

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: _____

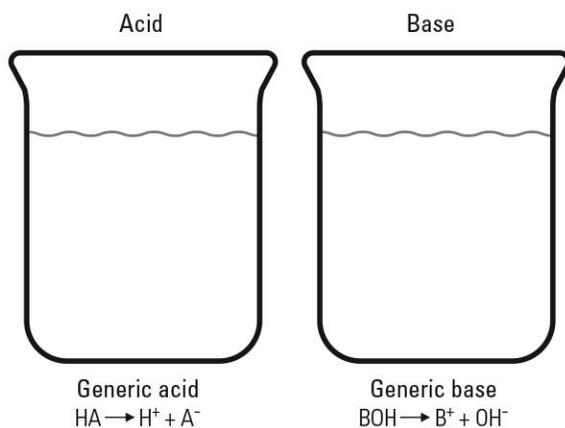
H₂SO₄: _____

KOH: _____

NaOH: _____

HNO₃: _____

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.

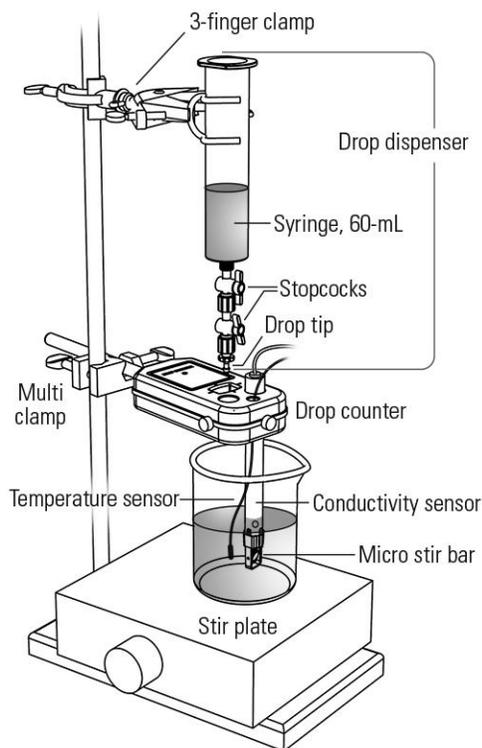
MODEL 1

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 through 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.

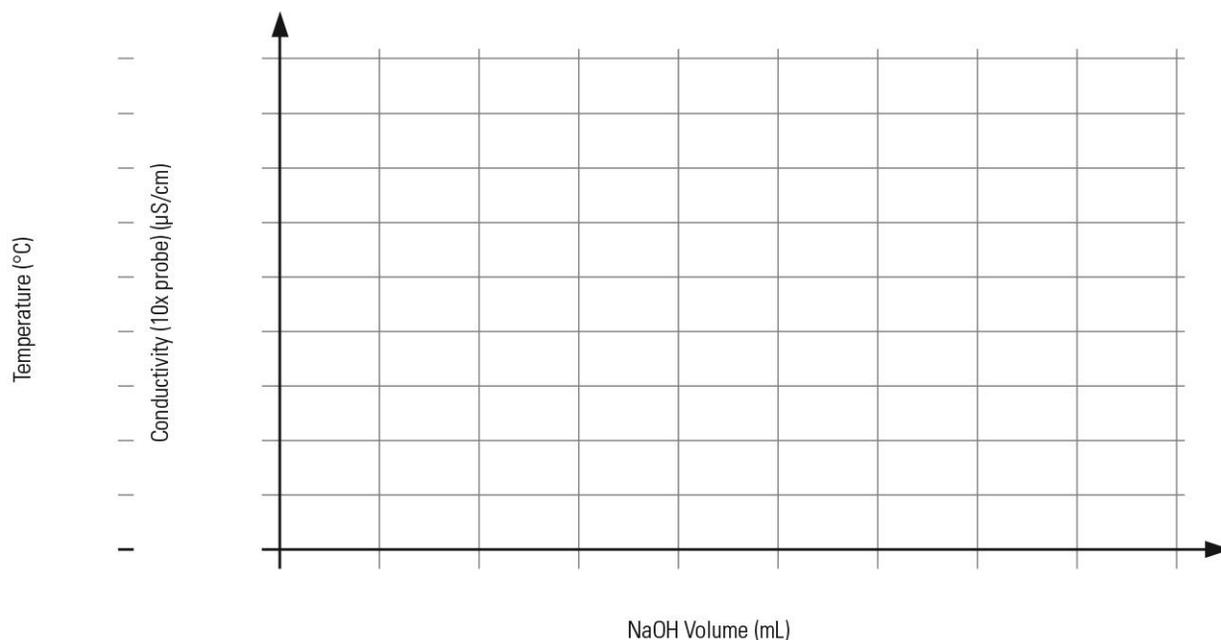
23. Save your experiment and dispose of the used solutions according to your teacher's instructions.
24. Sketch or attach a copy of your graph of Temperature and Conductivity vs Volume of HCl in the space provided in Model 1.

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)	

Temperature and conductivity vs volume of NaOH



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.

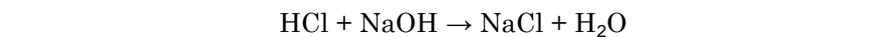
Table 2: Amount of reactants

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.



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.

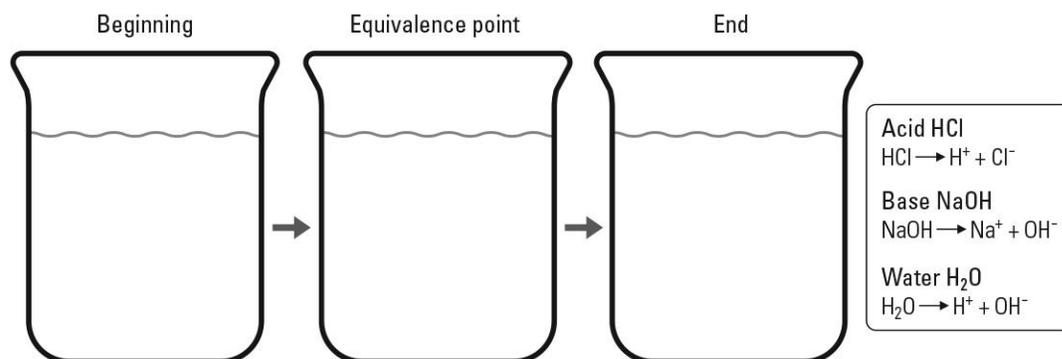
33. The chemical equation for a reaction can be re-written in ionic forms to indicate the actual substances that are reacting. Write both the complete equation and the net ionic equation for the reaction in Model 1.

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.

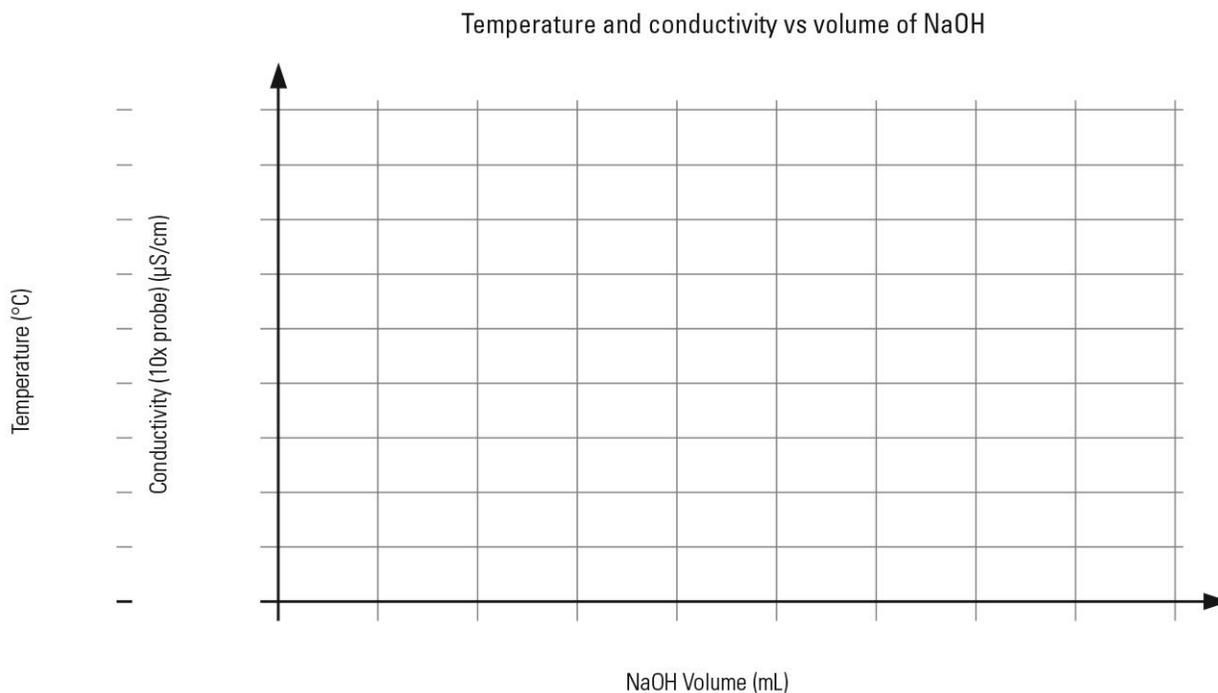
c. A reaction in which one of the products has a dark color.

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.

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)	

Temperature and conductivity vs volume of NaOH

**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.

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