to your normal laboratory procedures:

- This lab uses strong acids and bases. In case of contact with your skin, wash off the solution with a large amount of water.

Getting Your Brain in Gear

1. Write a balanced chemical equation and net ionic equation for the reaction of a strong acid, HCl, with a strong base, NaOH.

2. Write a balanced chemical equation and net ionic equation for the reaction of a weak acid, CH_3COOH with a strong base, NaOH.

3. Calculate the volume of 0.25 M NaOH needed to completely react with 30.0 mL of 0.15 M HCl.

MODEL 1

Building Model 1 – Titration of a Strong Acid with a Strong Base

1. Start a new experiment on the data collection system.

2 Use the multi-clamp to attach the drop counter to the ring stand. Use the illustration as a guide.

3. Use the three-finger clamp to attach the drop dispenser to the ring stand.

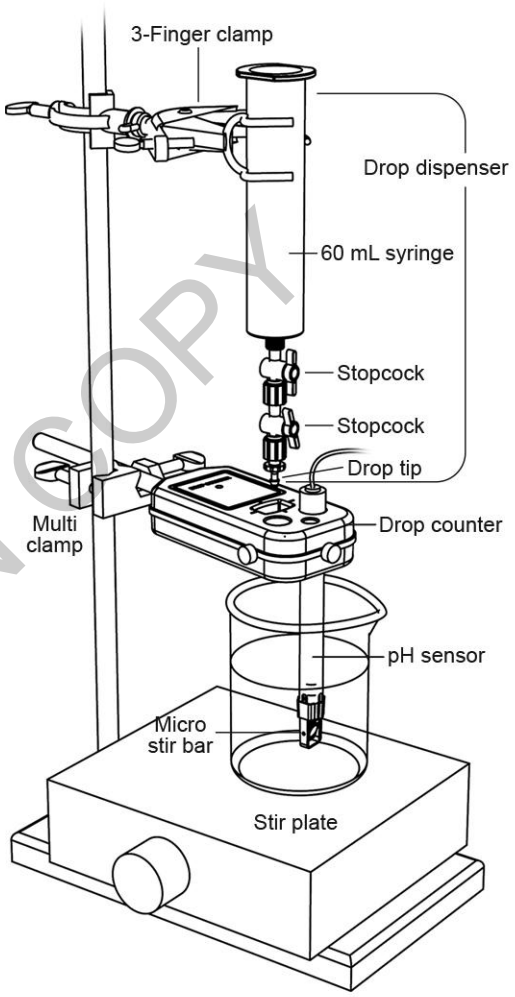
4. Rinse the drop dispenser syringe:

   a. Place a 250-mL beaker under the drop dispenser and open both stopcocks.

   b. Rinse the drop dispenser syringe and stopcock three times with approximately 20 mL of distilled water. This will remove any residue.

   c. Rinse the drop dispenser three times with 20 mL of the 0.10 M NaOH. This removes remaining water that would dilute the NaOH solution.

   d. Discard the rinse solution as directed by your teacher.



5. See Appendix A to set up and calibrate the drop counter and pH sensor.

   NOTE: Do not disconnect the drop counter from the data collection system or it will need to be calibrated again.

6. Assemble the rest of the apparatus using the following steps and the illustration as a guide.

   a. Position the magnetic stirrer on the base of the ring stand.

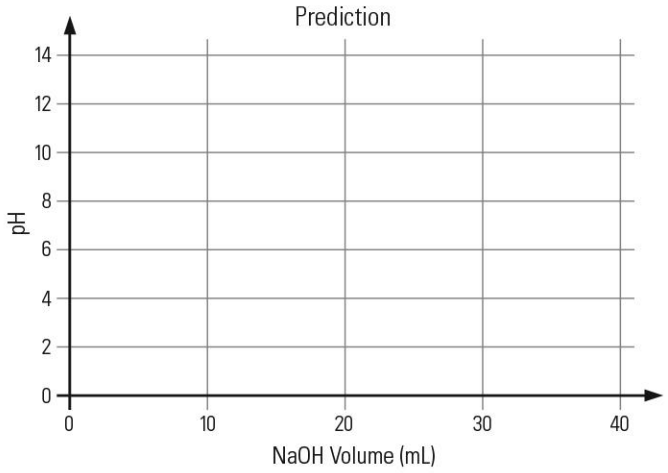
   b. Position the drop counter over the magnetic stirrer.

   c. Place the pH sensor through a large slot in the drop counter.

7. Display the pH on the *y*-axis of a graph and fluid volume on the *x*-axis.

8. Use the graduated pipet to transfer 20.00 mL of 0.10 M HCl and 30.0 mL of distilled water to a 150-mL beaker and set the beaker on the magnetic stirrer.

9. In this procedure you will be adding 0.10 M NaOH to the 0.10 M HCl analyte and measuring the pH as they mix. Predict what a graph of pH versus Volume of NaOH added will look like and sketch it below. Explain your reasoning.



10. Add two drops of phenolphthalein indicator solution to the solution in the beaker.

11. Turn on the magnetic stirrer at a slow and steady rate.

12. Start recording data.

13. Turn the drop dispenser stopcock carefully, allowing the titrant to drip slowly (1 to 2 drops per second) into the solution.

    NOTE: The top valve controls the flow rate and the bottom valve turns the flow on and off.

14. Record in the Model 1 Data Table the approximate pH where the phenolphthalein turns from clear to pink and the volume of titrant used. Do not stop the titration at this point. Continue the titration until the pH curve flattens, somewhere between pH 10 and pH 14.

15. Stop recording data.

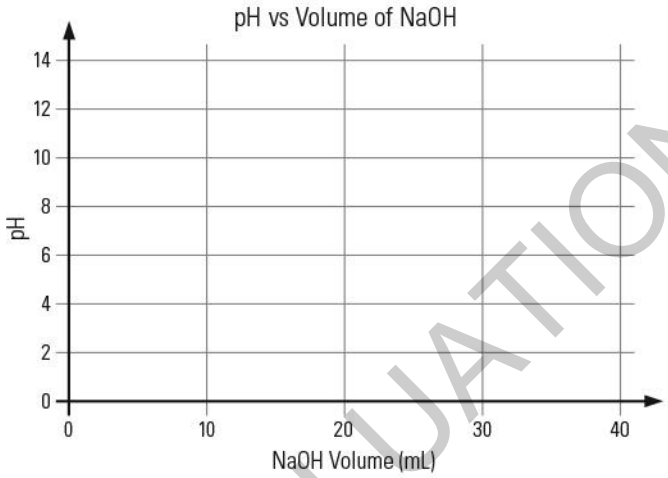
16. Save your experiment and dispose of the contents of the beaker according to your teacher's instructions.

17. Sketch or attach a copy of your graph of pH versus volume of NaOH added to Model 1. In the Model 1 Data Table, record the concentration of the base, the acid, and the volume of acid used.

Model 1 – Titration of a Strong Acid with a Strong Base

Table 1: Model 1 Data Table—Titration measurements

Titration Information	
Parameter	**Value**
Concentration of NaOH (M)	
Concentration of HCl (M)	
Volume of HCl sample (mL)	
Volume of titrant (NaOH) added when indictor changed color (mL)	
pH of indicator color change	



Analyzing Model 1 – Titration of a Strong Acid with a Strong Base

18. Compare your predicted titration graph with the one obtained in the lab. Reflect on any differences or similarities in the two graphs.

_____

_____

_____

19. Assuming the reaction between HCl and NaOH goes to completion, because they are a strong acid and base, calculate the volume of 0.10 M NaOH needed to completely neutralize the acid in the beaker.

20. The point in the reaction at which the number of moles of base added equals the number of moles of acid originally present in the sample is called the *equivalence point*. What volume of 0.10 M NaOH needs to be added to your acid to reach the equivalence point?

_____

21. Describe and label the equivalence point on the graph in Model 1.

_____

_____

22. For a strong acid–strong base titration, the pH at the equivalence point should be 7.

    a. Consider the products of the neutralization reaction and explain why an equivalence point pH of 7 makes sense.

_____

_____

    b. If the equivalence point pH of your graph is not close to 7, propose some sources of error that may have skewed your data.

_____

_____

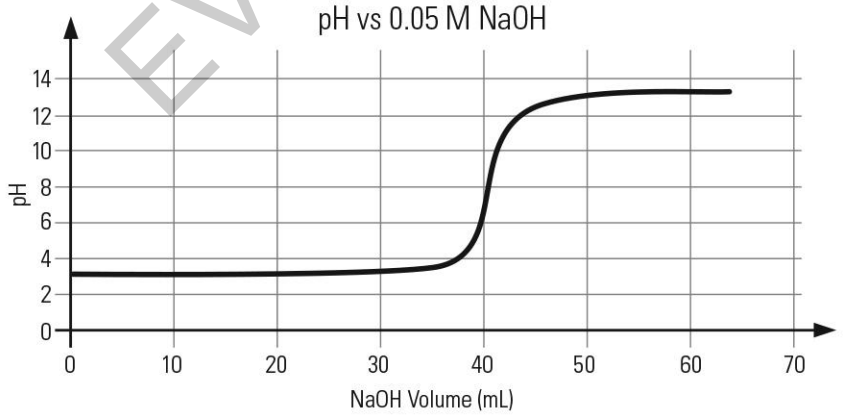
_____

23. The endpoint of a titration occurs when the indicator solution changes colors. Compare the pH when the indicator changed color during your titration and the pH of the equivalence point on your graph. Describe any similarities.

_____

_____

24. The graph below was produced from the titration of a 20.0 mL sample of HCl of unknown concentration with 0.05 M NaOH. Calculate the concentration of HCl in the sample using data from the graph.



25. There are several notable features of the shape of a titration curve besides the pH and volume coordinates of the equivalence point. These include the initial pH, the slope of the first section, and the slope at the end. Brainstorm some variables in a titration that might change one or more of these features in a titration curve. Share these ideas with your class.

_____

_____

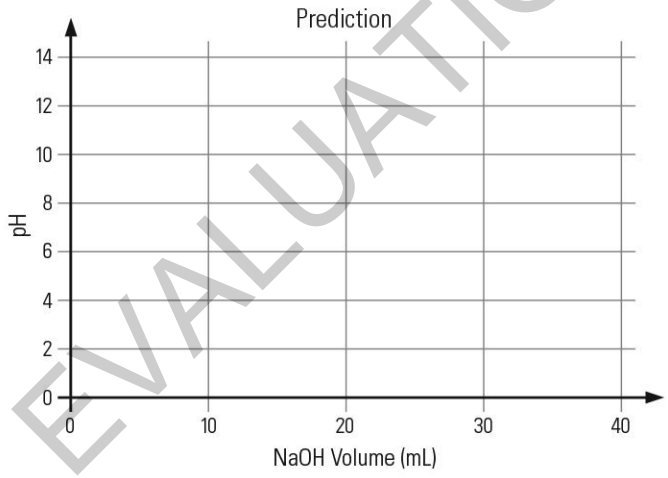
_____

MODEL 2

Building Model 2 – Changing the Shape of a Titration Curve

Your instructor will assign you a variable from the class list generated in Model 1. Develop a procedure using the titration technique from Model 1 that will allow you to compare at least three titration curves produced while adjusting your assigned variable. Your titration curve in Model 1 can be one of the three curves you compare. Be prepared to present your findings to the class and explain how your variable affects the shape of a titration curve.

1. Before doing the next titration, use the Prediction Tool on the data collection system to draw what you think the graph will look like when you vary your assigned variable. Sketch or attach a copy of your graph.



2. Carry out your procedure and complete the Model 2 Data Table.

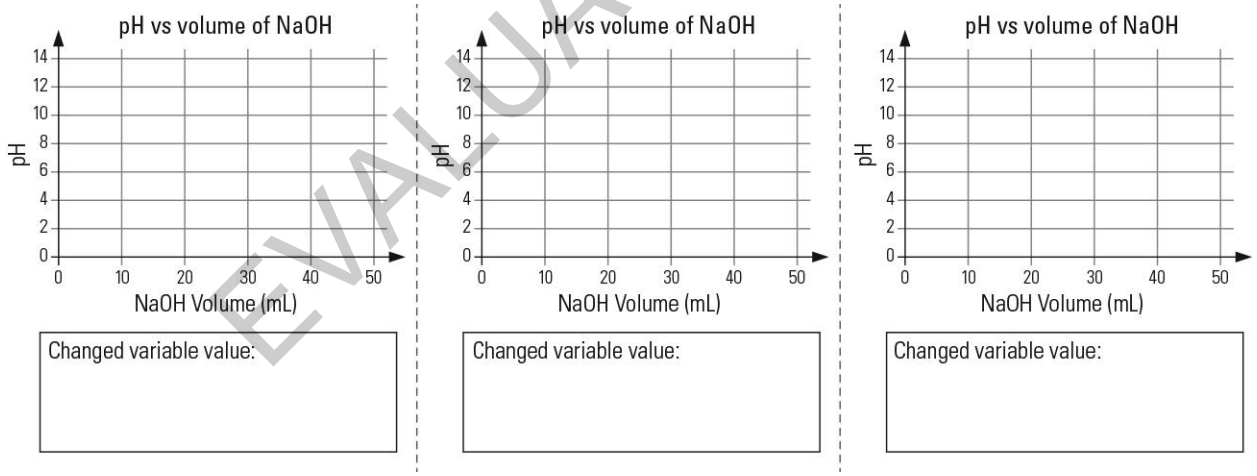
Model 2 – Changing the Shape of a Titration Curve

Variable to be studied : _____

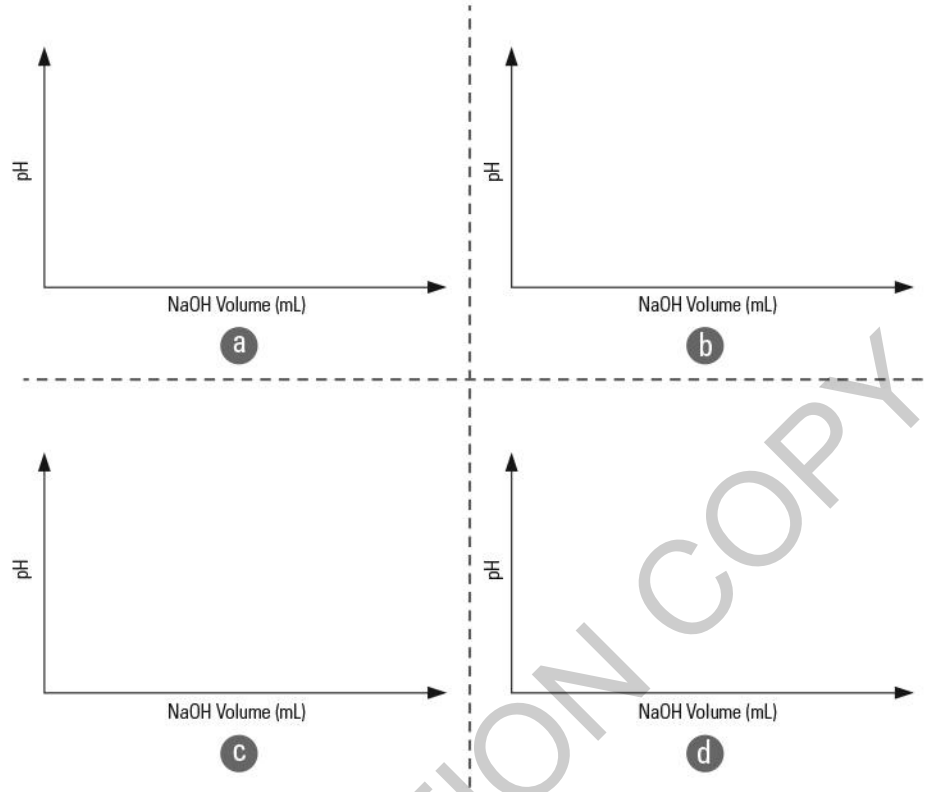
Table 2: Model 2 Data Table—Effect of changing the variable on the titration curve

	Trial 1 (from Model 1)	Trial 2	Trial 3
Concentration of NaOH used (M)			
Formula of acid used			
Titration Measurements			
Concentration of analyte (M)			
Volume of analyte (mL)			
Volume of titrant (mL)			
Number of moles of analyte (mol)			
Initial pH			

3. Graph—Sketch your graph here showing all three titration curves and record the value of the variable you changed.



4. Class Data—Sketch the results of other groups who investigated the other titration variables, showing the three curves on a single graph. Label the four graphs as Graphs A–D and indicate the variable for each.



Analyzing Model 2 – Changing the Shape of a Titration Curve

5. There are four points on a titration curve that define the curve: the starting pH, the slope of the curve between the start and the equivalence point, the volume of titrant needed to reach the equivalence point, and the pH at the equivalence point.

   a. Which graph from the class data shows the effect of varying the number of moles of acid in the analyte (concentration is constant, analyte volume changes) on the titration curve?

_____

   b. What feature(s) of the titration curve is(are) most affected by the number of moles of acid?

_____

_____

6. a. Which graph from the class data shows the effect on the titration curve of differing volumes of sample (the number of moles of acid is constant, the concentration changes)?

_____

   b. What feature(s) of the titration curve is(are) most affected by the volume of the sample (using the same volume of analyte and varying the total volume by adding water)?

_____

_____

7. a. Which graph from the class data shows the effect on the titration curve of differing concentrations of acid (volume is constant, the number of moles of acid changes).

_____

b. What feature(s) of the titration curve is(are) most affected by the concentration of the sample?

_____

_____

8. a. Which graph from the class data shows the effect on the titration curve of differing acid strength (acid concentration is constant, volume is constant)?

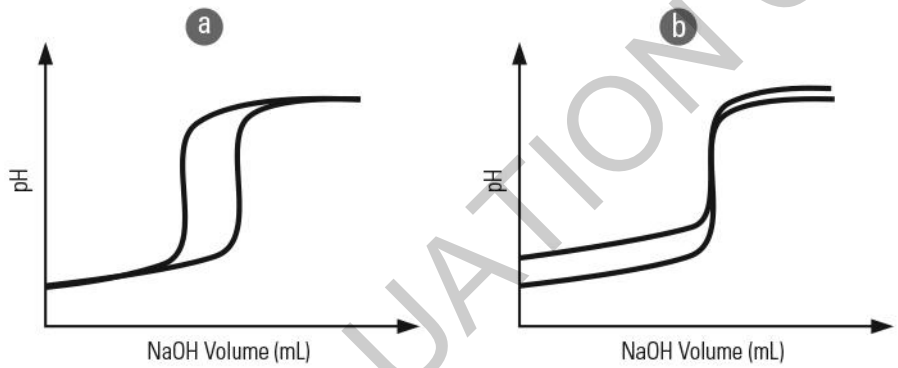
_____

b. What feature(s) of the titration curve is(are) most affected by the strength of the acid sample (analyte)?

_____

_____

9. Refer to the following titration curves:



a. Which of the titration curves shows two titrations done with the same titrant and sample concentrations, but with acids of two different strengths?

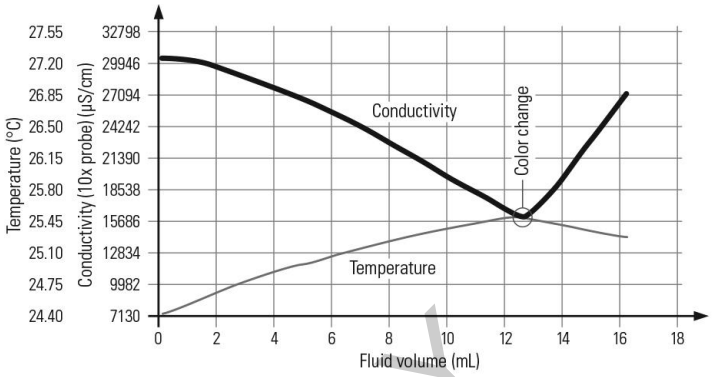
_____

b. In the graph that you chose above, which titration curve is from the weaker acid sample?

_____

Connecting to Theory

Titration is one of the most important analytical techniques in chemistry. It is one of the ways a scientist can determine how much of a substance is present in a sample. In this lab series, several types of titrations are encountered.



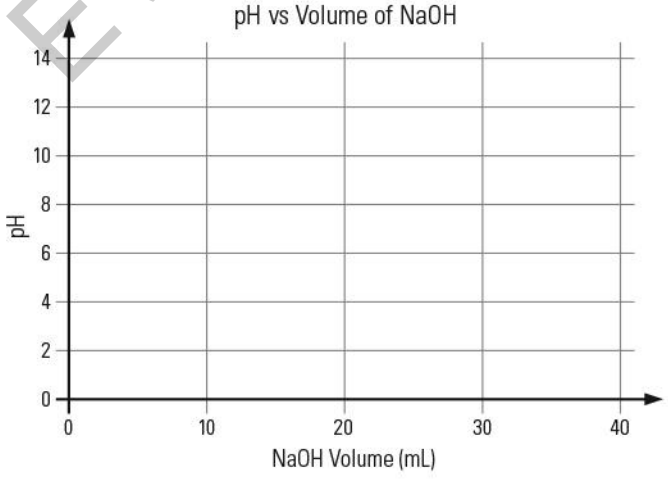
Titration can be performed using precipitation, the formation of complex molecules, and redox reactions. In an earlier lab you explored a thermometric titration which has a distinctive "V" shaped curve. Most titrations, including redox and acid–base titrations, have an "S" shape.

All titrations use a substance with a known concentration to determine the concentration of an unknown. In the next section, you are asked to use 0.10 M NaOH as the titrant to determine the concentration of an unknown acid.

Applying Your Knowledge – Determining the Concentration of an Unknown Acid

You will be given 15 mL of an unknown monoprotic acid. Use 0.10 M NaOH and the titration equipment to determine the concentration of the unknown acid. Identify the equivalence point by making a graph of pH vs volume of base.

1. Create a data table. Record your titration measurements. Sketch or attach a copy of your graph of pH versus volume of NaOH.



2. Which area of the graph is most critical in determining the concentration of the unknown acid? Why?

_____

_____

_____

3. Find the concentration of the unknown monoprotic acid.

4. Gather results from your peers. Compare your results and determine if your results are outside of a standard deviation.

5. What action should you take if your data is outside of the standard deviation?

_____

_____

6. What is the average molarity of the unknown acid?

_____

14. WEAK ACID TITRATION

Initial Question

Weak acids have a slightly different chemistry than strong acids. If the pH of a strong acid solution and a weak acid solution of equal concentration were analyzed, the weaker acid would have a higher pH. This is due to the partial ionization of the weak acid. However, if the weak acid is neutralized by a strong base, the weak acid is forced to ionize completely.

What information can you derive from a pH titration curve of a weak acid?

Materials and Equipment

Model1, Model 2, and Applying Your Knowledge

- Data collection system
- pH sensor
- Drop counter
- Drop dispenser:
  Syringe, 60-mL
  Stopcock (2)
  Drop tip
- Beaker, glass, 150-mL
- Beaker, 250-mL
- Mohr pipet, 25-mL
- Magnetic stirrer (stir plate)
- Micro stir bar
- Pipet pump
- Multi clamp
- Ring stand
- Three-finger clamp
- 0.50 M Sodium hydroxide (NaOH), 160 mL
- Distilled water, 260 mL
- Wash bottle
- Materials for drop counter and pH sensor calibration (refer to Appendix A)

Model 1

- 1.0 M Acetic acid (CH_3COOH), 20 mL

Model 2

- 0.05 M Maleic Acid ($C_3H_4O_4$), 50mL

Applying Your Knowledge

- Aspirin

Safety

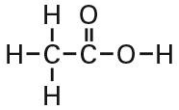
Add these important safety precautions to your normal laboratory procedures:

- Sodium hydroxide is caustic and should be handled with special care. In case of contact with your skin, wash off the sodium hydroxide with a large amount of water.

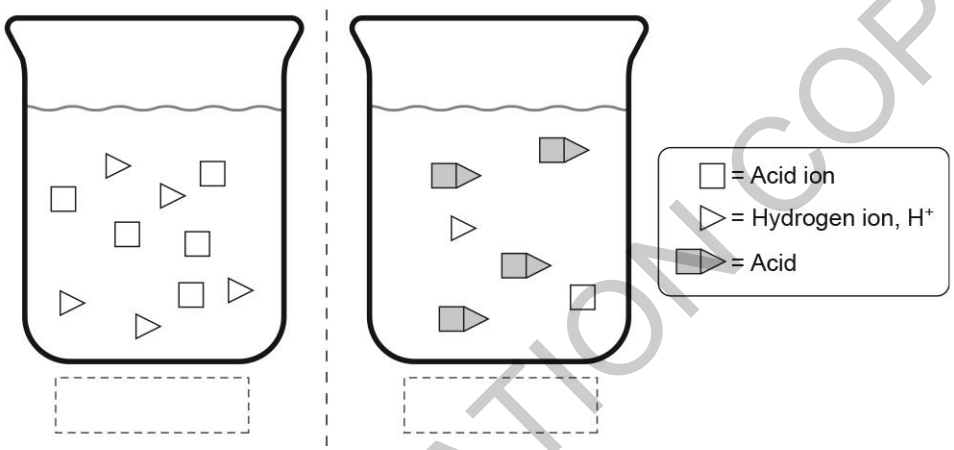
Getting Your Brain in Gear

1. Compare the ionization of a strong acid to that of a weak acid.

2. Acetic acid is a weak monoprotic acid. Circle the ionizable hydrogen on the formula below.



3. Analyze the following particulate-level representations of two acidic solutions. Label one beaker as the strong acid and the other as a weak acid. Explain your reasoning.



4. Write the K_a expression for the equation: $HA + H_2O \rightleftharpoons H_3O^+ + A^-$

5. Will the K_a of a weak acid be greater or less that the K_a of a strong acid? Why?

MODEL 1

Building Model 1 – pH Titration of a Weak Acid

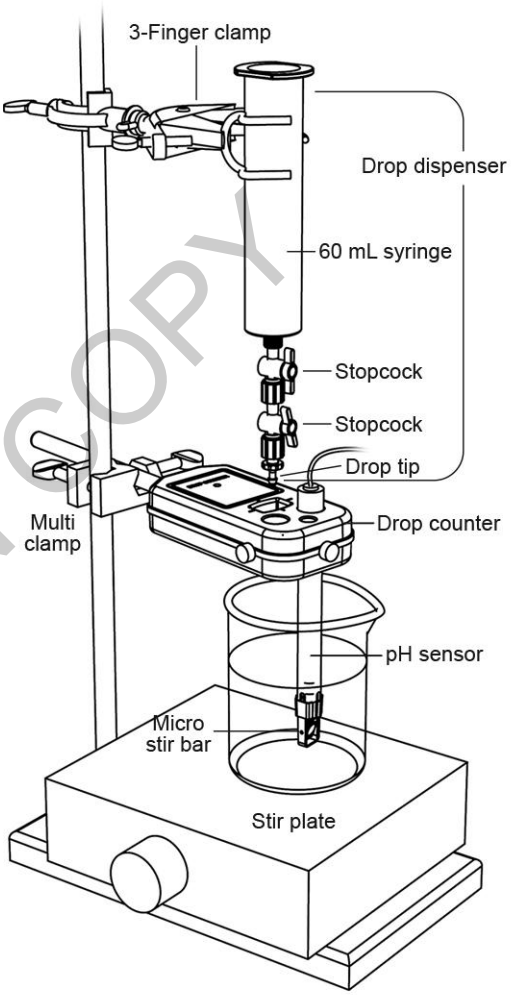
1. Start a new experiment on the data collection system.

2. If 0.50 M sodium hydroxide solution is the titrant and the weak acid, HA, is the analyte, which solution should go into the buret (or syringe) and which should go into the beaker?

_____

_____

_____



3. Use the multi-clamp to attach the drop counter to the ring stand. Use the illustration as a guide.

4. Use the three-finger clamp to attach the drop dispenser to the ring stand.

5. Rinse the drop dispenser syringe:

   a. Place a 250-mL beaker under the drop dispenser and open both stopcocks.

   b. Rinse the drop dispenser syringe and stopcock three times with approximately 20 mL of distilled water. This will remove any residue.

   c. Rinse the drop dispenser three times with 20 mL of the 0.5 M NaOH. This removes remaining water that would dilute the NaOH solution.

   d. Discard the rinse solution as directed by your teacher.

6. See Appendix A to set up and calibrate the drop counter and pH sensor and then set up the remaining equipment as illustrated.

   NOTE: Do not disconnect the drop counter from the data collection system or it will need to be calibrated again.

7. Display the pH on the *y*-axis of a graph and fluid volume on the *x*-axis.

8. Use the graduated pipet to transfer 10.00 mL of 1.00 M acetic acid solution to a 150-mL beaker and set the beaker on the magnetic stirrer as in the picture. Rinse the pipet with distilled water.

9. Add distilled water to the acid in the 150-mL beaker until the glass tip of the pH electrode is submerged.

10. In order for the tip of the pH electrode to be covered, distilled water must be added to the solution in the beaker.

    a. Does adding water to the analyte change the molarity of the sample?

    _____

    b. Does adding water to the analyte change the number of moles of acid in the sample?

    _____

    c. Will adding water to the analyte affect the volume of titrant needed to reach the equivalence point for the titration? Explain your answer.

    _____

    _____

11. Turn on the magnetic stirrer at a slow and steady rate.

12. Start recording data.

13. Turn the drop dispenser stopcock carefully, allowing the titrant to drip slowly at a rate of 1 to 2 drops per second into the solution.

    NOTE: The top valve controls the flow rate and the bottom valve turns the flow on and off.

14. Continue the titration until the pH curve flattens, at around pH 12–14.

15. Stop recording data.

16. Save your experiment and dispose of the contents of the beaker according to your teacher's instructions.

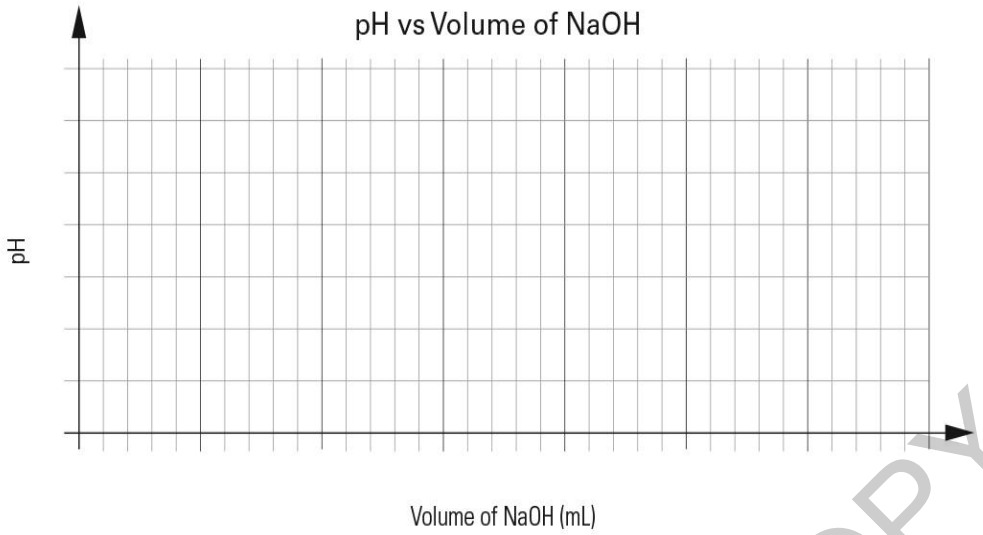
17. Sketch or attach a copy of your graph of pH versus volume of NaOH added to Model 1. In the Model 1 Data Table, record the concentration of the base and the weak acid, and the volume of the weak acid used.

Model 1 – pH Titration of a Weak Acid

Table 1: Model 1 Data Table—Determining the equivalence point

Titration Information	
Parameter	**Value**
Concentration of NaOH used (M)	
Concentration of CH_3COOH used (M)	
Volume of weak acid sample (mL)	

Model 1 Graph



Analyzing Model 1 – pH Titration of a Weak Acid

18. Write the net ionic equation for the neutralization being performed in the titration.

19. Answer the questions below to understand what information can be gained from a pH titration curve as the sodium hydroxide is added.

    a. Explain why the pH of the solution starts below 7.

_____

    b. What is happening to the pH of the weak acid solution as sodium hydroxide is added to the beaker? Explain what process is changing the pH.

_____

_____

_____

    c. The *equivalence point* represents the point in the titration where a *stoichiometrically equivalent* amount of base has been added to the acid. Using your graph, at what volume of titrant does this occur?

_____

_____

d. Describe the change in pH at or around the equivalence point.

e. Is the solution acidic, basic, or neutral at the equivalence point?

f. Using the net ionic equation for the reaction, identify the species present in the beaker at the equivalence point. Which species in the solution is responsible for the pH? Write a chemical reaction for that species reacting with water to support your answer.

20. The half-equivalence point is the volume of titrant halfway between the start of the titration and the equivalence point. Answer the questions below to determine the half-equivalence point on your titration curve and the information it provides.

a. Determine the volume of titrant at the half-equivalence point.

b. According to the titration curve, what is the pH at the half-equivalence point?

c. Calculate the concentration of hydronium ion, $[H_3O^+]$, at the half-equivalence point.

d. Calculate the number of moles of weak acid HA present before the titration and the number of moles that remain at the half-equivalence point.

e. Based on the balanced equation $CH_3COOH + OH^- \rightleftharpoons H_2O + CH_3COO^-$, calculate the number of moles of conjugate base A^- that have formed at the half-equivalence point.

f. How do the number of moles of HA and the number of moles of A^- compare at the half-equivalence point? Since the HA and A^- are in the same solution, how do the concentrations of HA and A^- compare at half equivalence point?

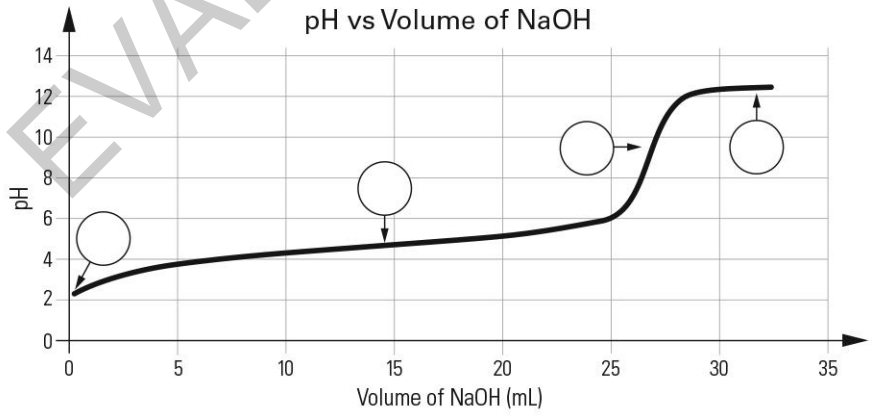
g. Write the acid ionization expression for a weak acid, HA.

h. Based on the relationship between the [HA] and [A^-] values, how can the acid ionization constant be simplified at the half-equivalence point?

i. How do the pK_a of the acid and the pH of the half-equivalence point compare?

j. Explain why the half-equivalence point is the most useful point on the titration curve for determining the K_a of an unknown acid.

21. Label the pH titration graph below with the letters corresponding to the following items:



a. The point in the titration where the pH is determined by the concentration and strength of the weak acid sample.

b. The point in the titration where the pH is determined by excess titrant.

c. The point in the titration where the pH is determined by the concentration and strength of the conjugate base of the weak acid.

d. The point in the titration where the pH is equal to the pK_a.

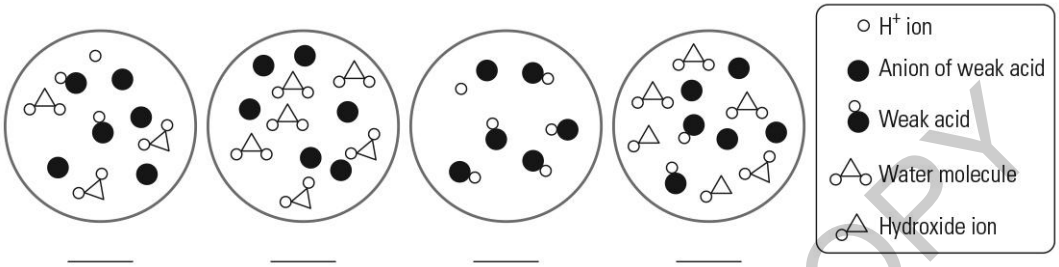
22. Label the particulate view pictures below with the letters corresponding to the following items:

a. Before the titration

b. Halfway to the equivalence point

c. At the equivalence point

d. After the equivalence point



23. An alternate way of doing the titration in Model 1 would be to use an acid–base indicator to determine the equivalence point. Ideally, the end point of the titration, the point at which an added indicator changes color, should occur at or near the equivalence point of the titration—the point where the acid has completely reacted with the base.

a. Using the pH titration curve that you created in Model 1, at what volume would each indicator below begin to change colors?

Table 2: Using indicators to detect the equivalence point

Indicator	Color Change	pH Where Change Occurs	Volume When Change Begins
Methyl red	Red to Yellow	4.2 to 6.3	
Bromothymol blue	Yellow to Blue	6.0 to 7.6	
Phenolphthalein	Clear to Pink	8.0 to 9.6	

b. Which indicator in the table above would have best identified the equivalence point of the titration in Model 1?

MODEL 2

Building Model 2 – pH Titration of a Weak Polyprotic Acid

NOTE: If the drop counter has been disconnected from the data collection system, it will need to be calibrated (see Appendix A).

1. Set up the titration as you did in Model 1. Use the graduated pipet to transfer 50.00 mL of 0.05 M maleic acid solution to a 150-mL beaker and set the beaker on the magnetic stirrer.

2. Add distilled water to the acid in the 150-mL beaker until the glass tip of the pH electrode is submerged.

3. Turn on the magnetic stirrer at a slow and steady rate.

4. Start recording data.

5. Turn the drop dispenser stopcock carefully, allowing the titrant to drip slowly at a rate of 1 to 2 drops per second into the solution.

6. Continue the titration until the pH curve flattens, at around pH 12–14.

7. Stop recording data.

8. Save your experiment and dispose of the contents of the beaker according to your teacher's instructions.

9. Sketch or attach a copy of your Model 2 graph of pH versus volume of NaOH added. In the Model 2 Data Table, record the concentration of the base and the weak acid, and the volume of the weak acid used.

Model 2 – pH Titration of a Weak Polyprotic Acid

Model 2 Graph

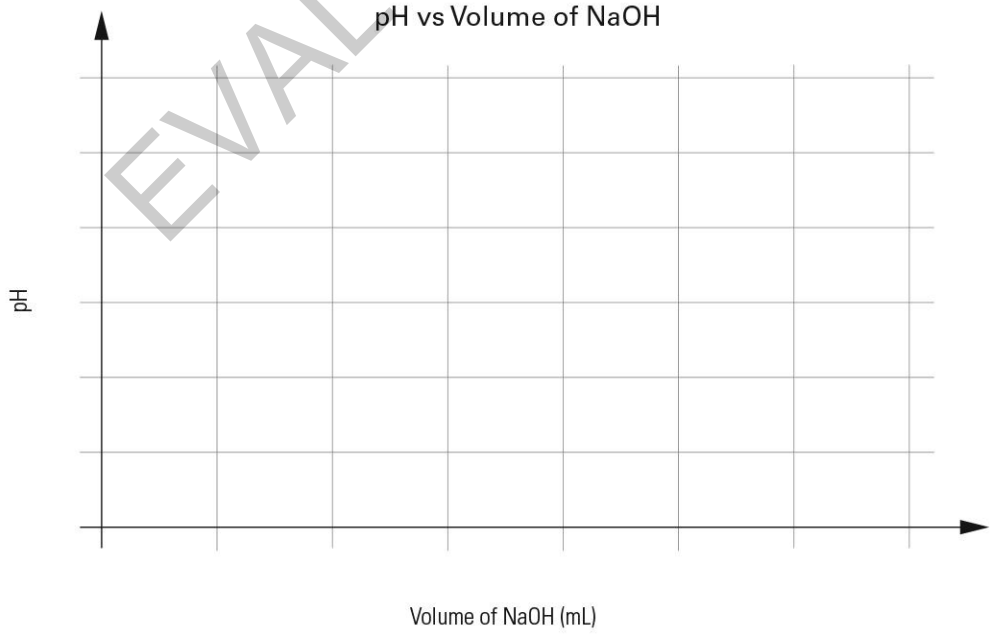
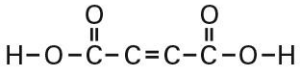


Table 3: Model 2 Data Table—Determining the equivalence point

Titration Information	
Parameter	**Value**
Concentration of NaOH used (M)	
Concentration of $C_3H_4O_4$ used (M)	
Volume of weak acid sample (mL)	

Analyzing Model 2 – pH Titration of a Weak Polyprotic Acid

10. Below is the structural formula for maleic acid. Circle the hydrogen atoms that can ionize.



11. What features are different on the Model 2 graph as compared to the graph in Model 1?

_____

_____

12. How is the structure of maleic acid related to the titration curve?

_____

_____

_____

13. Write the equation for the reaction of each hydrogen atom of maleic acid that ionizes with sodium hydroxide.

14. What volume of NaOH is required to reach each of the equivalence points?

_____

_____

15. Calculate the volume of titrant added to reach the half-equivalence point of each equivalence points.

16. Use the graph to determine the pH and pK_a at the half-equivalence points.

_____

17. Record the literature values of the pK_a for maleic acid.

_____

_____

18. What is the percentage of error between the literature values and the values you determined from the titration?

Connecting to Theory

K_a is the symbol for the equilibrium constant for the ionization of an acid. The following equation describes the ionization of an acid:

$$HA + H_2O \rightleftharpoons H_3O^+ + A^-$$

When equilibrium exists, the acid dissociation constant can be written as:

$$K_a = \frac{[H_3O^+][A^-]}{[HA]}$$

The value of K_a is an indication of the extent to which an acid dissociates. Strong acids dissociate nearly completely. Weak acids reach equilibrium, where the fraction that has dissociated remains constant at a given temperature. The numerical value of the equilibrium constant is unique to the acid and can be used to identify an unknown acid.

The half equivalence point is a very useful point in determining the K_a of an acid. At this point, the $[HA] = [A^-]$ so $K_a = [H_3O^+]$. Taking the negative log of both sides, the pK_a equals the pH.

Multiprotic acids are acids that have more than one acidic proton. Among organic molecules, those considered to be multiprotic have more than one carboxylic group (COOH).

$$K_{a1} = \frac{[H_3O^+][HA^-]}{[H_2A]}$$

$$K_{a2} = \frac{[H_3O^+][A^{2-}]}{[HA^-]}$$

If the K_a values for a multiprotic acid are distinct enough, then two equivalence points appear in a titration curve. But if the K_a values are too close, the multiprotic acid will not show titration curves with multiple equivalence points.

For example, fumaric acid has two acidic hydrogen atoms with the following K_a values:

$$K_{a1} = 9.33 \times 10^{-4}, \quad pK_{a1} = 3.03$$

$$K_{a2} = 3.63 \times 10^{-5}, \quad pK_{a2} = 4.44$$

where "1" and "2" refer to the first and second acidic hydrogen ions.

When fumaric acid is titrated, both acidic protons detach at nearly the same time and the two equivalence points are not easily detected. Usually the equivalence points show up as a single equivalence point somewhere between the two values.

Applying Your Knowledge – Determine the Amount of Acetylsalicylic acid in Aspirin

You will be given one solid aspirin tablet. Use titration to see if you can identify the acid in aspirin as acetylsalicylic acid based on the K_a value(s) and to determine if the amount of acetylsalicylic acid in the tablet matches the amount on the manufacturer's label.

NOTE: Acetylsalicylic acid is a weak acid and doesn't dissolve well. Therefore, for the titration, use a piece of the aspirin of approximately 0.1 g.

Before you perform the experiment, research and determine the following:

- How much acetylsalicylic acid is reported to be in one aspirin tablet, according to the bottle?

_____

- What is the percentage of acetylsalicylic acid in your aspirin?

- Being a weak acid, acetylsalicylic acid can be difficult to dissolve. Use approximately 0.1 g of aspirin for the titration. From the mass you measured, calculate the amount of acetylsalicylic acid in your sample.

- List observations that indicate the aspirin has fully dissolved.

_____

_____

_____

- What is the molecular formula and molar mass of acetylsalicylic acid?

_____

- Is acetylsalicylic acid monoprotic or polyprotic?

_____

- What are the equation(s) for the reaction(s) between acetylsalicylic acid and sodium hydroxide?

_____

_____

- Based on the literature value(s) of K_a for acetylsalicylic acid, how many equivalence points will you expect to see, and what are the value(s)?

After you have performed the experiment and collected your data, determine the percentage of error for K_a. Also determine the percentage difference in the reported mass of acetylsalicylic acid in one tablet and the experimental value based on your titration. Finally, identify at least three sources of error for your data.

15. INTRODUCTION TO BUFFERS

Initial Question

As you have seen in titration experiments, adding one drop of an acidic or basic solution to another solution can result in large changes in pH. However, many biological reactions only work within a narrow range of pH (between about 6 and 8). How does the body, a plant, or the soil keep the pH from changing drastically every time it comes in contact with an acid or base? In this lab, you will investigate solutions that help answer this question.

What is a buffer and what are the components of a buffer solution?

Materials and Equipment

Model 1

- Data collection system
- pH sensor
- Beaker (glass), 50-mL
- Graduated cylinder 25-mL
- Acetic acid (CH_3COOH), 20 mL
- Sodium acetate ($NaCH_3COO$) approx. 1 g
- Stirring rod
- Scoopula™ spatula
- Materials for pH sensor calibration (refer to Appendix A)

Model 2

- Data collection system
- pH sensor
- Beakers (5), 50-mL
- Graduated cylinder, 25-mL
- Graduated cylinder, 10-mL or volumetric pipet, 5-mL
- Solution 1: Distilled water, 20 mL
- Solution 2: 0.01 M Acetic acid (CH_3COOH), 20 mL
- Solution 3: 0.01 M Acetic acid (CH_3COOH) and 0.01 M Sodium acetate ($NaCH_3COO$), 20 mL
- Solution 4: 0.01 M Sodium bisulfate ($NaHSO_3$) and 0.01 M Sodium sulfate (Na_2SO_3), 20 mL
- Solution 5: 0.01 M Sodium bicarbonate ($NaHCO_3$) and 0.01 M Sodium carbonate (Na_2CO_3), 20 mL
- 0.01 M Sodium hydroxide (NaOH), 25 mL
- Stirring rod
- Wash bottle

Applying Your Knowledge

- Data collection system
- pH sensor
- Beakers (2), 100-mL
- Stirring rod
- Bufferin™ tablet, 325 mg
- Aspirin tablet, 325 mg
- Mortar and pestle
- Distilled water, 100 mL

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear goggles and work carefully to prevent spills
- Sodium hydroxide is corrosive. If you come in contact with it, flush the exposed area with large amounts of water.

Getting Your Brain in Gear

The Brønsted–Lowry Acid–Base Theory expands on the Acid–Base Theory of Svante Arrhenius. The Arrhenius theory is easy to use but covers a limited number of substances. Brønsted and Lowry developed a theory that includes far more. When discussing strong acids and bases, it is common practice to use the Arrhenius theory. When weak acids are involved, the Arrhenius theory is not always sufficient and other theories must be used.

1. What are the definitions of acids and bases according to Arrhenius?

   a. Acids

_____

_____

   b. Bases

_____

_____

2. What are the definitions of acids and bases according to Brønsted and Lowry?

   a. Acids

_____

_____

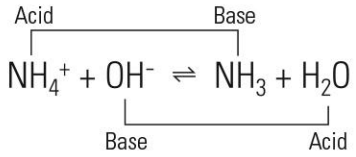
   b. Bases

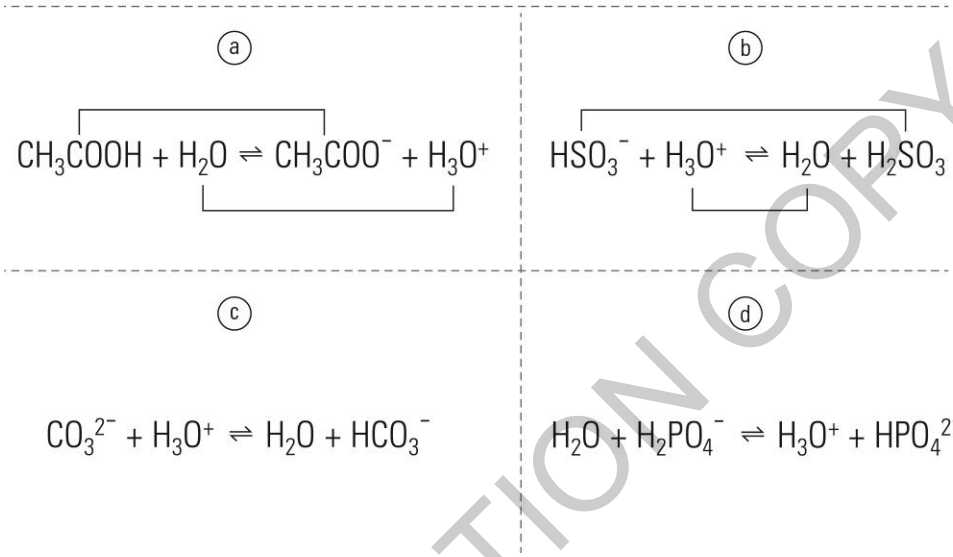
_____

_____

3. According to the Brønsted–Lowry theory, when acids and bases are combined, they react to form conjugate acid–base pairs. When weak acids and bases react, water often becomes a reactant. For items "a" and "b," add the labels "Acid" and "Base" to the appropriate molecule indicated by the bracket. For "c" and "d," first draw the brackets and then label the acid and base pairs.

   Example:





   e. What is different between the components of a conjugate acid–base pair?

_____

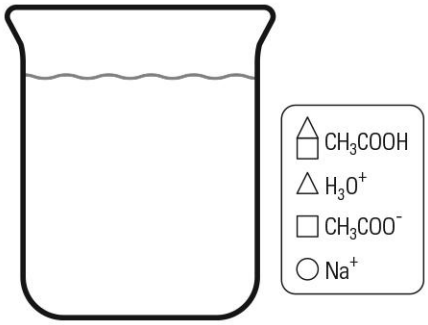
_____

4. In this lab, you will be working with mixtures of solutions, such as acetic acid (CH_3COOH) mixed with sodium acetate ($NaCH_3COO$).

   a. Write the net ionic equation for the reaction of $NaCH_3COO$ and CH_3COOH.

      NOTE: Water is a reactant.

b. In the beaker below, draw a particulate-level representation showing what the $NaCH_3COO$ and CH_3COOH solution looks like at the molecular level. You do not need to explicitly represent the water molecules. Use the particulate key as a guide.



c. What is the conjugate acid of CH_3COO^-?

_____

Model 1

Building Model 1 – Observing a Reaction System

1. Add 20 mL of acetic acid to a 50-mL beaker.
2. Calibrate the pH sensor.

   NOTE: You will need to re-calibrate the pH sensor for the other procedures if they are carried out in a different class period.
3. Measure the pH of the acetic acid solution and record the value in the Model 1 Data Table.

   NOTE: Make sure the glass bulb of the pH sensor is covered with solution.
4. Add a *pea size* amount of solid sodium acetate to the beaker. Use a stirring rod or gently swirl the solution until the sodium acetate dissolves.
5. Based on your reaction equation in the Getting Your Brain in Gear section, should the addition of $NaCH_3COO$ make the solution's pH increase, decrease or remain the same? Justify your answer.

_____

_____

6. Measure the pH of the solution and record the value in the Model 1 Data Table.

Model 1 – Observing a Reaction System

Table 1: Model 1 Data Table–pH change in acetic acid due to added sodium acetate

Solution	pH
Acetic acid	
Acetic acid and sodium acetate	

Analyzing Model 1 – Observing a Reaction System

7. Did the pH of the solution increase, decrease, or remain the same?

_____

8. a. Does $NaCH_3COO$ dissociate in water?

_____

   b How should the dissociation be represented in water, as $NaCH_3COO$ (aq) or $Na^+(aq) + CH_3COO^-(aq)$?

9. Two possible reaction equations are shown below.

Equilibrium: $CH_3COOH\ (aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3COO^-\ (aq)$

Stoichiometric addition: $CH_3COOH\ (aq) + NaCH_3COO(aq) \rightarrow NaCH_3COO\ (aq) + CH_3COOH\ (aq)$

Which of these reaction equations best explains the change in the pH observed? Justify your answer.

_____

_____

_____

10. Why is the Na^+ ion not shown in the equilibrium reaction?

_____

_____

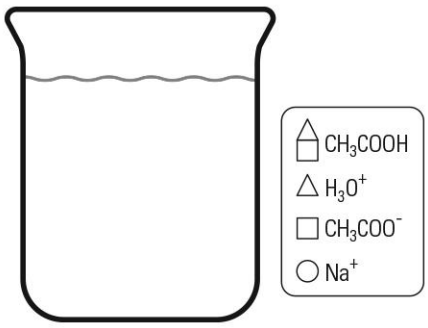
11. You answered the following questions in the Getting your Brain in Gear section. Revise your answer, if necessary, with the new information from Model 1.

In this lab, you will be working with mixtures of solutions, such as acetic acid (CH_3COOH) mixed with sodium acetate ($NaCH_3COO$).

a. Write a net ionic equation for the reaction of $NaCH_3COO$ and CH_3COOH.

NOTE: Water is a reactant.

b. In the beaker below, draw a particulate-level representation showing what the $NaCH_3COO$ and CH_3COOH solution looks like at the molecular level. You do not need to explicitly represent the water molecules. Use the particulate key as a guide.



MODEL 2

Building Model 2 – Observing the pH of Solutions

1. Using a graduated cylinder, measure 20 mL of each of the following five solutions into 50-mL beakers.

Table 2: Solutions to test

Solution #	Solution
1	Distilled water
2	0.01 M Acetic acid (CH_3COOH)
3	0.01 M Acetic acid (CH_3COOH) and 0.01 M Sodium acetate ($NaCH_3COO$)
4	0.01 M Sodium bisulfate ($NaHSO_3$) and 0.01 M Sodium sulfate (Na_2SO_3)
5	0.01 M Sodium bicarbonate ($NaHCO_3$) and 0.01 M Sodium carbonate (Na_2CO_3)

2. Measure the initial pH of each solution and record the results in the Model 2 Data Table.

   NOTE: Make sure the glass bulb at the bottom of the pH meter is covered with solution.

3. Using a graduated cylinder or volumetric pipet, add 5.0 mL of 0.01 M NaOH(aq) to each of the five solutions. Swirl each beaker gently and then measure and record the pH.

Model 2 – Observing the pH of Solutions

Table 3: Model 2 Data Table–Compare pH after adding 0.01 M NaOH

Solution Number	Solution	Initial pH	pH after Adding Base
1	Distilled water		
2	0.01 M Acetic acid (CH_3COOH)		
3	0.01 M Acetic acid (CH_3COOH) and 0.01 M Sodium acetate ($NaCH_3COO$)		
4	0.01 M Sodium bisulfate ($NaHSO_3$) and 0.01 M Sodium sulfate (Na_2SO_3)		
5	0.01 M Sodium bicarbonate ($NaHCO_3$) and 0.01 M Sodium carbonate (Na_2CO_3)		

Analyzing Model 2 – Observing the pH of Solutions

4. a. Which solution had the greatest change in pH?

_____

   b. Which solution had the least change in pH?

_____

5. A *buffer* is a solution that, upon addition of acid or base, does not have a large change in pH. Which of your solutions are buffers?

6. How are the two compounds present in each buffer solution related to one another?

7. Consider a buffer solution formed from 0.1 M HF and 0.1 M NaF.

   NOTE: NaF is soluble.

   a. What FOUR species, besides water, are extensively present in solution? (Hint: the 4th one is from the dissociation of HF.)

   b. Which of these ions is present as a spectator ion?

   c. What equilibrium exists for the remaining ions?

8. a. If a compound containing H^+ is added to this solution, what direction will the equilibrium reaction shift and what species is consumed in the process?

   b. Why is it necessary, then, to have NaF as well as HF present for this solution to behave as a buffer?

9. a. If a compound containing OH^- ions is added to this solution, what reaction will occur?

   b. What direction will the equilibrium reaction shift and what species is consumed in the process?

c. Why, then, is it necessary to have HF as well as NaF present for this solution to behave as a buffer?

_____

_____

10. The equilibrium reaction equation for the acetic acid/acetate buffer system is:

$$CH_3COOH(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3COO^-(aq)$$

a. Using the equilibrium reaction, explain why the pH changes only a little when a small amount of HCl is added.

_____

_____

_____

b. Using the equilibrium reaction, explain why the pH changes only a little if a small amount of NaOH is added to the buffer system above.

_____

_____

_____

11. Record the initial pH from the corresponding buffer systems in Model 2 in Table 4.

Table 4: Buffer systems

Solution Number	Buffer Solution Components	Initial pH	pK_a
3	0.01 M Acetic acid (CH_3COOH) and 0.01 M Sodium acetate ($NaCH_3COO$)		
4	0.01 M Sodium bisulfate ($NaHSO_3$) and 0.01 M Sodium sulfate (Na_2SO_3)		
5	0.01 M Sodium bicarbonate ($NaHCO_3$) and 0.01 M Sodium carbonate (Na_2CO_3)		

12. Chemists often characterize acids by their pK_a. The pK_a is defined as

$$pK_a = -\log(K_a)$$

The K_a of each of the acids and bases used in the buffers in Model 1 are given below. Calculate the pK_a for each and record them in Table 4.

acetic acid	$CH_3COOH\ (aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$	$K_a = 1.8 \times 10^{-5}$
bisulfite	$HSO_3^-\ (aq) \rightleftharpoons H^+(aq) + SO_3^{2-}(aq)$	$K_a = 1.0 \times 10^{-7}$
bicarbonate	$HCO_3^-\ (aq) \rightleftharpoons H^+(aq) + CO_3^{2-}(aq)$	$K_a = 5.6 \times 10^{-11}$

13. Identify a relationship between the pK_a of the acids and bases and the pH of the buffer solutions.

_____

_____

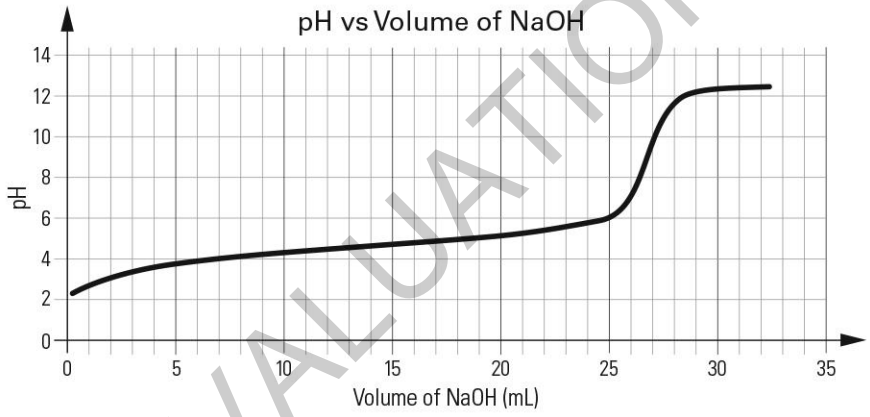
14. Use a reference source to find an acid that will be the foundation of a buffer solution with a pH of 6.5.

15. Suggest a compound that will provide a conjugate base for the acid you chose in the previous question.

_____

Connecting to Theory

Looking at a weak acid–strong base titration curve, you will find a region of the curve that is nearly flat in the acidic region. This occurs because, with this combination of reagents, a buffer solution has been created. As OH^- is added to a weak acid, the conjugate base is formed. The buffer solution created resists changes in pH, causing this region of the curve to appear relatively flat.



Applying Your Knowledge – Determining the Buffering Ability of Bufferin™

1. Obtain one 325 mg tablet of aspirin and a 325 mg tablet of Bufferin. Crush each tablet and place them in separate beakers containing 50 mL of distilled water. Stir until they are dissolved.

2. Measure and record the pH of each solution.

Table 5: Comparison of aspirin and Bufferin

Sample	pH
Aspirin	
Bufferin	

3. Record the active ingredients from the bottles of the two tablets you examined.

_____

_____

_____

4. Using words and reaction equations, explain the observed data.

_____

_____

_____

16. BUFFER PROPERTIES

Initial Question

Buffers are solutions that are resistant to changes in their pH when acids or bases are added. For example, human blood contains the bicarbonate ion. This ion can accept hydrogen ions to remove excess acidity in the blood or can donate hydrogen ions to remove alkalinity in the blood. Once the bicarbonate ions are used up, blood can rapidly become either too acidic or too basic. In other words, the bicarbonate buffer system in blood has a limited capacity.

How are buffers made, and what determines their capacity?

Materials and Equipment

Model 1

- Data collection system
- pH sensor
- Analytical balance
- Volumetric flask, 100-mL or 250-mL[1]
- Beakers (2), glass, 50-mL
- Sodium acetate ($NaCH_3COO$), about 1.0 g[2]
- Ammonium chloride (NH_4Cl), about 1.0 g[2]
- 0.3 M Acetic acid (CH_3COOH), 100 mL[2]
- 0.3 M Ammonia (NH_3), 100 mL[2]
- Distilled water, 150 mL[2]
- Marking pen

[1]The volume of the flask depends on the buffer assigned from the Model 1 Data Table.

[2]The volume and mass needed depends on the buffer assigned from the Model 1 Data Table.

Model 2

- Universal indicator, 3 drops
- Beral pipets (2)
- Test tubes (3), 20 mm × 150 mm, glass, 25-mL
- 0.10 M Hydrochloric acid (HCl), 20 mL
- 0.10 M Sodium hydroxide (NaOH), 20 mL
- Buffer solution from Model 1
- Distilled and deionized water

Applying Your Knowledge

- Data collection system
- pH sensor
- Beakers (2), 50-ml
- Volumetric flask, 100-ml
- Two of the following, to create 100 mL of buffer:
  - 0.3 M Acetic acid (CH_3COOH)
  - 0.3 M Sodium acetate ($NaCH_3COO$)
  - 0.3 M Sodium phosphate dibasic (Na_2HPO_4)
  - 0.3 M Sodium phosphate monobasic (NaH_2PO_4)
  - 0.3 M Ammonia (NH_3)
  - 0.3 M Ammonium chloride (NH_4Cl)
  - 0.3 M Potassium phosphate (K_3PO_4)
  - 0.3 M Phosphoric acid (H_3PO_4)
- 6 M Sodium hydroxide (NaOH), 5 drops[1]
- 6 M Hydrochloric acid (HCl), 5 drops[1]
- Stirring rod

[1]Your teacher will add the 5 drops of NaOH and HCl to test your buffer.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Wear your goggles.
- This lab uses strong acids and bases. If you come in contact with either of them, flush the area with plenty of water.

Getting Your Brain in Gear

1. For each solution described below, determine if it acts as a buffer. Explain your reasoning.

   a. 0.50 mole of HCl and 0.50 mole of NaCl in 250 mL of water

_____

_____

   b. 0.50 mole of HNO_2 and 0.50 mole of $NaNO_2$ in 250 mL of water

_____

_____

   c. 1.00 mole of CH_3COOH and 0.50 mole NaOH in 250 mL of water

_____

_____

2. Consider a buffer made of an equal number of moles of HF and NaF.

   a. Write a net ionic equation to illustrate how the buffer solution reacts to keep the pH stable when strong acid is added.

   b. Write a net ionic equation to illustrate how the buffer solution reacts to keep the pH stable when strong base is added.

MODEL 1

Building Model 1 – Buffer Preparation

1. After your instructor assigns you a buffer from Model 1 to prepare, refer to the Model 1 Data Table to determine the chemicals and the molarities you will need for your buffer.

   Solution assigned: _____

2. What component(s) of your assigned buffer system are available (refer to the Materials and Equipment list for Model 1)?

_____

_____

3. Calculate the number of moles of weak acid and conjugate base, or weak base and conjugate acid, you will need in the final solution to make the buffer you have been assigned.

4. Calculate the mass of the solid and volume of solution you will need to make your assigned buffer.

5. Obtain the appropriate size volumetric flask.

6. Fill the volumetric flask halfway with distilled water.

7. Obtain _____ grams of solid _____ and add it to the volumetric flask.

   NOTE: Do not *fill the flask with water.*

8. Use a graduated cylinder to measure _____ milliliters of _____ and add it to the volumetric flask. Swirl the flask to mix the solution.

9. Fill the volumetric flask to the mark with distilled water. Mix the solution thoroughly by inverting the flask several times.

10. Rinse a 50-mL beaker three times with distilled water.

11. Rinse the 50-mL beaker twice with small portions of your buffer solution.

12. Pour about 25 mL of your buffer solution into the 50-mL beaker and measure the pH of your solution. Record the pH in the Model 1 Data Table.

13. Why is it necessary to rinse the 50-mL beaker with distilled water, and then with the solution you want to test?

_____

_____

_____

14. Label and save your remaining buffer for building Model 2. Share your pH data with your classmates to complete the Model 1 Data Table.

Model 1 – Buffer Preparation

Table 1: Model 1 Data Table—pH of buffers of different volumes and concentrations

Solution Number	Molarity of Weak Base	p*Ka*	Molarity of Conjugate Acid	Ratio of Weak Base to Conjugate [BOH] / [B+]	Total Volume of Buffer Solution	pH of Buffer Solution	$\lvert pK_a - pH \rvert$
1	0.05 M NH_3		0.05 M NH_4^+		100 mL		
2	0.10 M NH_3		0.10 M NH_4^+		100 mL		
3	0.10 M NH_3		0.10 M NH_4^+		250 mL		
4	0.15 M NH3		0.15 M NH_4^+		100 mL		
5	0.15 M NH_3		0.05 M NH_4^+		100 mL		
6	0.05 M NH_3		0.15 M NH_4^+		100 mL		
Solution Number	**Molarity of Weak Acid**	**p*Ka***	**Molarity of Conjugate Base**	**Ratio of Weak Acid to Conjugate [HA] / [A^-]**	**Total Volume of Buffer Solution**	**pH of Buffer Solution**	**$\lvert pK_a - pH \rvert$**
7	0.05 M CH_3COOH		0.05 M CH_3COO^-		100 mL		
8	0.10 M CH_3COOH		0.10 M CH_3COO^-		100 mL		
9	0.10 M CH_3COOH		0.10 M CH_3COO^-		250 mL		
10	0.15 M CH_3COOH		0.15 M CH_3COO^-		100 mL		
11	0.15 M CH_3COOH		0.05 M CH_3COO^-		100 mL		
12	0.05 M CH_3COOH		0.15 M CH_3COO^-		100 mL		

Analyzing Model 1 – Buffer Preparation

15. Use a reference source to look up the K_a and determine the pK_a of the weak acid or conjugate acid involved in each of the solutions in the Model 1 Data Table.

16. Calculate the weak acid or weak base to conjugate ratio for each buffer solution in Model 1.

    a. Which ratios of weak acid or weak base to the conjugate solution have the pH of the buffer the closest to the pK_a?

17. Compare the buffers having the same molarity of components, but with different total volumes. Does the volume of the buffer system prepared affect the pH of the resulting solution? Provide specific examples from Model 1 to support your answer.

18. How would you respond to a person who mistakenly said "Buffers are made so that the solution remains neutral"? Provide specific examples from Model 1 to support your answer.

19. Suppose you wanted to make a buffer solution that would keep the pH near 3. Which of the following mixtures would suffice?

Solution A	0.10 M lactic acid and 0.10 M sodium lactate
Solution B	0.10 M hypochlorous acid 0.10 M sodium hypochlorite
Solution C	0.10 M benzoic acid and 0.10 M sodium benzoate

MODEL 2

Building Model 2 – Buffer Capacity

1. Rinse three test tubes several times with distilled water. Assign one pipet for the deionized water, one for the buffer, and one for the universal indicator.

2. Place 10 drops of deionized water in a test tube. Add one drop of universal indicator to the water and note the initial color. Add 0.10 M HCl solution drop-wise, mixing between drops, until the solution changes to red-orange (pH ≤ 3). In Model 2, record the number of drops of HCl solution added to make this color change occur.

3. Place 10 drops of your buffer solution in a test tube. Add one drop of universal indicator to the solution and note the initial color. Add 0.10 M HCl solution drop-wise, mixing between drops, until the solution changes to red-orange (pH ≤ 3). Record the number of drops of HCl solution added to make this color change occur.

   NOTE: If your solution contains CH_3COOH and CH_3COO^-, then don't carry out this step.

4. Place 10 drops of deionized water in a test tube. Add one drop of universal indicator to the water, and note the initial color. Add 0.10 M NaOH solution drop-wise, mixing between drops, until the solution changes to purple (pH ≥ 11). Record the number of drops of NaOH solution added to make this color change occur.

5. Place 10 drops of your buffer solution in a test tube. Add one drop of universal indicator to the solution, and note the initial color. Add 0.10 M NaOH solution drop-wise, mixing between drops, until the solution changes to purple (pH ≥ 11). Record the number of drops of NaOH solution added to make this color change occur.

   NOTE: If your solution contains NH_4^+ and NH_3, then don't carry out this step.

6. Share your data with your classmates to complete the Model 2 Data Table.

Model 2 – Buffer Capacity

Drops of HCl needed in distilled water to turn the color red-orange: _____

Drops of NaOH needed in distilled water to turn the color purple: _____

Table 2: Model 2 Data Table—Comparing buffer capacity

Solution Number	Molarity of Weak Base	Molarity of Conjugate Acid	Total Volume of Buffer Solution	Drops of HCl Needed	Drops of NaOH Needed
1	0.05 M NH_3	0.05 M NH_4^+	100 mL		
2	0.10 M NH_3	0.10 M NH_4^+	100 mL		
3	0.10 M NH_3	0.10 M NH_4^+	250 mL		
4	0.15 M NH_3	0.15 M NH_4^+	100 mL		
5	0.15 M NH_3	0.05 M NH_4^+	100 mL		
6	0.05 M NH_3	0.15 M NH_4^+	100 mL		
Solution Number	**Molarity of Weak Acid**	**Molarity of Conjugate Base**	**Total Volume of Buffer Solution**	**Drops of HCl Needed**	**Drops of NaOH Needed**
7	0.05 M CH_3COOH	0.05 M CH_3COO^-	100 mL		
8	0.10 M CH_3COOH	0.10 M CH_3COO^-	100 mL		
9	0.10 M CH_3COOH	0.10 M CH_3COO^-	250 mL		
10	0.15 M CH_3COOH	0.15 M CH_3COO^-	100 mL		
11	0.15 M CH_3COOH	0.05 M CH_3COO^-	100 mL		
12	0.05 M CH_3COOH	0.15 M CH_3COO^-	100 mL		

Analyzing Model 2 – Buffer Capacity

The *buffer capacity* of a solution is related to the number of moles of acid and base that the solution can neutralize without a significant change in pH.

For each set of solutions shown below, consider the similarities and differences in their components. Refer to both the Model 1 Data Table and the Model 2 Data Table.

7. Compare the buffer volume, molarity, and pH:

   a. What is the molarity ratio of weak base to conjugate acid in solutions 2 and 3?

_____

   b. Was there a change in pH between solutions 2 and 3?

_____

   c. What is the molarity ratio of weak acid to conjugate base in solutions 8 and 9?

_____

d. Was there a change in pH between solutions 8 and 9?

_____

e. For solutions 2 and 3, and solutions 8 and 9, was there a difference in the number of drops of HCl or NaOH needed to obtain pH 1 or pH 14?

_____

f. Considering the previous questions, what can be concluded about changing the volume of the buffer system without changing the ratio of weak acid to conjugate base, or weak base to conjugate acid, and its effect on pH?

_____

_____

8. The following questions compare the number of moles of each buffer system component and the buffer capacity in solutions of equal volume:

a. What is the ratio of the number of moles of weak base between solutions 1 and 2 and between solutions 1 and 4?

_____

b. Was there a change in pH between solutions 1, 2 and 4?

_____

c. What is the ratio of the number of moles of weak acid between solutions 7 and 8 and between 7 and 10?

_____

d. Was there a change in pH between solutions 7, 8, and 10?

_____

e. For solutions 1, 2, and 4, and solutions 7, 8, and 10, was there a difference in the number of drops of HCl or NaOH needed to obtain pH 1 or pH 14?

_____

f. Considering the previous questions, what can be concluded about buffer capacity and concentration? Give evidence from your data to support your answer.

_____

_____

_____

9. Do buffer systems stop the pH from changing? Give evidence from your data to support your answer.

_____

_____

_____

10. Do buffers with greater concentrations have greater buffer capacity? Give evidence from your data to support your answer.

_____

_____

_____

11. If you wanted to make a buffer of pH 9.5 with a buffer capacity greater than that in Solution 1 of Model 2, what would have to change in the buffer system?

_____

_____

Connecting to Theory

Buffers are made from a weak acid or base and their respective conjugate. Two nutritional labels are shown below. One is from Monster Energy® drink and the other is from Mountain Dew®. By inspecting each label, you should be able to identify an acid and its conjugate. Together these form a buffer solution.

Remember, when acids are made from polyatomic acids, their ending is changed to "ic." The polyatomic ion of the conjugate will have an "ate" ending.

Nutrition Facts
Monster MW2 Assault Energy Drink
Serving Size - 8 fl. oz.
Servings per container - 2

Amount Per Serving
Calories - 100
Total Carb - 25g
Sugars - 25g
Vitamin B2 - 1.7mg
Vitamin B3 - 20mg
Vitamin B6 - 2mg
Vitamin B12 - 6mcg
Sodium - 1000mg
Taurine - 1000mg
Panax Ginseng - 200mg
Energy Blend - 2500mg

Ingredients: Carbonated Water, Sucrose, Glucose, Citric Acid, Sodium Citrate, Taurine, Natural Flavors, Panax Ginseng Root Extract, Phosphoric Acid, L-Caratine, Caffeine, Sorbic Acid, Benzoic Acid, Caramel Color, Niacinamide, Sucralose, Sodium Chloride, Glucuronolactone, Inositol, Gurana Seed Extract, Certified Color, Pyrodozine Hydrochloride, Riboflaven, Maltodextrin, Cyanocobalamin

Consume Responsibly - Limit 3 cans per day. Not recommended for children, pregnant women, or people sensitive to caffeine.

Nutrition Facts
Halo 3 Mountain Dew Game Fuel
Serving Size - 1 Can

Amount Per Serving
Calories - 170
Total Carb - 0g
Sodium - 65mg
Total Carbohydrates - 46g
Sugars - 46g
Protein - 0g

Caffeine Content: 73mg/12 fl. oz.

Ingredients: Carbonated Water, High Fructose Corn Syrup, Citric Acid, Natural Flavors, Sodium Benzoate, Gum Arabic, Caffeine, Sodium Citrate, Yellow 5, Gylcerol Ester of Wood Rosin, Cacium Disodium Edta, Yellow 6, Red 40, Brominated Vegetable Oil

Halo 3 Mountain Dew Game Fuel is not a significant source of other nutrients.

Applying Your Knowledge – Making Your Own Buffer System

Listed below are solutions that can be combined to make buffers. Your teacher will assign you a pH. Your job will be to make 100 mL of a buffer solution with that pH, using these components.

After your teacher measures the initial pH, you will divide your solution between two beakers.

Your teacher will add 5 drops of 6.0 M HCl to one beaker and measure the pH to determine if it has changed. Five drops of 6.0 M NaOH will be added to the other beaker and similar measurements will be made.

Your first task is to find all of the conjugate relationships in the list below. Show each relationship and the information needed to calculate the pH for each. You need to be ready to prepare the solution that matches the assigned pH.

- 0.3 M Ammonium chloride (NH_4Cl)
- 0.3 M Sodium acetate ($NaCH_3COO$)
- 0.3 M Sodium phosphate dibasic (Na_2HPO_4)
- 0.3 M Phosphoric acid (H_3PO_4)
- 0.3 M Potassium phosphate (K_3PO_4)
- 0.3 M Sodium phosphate monobasic (NaH_2PO_4)
- 0.3 M Acetic acid (CH_3COOH)
- 0.3 M Ammonia (NH_3)

17. MOVING ELECTRONS

Initial Question

Reactions that occur without outside intervention are said to occur spontaneously. Non-spontaneous reactions can occur if some outside factor provides enough energy. Electrolysis is the process of using electricity to force a non-spontaneous reaction to occur. Electrolysis can be used to separate pure metals from their ore and plate metals onto surfaces.

How can you make a non-spontaneous reaction do useful things?

Materials and Equipment

All Models

- Data collection system
- Voltage–current sensor
- Wire leads, 2 red, 1 black
- Electrodes (2)
- Alligator clips (4), 2 red, 2 black
- 9 V Battery
- 9 V Battery cap with leads
- Beaker, glass, 400-mL
- Stirring rod
- Wash bottle with distilled water

Model 1

- Test tubes (2), 10 mm × 75-mm
- Universal indicator, 20 drops
- Scoopula™ spatula
- Epsom salt (Magnesium sulfate, $MgSO_4$), 4–6 marble-size scoops
- Distilled water, 600 mL

Model 2

- Potassium iodide, KI, 1 marble-size scoop
- Scoopula™ spatula
- Copper(II) bromide, ($CuBr_2$), 1 marble-size scoop
- Distilled water, 600 mL

Model 3

- Copper strip
- Steel wool
- Metals strip, spoon, or key
- 1.0 M Copper(II) sulfate ($CuSO_4$), 100 mL
- Analytical balance, 1 per class

Applying Your Knowledge

- Copper strip
- Steel wool
- Metal strip, spoon, or key
- 1.0 M Copper(II) sulfate, ($CuSO_4$), 100 mL
- Analytical balance, 1 per class

Safety

Add these important safety precautions to your normal laboratory procedures:

- Potassium iodide and copper(II) bromide solutions may cause skin irritation. If you come in contact with either of them, flush the area with plenty of water.

Getting Your Brain in Gear

1. The following reaction is a spontaneous oxidation–reduction reaction:

$$Cu^{2+}(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + Cu(s)$$

   a. What is the oxidation half-cell reaction?

_____

   b. What is the reduction half-cell reaction?

_____

   c. Using a standard reduction potential table, what is the overall standard cell potential for this reaction?

   d. How can we say that this reaction is spontaneous?

_____

_____

2. What is the oxidation number for sulfur in sulfate (SO_4^{2-})?

_____

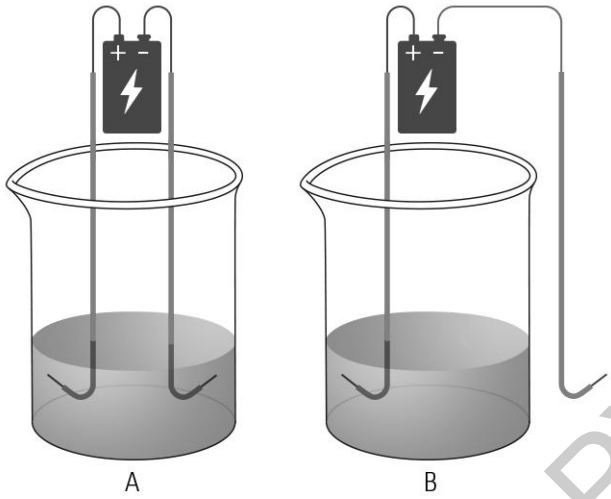
3. When you use universal indicator, what ion is present if the solution is in the range of orange to red? What ion is present if the solution is in the range of blue to purple? What does a blue-green solution color indicate?

_____

_____

_____

4. Like water moving in a stream, the movement of electrons through a circuit is called a *current*. Which of these ionic solutions would have a current? Justify your answer.



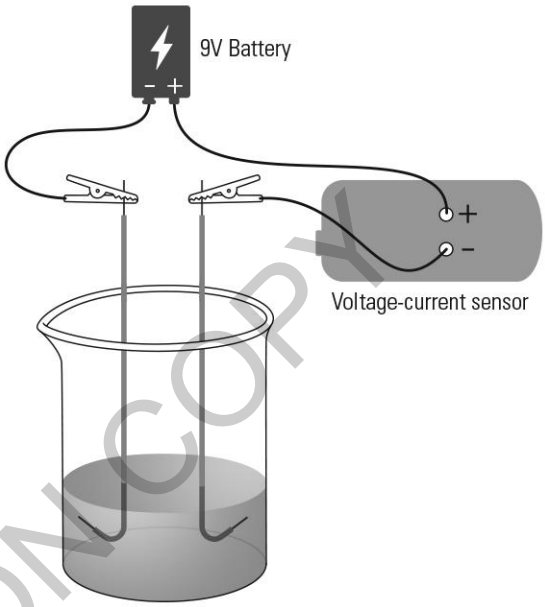
MODEL 1

Building Model 1 – Electrolysis of Water

1. Connect the voltage–current sensor to the data collection system.

2. Set up the electrodes, 9 V battery, and voltage-current sensor as shown in the circuit diagram. Place the alligator clips over the banana plugs when needed to connect to wires or electrodes.

   NOTE: You will use this setup for the rest of the lab.



3. Create a graph of current versus time.

4. Add approximately 300 mL of deionized water to a 400-mL beaker (fill it to the 300-mL line). Place the electrodes into the water and start collecting data.

5. Record the current in the Model 1 Data Table.

6. Add 2–3 marble-size scoops of Epsom salt ($MgSO_4$) to the distilled water.

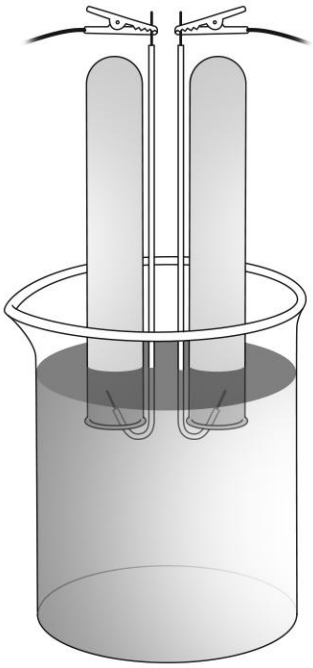
7. Stir the mixture to dissolve the Epsom salt. Be careful not to hit the electrodes.

8. Record the current and your observations in the Model 1 Data Table.

9. Stop data collection.

10. Disconnect the circuit from the battery and obtain a fresh sample, 300 mL, of deionized water. Rinse the electrodes and place them back in the beaker.

11. With the battery still disconnected, add 2–3 scoops of the Epsom salt and 10 drops of universal indicator. The indicator will turn blue to purple in basic solutions and orange to red in acidic solutions.



12. Stir the solution. Once all of the Epsom salt has dissolved, record the color of the solution in the Model 1 Data Table.

13. Completely fill two test tubes with the Epsom salt solution. Cover the test tubes with your fingers to hold the solution in. Invert them into the beaker so the solution does not spill. Remove your fingers once the test tubes are inverted in the solution.

    NOTE: Magnesium sulfate (Epsom salt) is non-toxic (it is often added to bath water).

14. Insert the electrodes into the openings of the inverted test tubes.

15. Start data collection and reconnect the battery.

16. Record the current and your observations in the Model 1 Data Table.

17. After 2 minutes, stop data collection and disconnect the battery.

Model 1 – Electrolysis of Water

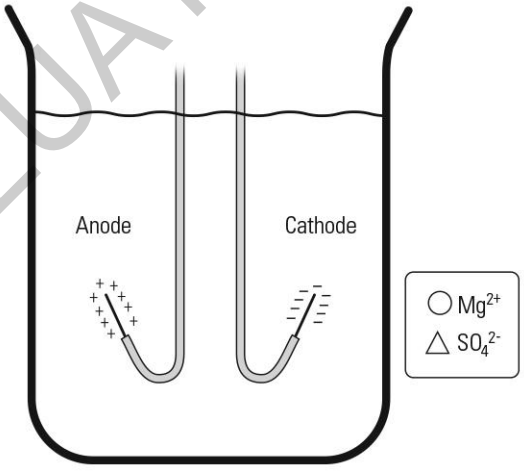
Table 1: Model 1 Data Table—Determine the half-reactions

Solution	Current (A)	Observations
Deionized water		
Deionized water + magnesium sulfate		
Deionized water + magnesium sulfate + universal indicator, *before* battery is connected		
Deionized water + magnesium sulfate + universal indicator, *after* battery is connected		

Analyzing Model 1 – Electrolysis of Water

18. Why does the current change when the magnesium sulfate is added to water?

19. Draw a particulate-level representation of the Epsom salt solution. Predict which way the ions flow.



20. The cathode of the electrolytic cell was attached to the negative end of the battery. At the cathode, reduction occurred. In this cell, the reaction could be

$$Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$$

OR

$$2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$$

Based on your observations, which reaction occurred? Justify your answer.

_____

_____

_____

21. The anode of the electrolytic cell is attached to the positive end of the battery (through the voltage–current sensor). Based on your observations, what is one of the products of this oxidation? Explain.

_____

_____

22. The sulfur in sulfate is already in a very high oxidation state so it is safe to assume that the water, not sulfur, is being oxidized at the anode. What is the balanced half-cell reaction equation for the reaction occurring at the anode?

_____

23. Based on the oxidation and reduction half-reactions, what is the overall balanced equation for the electrolysis?

MODEL 2

Building Model 2 – Electrolysis of Potassium Iodide and Copper(II) Bromide

Electrolysis of Potassium Iodide

1. Connect the voltage–current sensor to the data collection system.
2. Set up the electrodes, the 9 V battery, and current sensor as in Model 1.
3. Create a graph of current versus time.
4. Obtain a fresh 300-mL sample of deionized water. Rinse the electrodes and place them back in the beaker.
5. With the battery still disconnected, add one marble-size scoop of potassium iodide. Stir the solution, taking care not to hit the electrodes.

6. After the potassium iodide has dissolved, start data collection and connect the battery.

7. Record the current and your observations in the Model 2 Data Table.

8. After about 30 seconds, stop data collection and disconnect the battery.

Electrolysis of Copper(II) Bromide

9. Obtain a fresh 300-mL sample of deionized water. Rinse the electrodes and place them back in the beaker.

10. With the battery still disconnected, add a marble-size scoop of copper(II) bromide. Stir the solution, taking care not to hit the electrodes.

11. Start data collection and reconnect the battery.

12. Record the current and your observations in the Model 2 Data Table.

13. After 30 seconds, stop data collection and disconnect the battery.

Model 2 – Electrolysis of Potassium Iodide and Copper(II) Bromide

Table 2: Model 2 Data Table—Anode and cathode activity

Solution	Current (A)	Observations
Deionized water with potassium iodide		
Deionized water with copper(II) bromide		

Analyzing Model 2 – Electrolysis of Potassium Iodide and Copper(II) Bromide

14. When the electrodes were placed in the KI solution, there were two possible reduction reactions that could occur at the cathode:

$$K^+(aq) + e^- \rightarrow K(s)$$

OR

$$2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$$

Which reaction occurred? Justify your answer.

_____

_____

_____

15. When the electrodes were placed in the KI solution, there were two possible oxidation reactions that could occur at the anode:

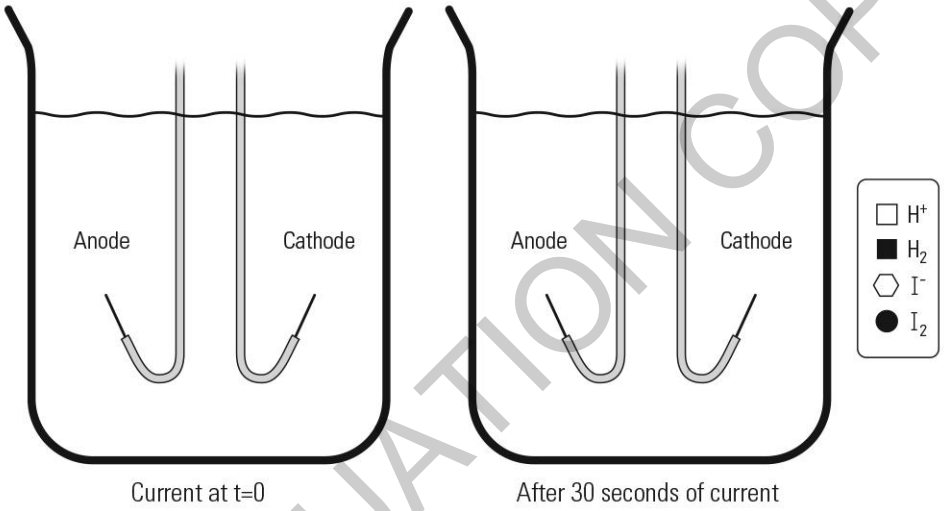
$$2I^-(aq) \rightarrow I_2(s) + 2e^-$$

OR

$$2H_2O \rightarrow O_2(g) + 4e^- + 4H^+(aq)$$

Which reaction occurred? Justify your answer.

16. Draw a particulate-level representation of the potassium iodide solution immediately after the current started and then after 30 seconds later. Add the charge on each electrode.



17. Based on your observation, how is the half-reaction cell voltage related to the reaction that occurs experimentally?

Table 3: Potentials for KI and H_2O half-reactions

Half-Reaction	E°
$K^+(aq) + e^- \rightarrow K(s)$	–2.93 V
$2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$	–0.83 V
$2I^-(aq) \rightarrow I_2(s) + 2e^-$	–0.53 V
$2H_2O \rightarrow O_2(g) + 4e^- + 4H^+(aq)$	–1.23 V

18. The aqueous solution in Model 1 contains magnesium sulfate. Magnesium ions and sulfate ions have the following reduction and oxidation reactions and potentials:

$Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$ $\quad E^o = -1.18$ V

$2SO_4^{2-}(aq) \rightarrow S_2O_8^{2-}(aq) + 2e^-$ $\quad E^o = -2.05$ V

Why did neither of these half-reactions occur when the magnesium sulfate solution was electrolyzed?

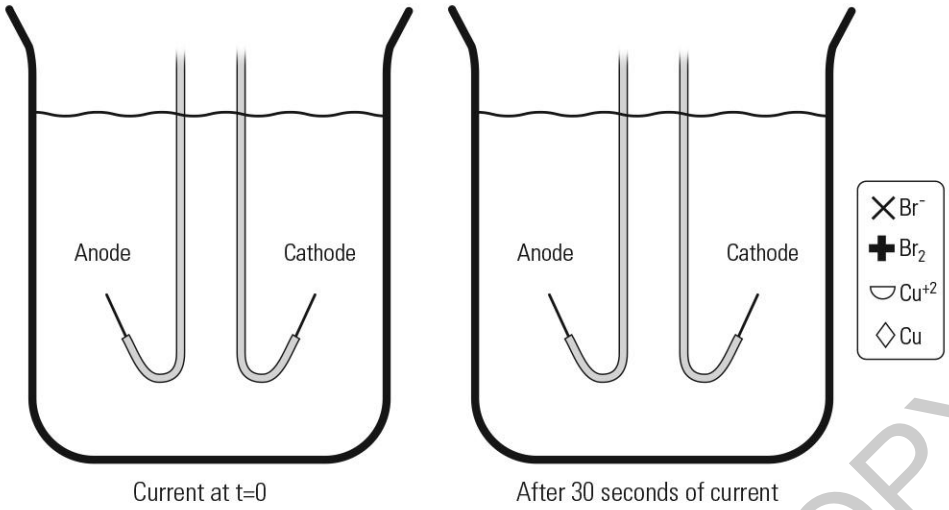
19. What are the two possible reduction reactions and their half-cell potentials that could occur when the electrodes are placed in the copper(II) bromide solution?

20. Which reduction reaction occurred when a solution of copper(II) bromide was electrolyzed? Give a theoretical and an experimental justification for your answer.

21. What are the two possible oxidation reactions that could occur when the electrodes are placed in the copper(II) bromide solution?

22. Which oxidation process occurred when a solution of copper(II) bromide was electrolyzed? Give a theoretical and an experimental justification for your answer.

23. Draw a particulate-level representation of the copper(II) bromide solution immediately after the current started and then 30 seconds later. Add the charge on each electrode.



MODEL 3

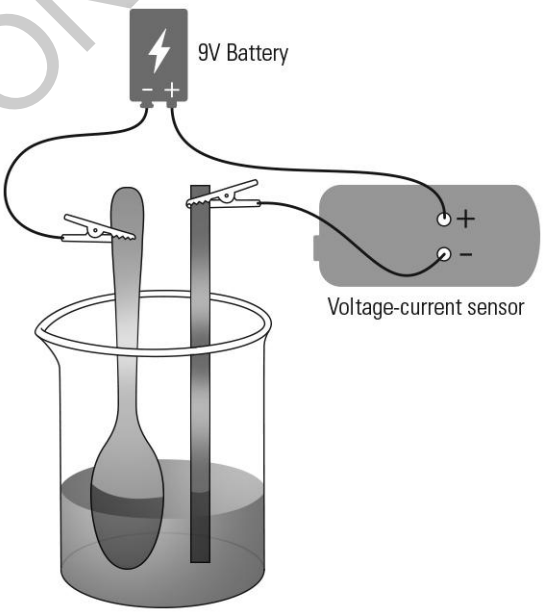
Building Model 3 – Charge and Number of Electrons

1. Your teacher will assign each group an amount of time to carry out the reaction.

2. Connect the voltage–current sensor to the data collection system.

3. Set up the electrodes, 9 V battery, and voltage–current sensor as in Model 1, except use a spoon or metal strip as one of the electrodes and a clean, shiny copper strip as the other. Do not let the spoon come in contact with the other electrode; it will cause a short circuit.

4. Clean the copper strip with steel wool if necessary and rinse it with distilled water. Leave the copper strip out of the solution until you are ready to start data collection. Dry the copper strip and measure its mass. Record the mass in the Model 3 Data Table next to the reaction time assigned to your group.



5. Create a graph of current versus time.

6. Rinse the beaker and obtain 100 mL of 1.0 M copper(II) sulfate (fill the beaker to the 100-mL line).

7. When the battery is connected, there are two possible reduction reactions that could occur at the cathode in the copper(II) sulfate solution:

$Cu^{+2}(aq) + 2e^- \rightarrow Cu(s)$ $\quad E^o = 0.34$ V OR

$2H_2O + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ $\quad E^o = -0.83$ V

Which reaction will occur and why?

8. When the battery is connected, there are two possible reduction reactions that could occur at the anode in the copper(II) sulfate solution:

$Cu(s) \rightarrow Cu^{+2}(aq) + 2e^-$ $\quad E^o = -0.34$ V OR

$2H_2O \rightarrow O_2(g) + 4e^- + 4H^+(aq)$ $\quad E^o = -1.23$ V

Which reaction will occur and why?

9. Based on the half-reactions that occur at the anode and cathode, what physical observations could you make during this reaction? Is the copper strip the anode or the cathode?

10. Start data collection and connect the battery.

11. Record the current in the Model 3 Data Table.

12. After the assigned time has elapsed, disconnect the battery and stop data collection.

13. Carefully remove the strip of copper and the spoon.

14. Dry the copper strip. Record the mass of the copper strip in the Model 3 Data Table.

15. Share your measurements with your classmates to complete the columns of initial and final mass of the copper strip in the Model 3 Data Table.

Model 3 – Charge and Amount in Moles

Table 4: Model 3 Data Table— Aqueous to solid

Reaction Time (min)	Current (A)	Initial Mass of Copper Strip (g)	Final Mass of Copper Strip (g)	Change in Mass of Copper (g)	Number of Moles of Copper Reacted (mol)	Number of Moles of Electrons (mol)	Charge (C)	Ratio: Charge/ Number of Moles of Electrons (C/mol e^-)
5								
7								
9								
11								
13								
15								
Average ratio of charge to the number of moles of electrons:								

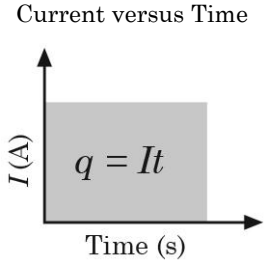
Analyzing Model 3 – Charge and Amount in Moles

16. Calculate the change in mass of the copper or each reaction time. Record these values in the Model 3 Data Table.

17. For each reaction time, use the change in mass of copper of the copper strip to calculate the number of moles of copper that reacted and record the results in the Model 3 Data Table.

18. Use the half-reaction and the number of moles of copper lost by the copper strip to calculate the number of moles of e^- that reacted. Record the results in the Model 3 Data Table.

19. By plotting current (A) versus time (s), and using the equation $q = It$, where q is the charge measured in coulombs (abbreviated as "C"), the current I is measured in amperes (abbreviated as "A"), and time t is measured in seconds, you can determine the charge required—the charge is the area under the curve. Calculate the charge and record it in the Model 3 Data Table.



20. What happens to the change in mass of copper as the charge increases?

_____

_____

21. Calculate the ratio of charge to the number of moles of electrons for all of the reaction times and record it the Model 3 Data Table.

22. What is the average ratio of the charge to moles of electrons for your data?

_____

_____

23. Is the ratio of charge to moles of electrons consistent for all the groups?

_____

_____

Connecting to Theory

Michael Faraday was one of the greatest experimental scientists. He was self-taught and felt uncomfortable with his math abilities so would rely on other scientists for help. Faraday has influenced modern chemistry, environmentalism, and physics. For nineteen years he would show off his discoveries during Christmas Lectures, which were designed to inspire young scientists. His Christmas Lectures became a tradition and continue to this day at the Royal Institution in London.

In Model 3, you calculated the ratio of charge to the number of moles of electrons. This ratio is known as Faraday's constant. A Faraday F is equal to 96,485 coulombs per mole of electrons. It is usually expressed as

$$F = \frac{96{,}485 \text{ coulumbs}}{1 \text{ mole } e^-}$$

Applying Your Knowledge – Plating Copper on a Spoon

Electroplating is the process of coating an electrically conductive object with a layer of metal using an electric current. The process, also known as electrodeposition, is used to improve the appearance and increase hardness and corrosion resistance of the plated objects.

After calculating the length of time it will take to plate 0.1 g of copper onto a spoon, create an electroplating cell from $CuSO_4$ solution using a key or spoon, and a copper strip, using the same setup as in the earlier models.

1. Calculate the average current for Model 3.

2. Using the average current and Faraday's constant, determine how long it will take to plate 0.1 g of copper onto a spoon.

3. Perform the experiment to plate 0.1 g of copper onto a spoon and determine the actual yield of copper.

   Copper yield: _____ g

4. What is the percent error of your yield?

$$\text{Percent Error} = \frac{\left|\text{Theoretical Value} - \text{Experimental Value}\right|}{\text{Theoretical Value}} \times 100$$

5. What factors may have caused the deviation from your theoretical and your actual yield?

_____

_____

_____