The Buffer in Lemonade

One important property of weak acids and weak bases is their ability to form buffers. A buffer is the combination of a weak acid and a salt of the weak acid. Acetic acid and sodium acetate are an example of this kind of buffer pair. Buffers resist changes in pH upon the addition of small amounts of H^+ or OH^- ions. The dissociation equation for acetic acid contains both of the buffer components, $HC_2H_3O_2$ and $C_2H_3O_2^-$:

$$HC_2H_3O_2(aq) \leftrightarrow H^+(aq) + C_2H_3O_2^-(aq)$$

When a small amount of an HCl solution is added to the buffer solution, most of the H^+ ions are removed when they react with acetate ions:

$$H^+(aq) + C_2H_3O_2^-(aq) \leftrightarrow HC_2H_3O_2(aq)$$

When a solution of NaOH is added to the buffer, most of the OH^- ions are removed when they react with acetic acid molecules:

$$OH^-(aq) + HC_2H_3O_2(aq) \leftrightarrow H_2O(l) + C_2H_3O_2^-(aq)$$

Buffers are incorporated into various consumer products to help control the effects of varying pH. The popular powdered drink mix used in this experiment uses a citric acid–sodium citrate buffer to “control acidity,” according to its label.

OBJECTIVES

- Use a pH Sensor to monitor pH as you titrate a given volume of the commercial brand of lemonade drink.
- Use a pH Sensor to monitor pH as you titrate an unbuffered solution of 0.010 M citric acid.
- Compare the results of the unbuffered solution with the lemonade buffer system.

CHOOSE A METHOD

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

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

MATERIALS

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

Chromebook, computer, **or** mobile device	0.01 M citric acid solution
Graphical Analysis app	0.10 M NaOH solution
Go Direct pH	lemonade drink
Stir Station	pipet bulb or pump
magnetic stirring bar	waste container
250 mL beaker	wash bottle
100 mL graduated cylinder	distilled water

Materials required only for Method 1 (buret)

Electrode Support	buret clamp or utility clamp
50 mL buret	

Materials required only for Method 2 (Drop Counter)

Go Direct Drop Counter	100 mL beaker
60 mL reagent reservoir	utility clamp

METHOD 1: Measuring Volume Using a Buret

1. Obtain and wear goggles.
2. Use a graduated cylinder to measure out 40 mL of the lemonade drink and 60 mL of distilled water into a 250 mL beaker. **Caution**: *Do not eat or drink in the laboratory.*
3. Place the beaker on a Stir Station and add a magnetic stirring bar.
4. Launch Graphical Analysis. Connect the pH Sensor to your Chromebook, computer, or mobile device.
5. Use an Electrode Support to suspend a pH Sensor on a Stir Station as shown in Figure 1. Position the pH Sensor in the lemonade mixture and adjust its position so that it is not struck by the stirring bar.
6. Obtain a 50 mL buret and rinse the buret with a few mL of the 0.10 M NaOH solution. **DANGER**: *Sodium hydroxide solution,* NaOH: *Causes severe skin burns and eye damage. Do not breathe mist, vapors, or spray*. Dispose of the rinse solution as directed by your teacher. Use a buret clamp or a utility clamp to attach the buret to the Stir Station as shown in Figure 1. Fill the buret a little above the 0.00 mL level of the buret with 0.10 M NaOH solution. Drain a small amount of NaOH solution so it fills the buret tip and leaves the NaOH at the 0.00 mL level of the buret. Use a waste container to catch the solution as it leaves the buret. Record the precise concentration of the NaOH solution in your data table.

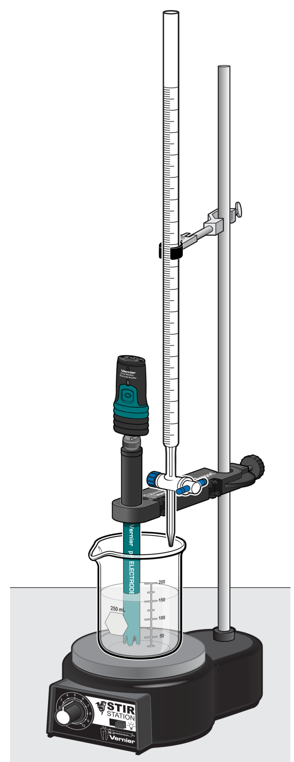

Figure 1

7. Set up the data-collection mode.
   a. Click or tap Mode to open Data Collection Settings. Change Mode to Event Based.
   b. Enter **Volume** as the Event Name and **mL** as the Units. Click or tap Done.
   c. Proceed directly to Step 8.

8. You are now ready to perform the titration. This process goes faster if one person manipulates and reads the buret while another person enters volumes.
   a. Click or tap Collect to start data collection.
   b. Before you have added any NaOH solution, click or tap Keep and enter **0** as the buret volume in mL. Click or tap Keep Point to store the first data pair for this experiment.
   c. Add 2.0 mL of NaOH titrant. When the pH stabilizes, click or tap Keep and enter the current buret reading (to the nearest 0.01 mL). Click or tap Keep Point.
   d. Continue to add 2.0 mL increments, entering the buret level after each increment. When the pH has leveled off between 10.5 and 11, click or tap Stop to stop data collection.

9. Examine the graph and find the *equivalence point*—that is the largest increase in pH upon the addition of 2.0 mL of NaOH solution. Move to the region of the graph with the largest increase in pH (**Note**: You can also adjust the Examine line by dragging the line.). Find the NaOH volume just *before* this jump and record this value in the data table. Then, record the NaOH volume *after* the 2.0 mL addition producing the largest pH increase.

10. Use a graduated cylinder to measure out 40 mL of 0.010 M citric acid solution and 60 mL of distilled water into a 250 mL beaker. Position the pH Sensor, beaker, and stirring bar as you did in Step 5. Refill the buret to the 0.00 mL level of the buret with 0.10 M NaOH solution.

11. Repeat Steps 8–9. **Note**: The previous data set is automatically saved.

12. When you are finished, dispose of the beaker contents as directed by your teacher. Rinse the pH Sensor and return it to the pH storage solution.

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

14. Print a graph of pH *vs*. volume (with two curves displayed). Label each curve as "buffered lemonade" or "unbuffered citric acid".

METHOD 2: Measuring Volume with a Drop Counter

1. Obtain and wear goggles.

2. Use a graduated cylinder to measure out 40 mL of the lemonade drink and 60 mL of distilled water into a 250 mL beaker. **Caution**: *Do not eat or drink in the laboratory*.

3. Obtain approximately 50 mL of 0.1 M NaOH solution in a 100 mL beaker.
   WARNING: *Sodium hydroxide solution,* NaOH: *Causes skin and eye irritation.*

4. Obtain the plastic 60 mL reagent reservoir. **Note**: The bottom valve will be used to open or close the reservoir, while the top valve will be used to finely adjust the flow rate. For now, close both valves by turning the handles to a horizontal position.

Rinse it with a few mL of the 0.1 M NaOH solution. Use an Electrode Support to attach the reagent reservoir to the Stir Station. Add the remainder of the NaOH solution to the reagent reservoir.

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

5. Launch Graphical Analysis. Connect the pH Sensor and the Drop Counter to your Chromebook, computer, or mobile device.

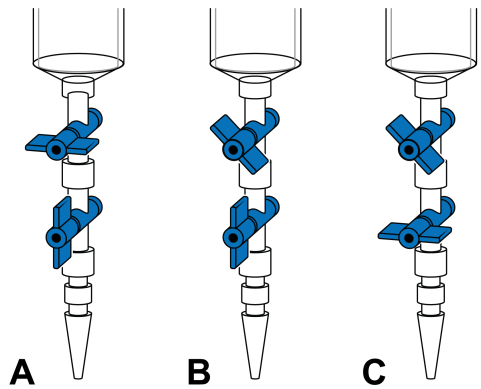

Figure 2

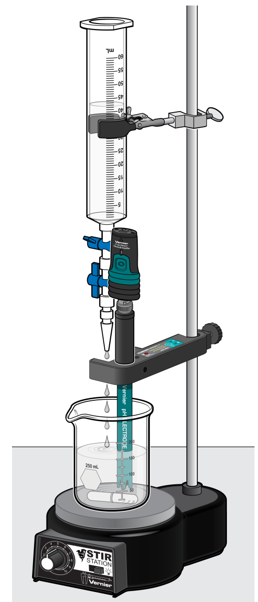

Figure 3

6. Calibrate the Drop Counter so that a precise volume of titrant is recorded in units of milliliters.
   a. Attach the Drop Counter to the Stir Station.
   b. Adjust the handles on the reagent reservoir so the top valve is closed (horizontal) and the bottom valve is open (vertical) (see Figure 2A).
   c. Place a 10 mL graduated cylinder directly below the slot on the Drop Counter, lining it up with the tip of the reagent reservoir.
   d. Click or tap the Volume meter and choose Calibrate.
   e. Follow the on-screen prompts to calibrate the Drop Counter. To adjust the drop flow, slowly open the top valve of the reagent reservoir (see Figure 2B) so that drops are released at a slow rate (~1 drop every two seconds). When the volume of solution in the graduated cylinder is between 9 and 10 mL close the bottom valve (see Figure 2C).
   f. Discard the solution in the graduated cylinder as indicated by your instructor and set the graduated cylinder aside.

7. Assemble the apparatus.
   a. Insert the pH Sensor through the large hole in the Drop Counter.
   b. Adjust the positions of the Drop Counter and reagent reservoir so they are both lined up with the center of the Stir Station.
   c. Lift up the pH Sensor, and slide the beaker containing the lemonade onto the Stir Station. Lower the pH Sensor into the beaker.
   d. Place the stirring bar in the beaker and adjust the position of the pH Sensor so that it will not be struck by the stirring bar.
   e. Adjust the reagent reservoir so its tip is just above the Drop Counter slot.

8. Turn on and adjust the Stir Station so it is stirring at a fast rate.

9. You are now ready to begin collecting data. Click or tap Collect to start data collection. No data will be collected until the first drop goes through the Drop Counter slot. Fully open the **bottom valve**—the top valve should still be adjusted so drops are released at a rate of about 1 drop every 2 seconds. When the first drop passes through the Drop Counter slot, check the graph to see that the first data pair was recorded.

10. Continue watching your graph to see when a large increase in pH takes place—this will be the equivalence point of the reaction. When this jump in pH occurs, let the titration proceed for several more milliliters of titrant, then click or tap Stop to stop data collection. Turn the bottom valve of the reagent reservoir to a closed (horizontal) position.

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

12. Repeat the titration using unbuffered citric acid solution.

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

PROCESSING THE DATA

1. Determine the volume of NaOH added at the equivalence point for each trial.

   Method 1

   Add the two NaOH values determined in Step 9 and divide by two.

   Method 2

   a. Determine the peak value on the first derivative *vs*. volume plot.
      i. Click or tap Column Options, ⋯, in the pH column header in the table. Then, choose Add Calculated Column.
      ii. Enter **d1** as the Name and leave the Units field blank.
      iii. Click or tap Insert Expression and choose 1st Derivative(Y,X) as the expression.
      iv. Select pH as Column Y and Volume as Column X. Click or tap Apply.
      v. To display a graph of d1 *vs*. volume, click or tap the y-axis label, select only d1, and dismiss the box.
      vi. On the graph of d1 *vs*. volume, examine the data to determine the volume at the peak value of the first derivative.

   b. Determine the zero value on the second derivative *vs*. volume plot.
      i. Click or tap More Options, ⋯, in the Volume column header in the table. Then, choose Add Calculated Column.
      ii. Enter **d2** as the Name and leave the Units field blank.
      iii. Click or tap Insert Expression and choose 2nd Derivative(Y,X) as the expression.
      iv. Select pH as Column Y and Volume as Column X. Click or tap Apply.
      v. Click or tap the y-axis label, select only d2 to display a graph of d1 *vs*. volume, and dismiss the box.
      vi. Click or tap the y-axis label, select only the d2 column, and dismiss the box. On the displayed graph of d2 *vs*. volume, examine the data to determine the volume when the 2nd derivative equals approximately zero.

2. Calculate the number of moles of NaOH used in each titration. Which solution reacted with more NaOH when the equivalence point was reached?

3. Examine the graph of each titration. How does the titration curve of the buffered lemonade compare to the curve of the unbuffered citric acid solution?

DATA TABLE AND CALCULATIONS

	Lemonade	Citric acid solution
Concentration of NaOH	M	M
NaOH volume added before the largest pH increase	mL	mL
NaOH volume added after the largest pH increase	mL	mL

Volume of NaOH added at the equivalence point	mL	mL
Moles NaOH	mol	mol