PRELIMINARY ACTIVITY FOR

Buffer Investigations

Guided Inquiry Version

Organisms are often very sensitive to the effect of acids and bases in their environment. They need to maintain a stable internal pH in order to survive—even in the event of environmental changes. Many naturally occurring biological, geological, and human-made chemicals are capable of stabilizing the environment's pH in a process called *buffering*. This may allow organisms to better survive in diverse environments found throughout the earth.

A *buffer* is a mixture of a weak acid and its conjugate base, or a weak base and its conjugate acid. A buffer's function is to absorb acids (H^+ or H_3O^+ ions) or bases ($OH^–$ ions) so that pH changes very, very little. The bicarbonate-carbon dioxide *buffer system*, for example, keeps the pH of blood in humans between 7.3 and 7.5.

Baking soda, like many substances, has some buffering ability. In the Preliminary Activity, you will determine the buffering ability of a baking soda solution. You will first use a pH Sensor to monitor pH as you add hydrochloric acid (HCl) to one portion of the sample. Subsequently, you will monitor pH as you add basic sodium hydroxide (NaOH) solution to another portion of the sample. When data collection is complete, you will determine the total pH change of the baking soda sample.

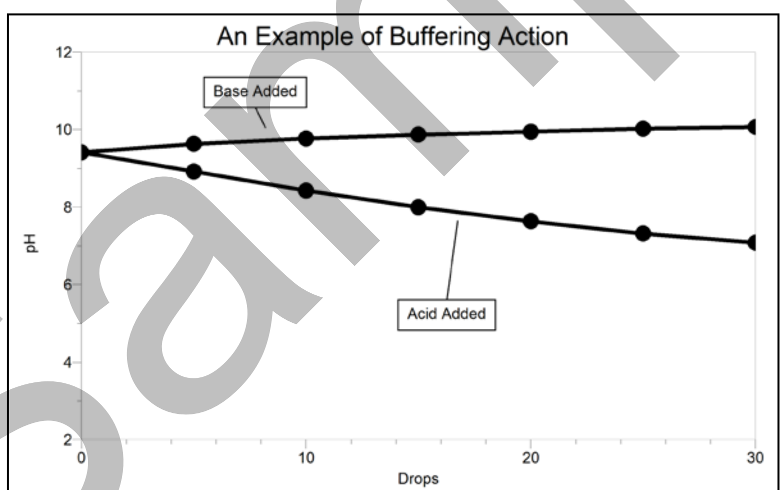

Figure 1 *Buffering action upon the addition of acid and base*

Table 1: Illustrative pH Values										
		pH after number of drops added								
Material	Added	0	5	10	15	20	25	30	ΔpH	Total
Laundry detergent	acid	9.41	8.92	8.43	8.00	7.63	7.32	7.08	–2.33	3.0
	base	9.41	9.63	9.77	9.87	9.94	10.02	10.07	0.66	

After completing the Preliminary Activity, you will investigate your assigned researchable question. Use reference sources to find out more about buffers and buffer systems before planning and conducting your investigation.

PROCEDURE

1. Obtain and wear goggles.

2. Connect the pH Sensor to the data-collection interface. Start the data-collection program and choose New from the File menu.

3. Set up the data-collection software for the Events with Entry mode.

4. Use a utility clamp to fasten the pH Sensor to a ring stand as is shown in Figure 2.

Testing the effect of acid on baking soda solution

5. Use a rinse bottle to thoroughly rinse the pH Sensor with distilled water.

   Important: Do not let the pH electrode dry out. Keep it in a 250 mL beaker with about 100 mL of tap water when not in use. The tip of the probe is made of glass—it is fragile. Handle with care!

6. Obtain a 20 mL portion of baking soda solution in a 50 mL beaker. Immerse the pH Sensor in the baking soda solution and swirl the beaker

7. Keep a data point for "0" drops of hydrochloric acid before any acid is added.

8. Add 5 drops of 0.10 M HCl to the baking soda solution. **CAUTION:** *Handle this hydrochloric acid with care. It can cause painful burns if it comes into contact with skin, eyes, or clothing.*

9. Swirl thoroughly. When the pH is stable, keep a data point for "5" drops of acid.

10. Repeat Steps 8 and 9, adding 5 drops at a time, until you have added a total of 30 drops of hydrochloric acid.

11. Stop data collection after you have added a total of 30 drops.

12. Record the pH values in your data table.

13. Store this first run.

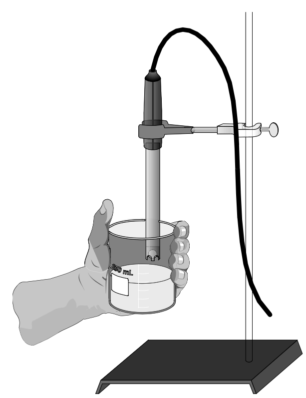

Figure 2

Testing the effect of base on baking soda solution

14. Repeat Steps 5–12 substituting the base 0.10 M NaOH for the acid. **CAUTION:** *Sodium hydroxide solution is caustic. Avoid spilling it on your skin or clothing.*

15. Print graphs as directed by your instructor.

QUESTIONS

1. Determine the total pH change of your baking soda sample.
   a. Determine the change of pH (ΔpH) upon the addition of acid.

   b. Determine the ΔpH upon the addition of base.

   c. Subtract the ΔpH for the acid from the ΔpH for the base to determine the total pH change.

2. Is a baking soda solution acidic, or is it basic? How can you tell which it is?

3. What was the effect of adding HCl? Why did this happen?

4. What was the effect of adding NaOH? Why did this happen?

5. List five materials whose buffering action might be interesting.

6. List two biological buffer systems.

Investigation
1

Investigating Buffers

OVERVIEW

In the Preliminary Activity, your students will determine the buffering ability of a baking soda solution sample. They will first use a pH Sensor to monitor pH as they add hydrochloric acid (HCl) to one portion of the sample. Subsequently, they will monitor pH as they add basic sodium hydroxide (NaOH) solution to another portion of the sample. When data collection is complete, they will determine the total pH change of the baking soda solution sample. A student handout for the Open Inquiry version of the Preliminary Activity can be found at the end of this investigation. A Guided Inquiry version is found on the CD accompanying this book.

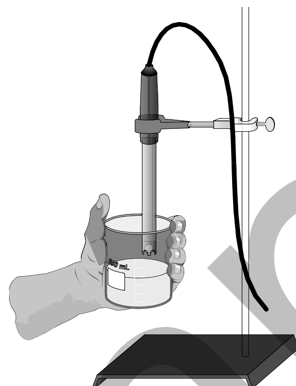

Figure 1

During the subsequent Inquiry Process, your students will first find out more about buffers and buffer systems using the course textbook, other available books, and the Internet. They will then generate and investigate researchable questions dealing with a set of buffers or a buffer system. (In the Guided Inquiry approach, students will plan and conduct investigations of the researchable question(s) assigned by you.)

LEARNING OUTCOMES

In this inquiry investigation, students will

- Identify variables, design and perform the investigation, collect data, analyze data, draw a conclusion, and formulate a knowledge claim based on evidence from the investigation.
- Use a pH Sensor to measure pH and pH changes.
- Determine buffering ability of various materials.
- Investigate buffer systems.

THE INQUIRY PROCESS

Suggested Time to Complete the Experiment

See page xiii in the Doing Inquiry Investigations section for more information on carrying out each phase of an inquiry experiment.

	Inquiry Phase	Open Inquiry	Guided Inquiry
I	Preliminary Activity	30 minutes	30 minutes
II	Generating Researchable Questions (Omitted in Guided Inquiry Approach)	10 minutes	0 minutes
III	Planning	10 minutes	10 minutes
IV	Carrying Out the Plan	30 minutes	30 minutes
V	Organizing the Data	10 minutes	10 minutes
VI	Communicating the Results	10 minutes	10 minutes
VII	Conclusion	5 minutes	5 minutes

MATERIALS

Make the following materials available for student use. Items in bold are needed for the Preliminary Activity.

data-collection interface
data-collection program
Vernier pH Sensor
goggles
lab apron
ring stand
utility clamp
distilled water
rinse bottle
250 mL beaker
25 mL graduated cylinder
50 mL beaker
1% baking soda solution
Beral pipet
0.10 M HCl
0.10 M NaOH
others as requested by students

I Preliminary Activity

This inquiry begins with an activity to reinforce prior knowledge of the use of Vernier data-collection technology and to introduce a method for collecting pH data using a pH Sensor.

Sample Results

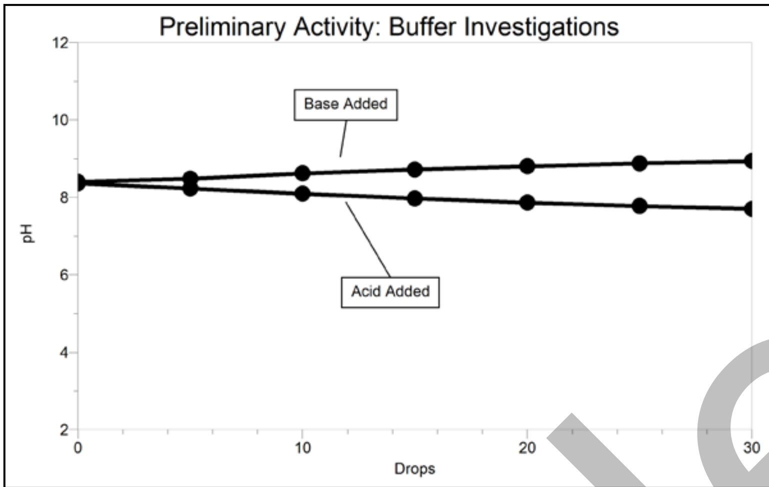

Figure 2 *Buffering action upon the addition of acid and base*

Table 1: pH Values of Baking Soda Solution										
		pH after number of drops added								
Material	Added	0	5	10	15	20	25	30	ΔpH	Total
Baking soda	acid	8.36	8.23	8.10	7.97	7.87	7.78	7.70	–0.66	1.2
	base	8.40	8.48	8.62	8.72	8.80	8.88	8.94	0.54	

Answers to the Questions

1. Determine the total pH change of your baking soda sample.
   a. Determine the change of pH (ΔpH) upon the addition of acid.

      Answers will vary. For the sample data, 7.70 – 8.36 = –0.66

   b. Determine the ΔpH upon the addition of base.

      Answers will vary. 8.94 – 8.40 = 0.54

   c. Subtract the ΔpH for the acid from the ΔpH for the base to determine the total pH change.

      Answers will vary. 0.54 – (–0.66) = 1.20

2. Is a baking soda solution acidic, or is it basic? How can you tell which it is?

   Answers will vary. A baking soda solution is basic. Its pH, before drops of acid or base are added, was greater than 7.

3. What was the effect of adding HCl? Why did this happen?

   Answers will vary. The pH dropped as HCl was added because HCl is more acidic than the baking soda solution.

4. What was the effect of adding NaOH? Why did this happen?

   Answers will vary. The pH increased as NaOH was added because NaOH is more basic than the baking soda solution.

5. List five materials whose buffering action might be interesting.

   Answers will vary. Some of the numerous possibilities are blended liver, potato roots, plant leaves, fruit juices (from real fruit), egg white, gelatin, milk, casein, yoghurt, vitamin C, soft drinks, soda water, Alka-Seltzer®, Tums®, aspirin, Bufferin®, table salt, shampoo, laundry detergent, hard water, soft water, acetic acid, sodium acetate, citric acid, sodium citrate, KH_2PO_4, and K_2HPO_4.

6. List two biological buffer systems.

   Answers will vary. Acetic acid–sodium acetate, citric acid–sodium citrate, KH_2PO_4–K_2HPO_4, and sodium carbonate–sodium bicarbonate are four common biological buffer systems.

II Generating Researchable Questions

Note: Researchable questions are assigned by the instructor in the Guided Inquiry approach. See page xiii in the Doing Inquiry Investigations section for a list of suggestions for generating researchable questions. Some possible researchable questions for this investigation are listed below:

Recommended for Open Inquiry or Guided Inquiry (sample results provided)

- How do the buffering actions of gelatin and potatoes compare?
- How do the buffering actions of liver and egg white compare?

Recommended for Open Inquiry or Guided Inquiry (sample results not provided)

- How do the buffering actions of citric acid containing and phosphoric acid containing soft drinks compare?
- How do the buffering actions of milk and yogurt solutions compare?
- How do the buffering actions of apple juice, grape juice, and grapefruit juice compare?
- How do the buffering actions of shampoo, dishwashing detergent, and laundry detergent compare?
- How do the buffering actions of Bufferin® and another aspirin product compare?
- How do the buffering actions of Tums® and Rolaids® compare?
- How do the buffering actions of Na_2CO_3 and $NaHCO_3$ solutions compare?
- How do the buffering actions of citric acid and acetic acid compare?
- How do the buffering actions of sodium citrate and sodium acetate compare?

Recommended for Advanced Students (sample results provided)

- How do the buffering actions of monobasic sodium phosphate (KH_2PO_4), dibasic sodium phosphate (K_2HPO_4), and a 50–50 mixture of KH_2PO_4 and K_2HPO_4 solutions compare?
- How do the buffering actions of citric acid, sodium citrate, and a 50–50 mixture of citric acid and sodium citrate solutions compare?

Recommended for Advanced Students (sample results not provided)

- How do the buffering actions of sodium carbonate, sodium bicarbonate, and a 50:50 mixture of sodium carbonate and sodium bicarbonate solutions compare?

There are many more possible researchable questions. Students should choose a researchable question that addresses the learning outcomes of your specific standards. Be sure to emphasize experimental control and variables. (Instructors using the Guided Inquiry approach select the researchable questions to be investigated by their students. We encourage you to assign multiple researchable questions because this strategy enhances student interaction and learning during phases IV–VII.)

III Planning

During this phase students should formulate a hypothesis, determine the experimental design and setup, and write a method they will use to collect data. The plan should list laboratory safety concerns and specify how they will be addressed during the investigation. Circulate among the student groups asking questions and making helpful suggestions.

IV Carrying out the Plan

During this phase, students use their plan to carry out the investigation and collect data. Circulate among the student groups asking questions and making helpful suggestions.

V Organizing the Data

See page xv in the Doing Inquiry Investigations section for suggestions concerning how students can organize their data for their inquiry presentations.

VI Communicating the Results

See page xv in the Doing Inquiry Investigations section for a list of inquiry-presentation strategies.

VII Conclusion

Using your notes recorded during the Communicating the Results phase, summarize the group results for the experiment and tell how they will fit into the upcoming instruction.

VIII Assessment

See page xv in the Doing Inquiry Investigations section for ideas on assessment strategies.

SAMPLE RESULTS

Student results will vary depending on experimental design.

Comparing the Buffering Actions of Gelatin and Potato

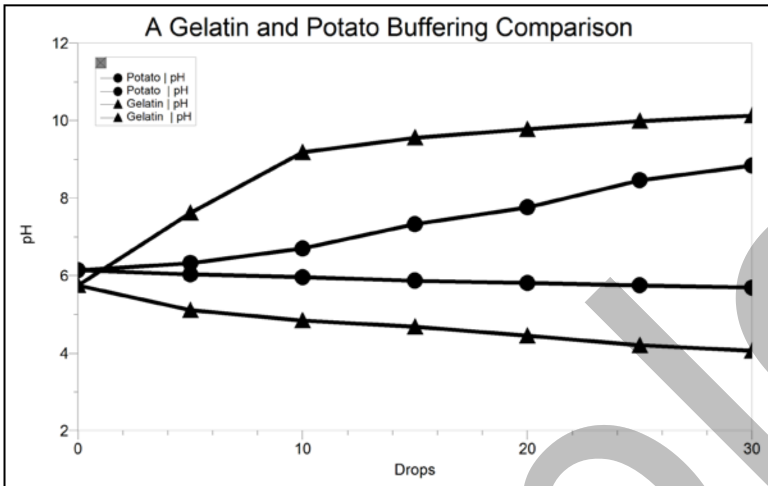

Figure 3 *Comparing the buffering actions of gelatin and potato*

Table 2: Gelatin and Potato Comparison										
		pH after number of drops added								
Material	Added	0	5	10	15	20	25	30	ΔpH	Total
Gelatin	acid	5.75	5.11	4.84	4.68	4.45	4.20	4.06	–1.69	6.1
	base	5.75	7.62	9.18	9.56	9.78	9.99	10.13	4.38	
Potato	acid	6.14	6.03	5.96	5.87	5.81	5.75	5.69	–0.45	3.2
	base	6.14	6.32	6.70	7.33	7.76	8.46	8.84	2.70	

These results address the question, "How do the buffering actions of gelatin and potatoes compare?" Gelatin and potato solutions were tested using the Preliminary Activity protocol.

Although gelatin and potato are both slightly acidic and have similar pH values, 5.75 and 6.14, respectively, potato was found to have greater buffering capability, as evidenced by its smaller total change in pH.

Comparing the Buffering Actions of Liver and Egg White

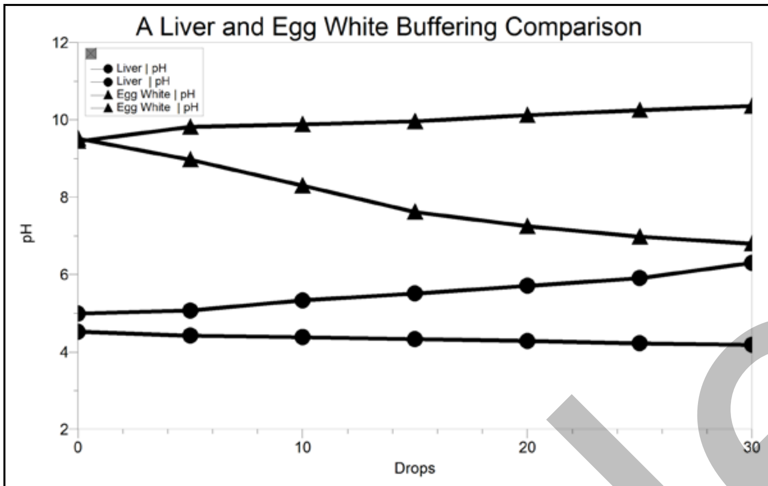

Figure 4 *Comparing the buffering actions of liver and egg white*

Table 3: Liver and Egg White Comparison										
		pH after number of drops added								
Material	Added	0	5	10	15	20	25	30	ΔpH	Total
Liver	acid	4.52	4.42	4.38	4.33	4.28	4.22	4.18	–0.34	1.7
	base	4.99	5.07	5.33	5.51	5.71	5.91	6.30	1.31	
Egg white	acid	9.52	8.97	8.30	7.62	7.25	6.98	6.80	–2.72	3.6
	base	9.45	9.82	9.88	9.96	10.12	10.25	10.36	0.91	

These results address the question, "How do the buffering actions of liver and egg white compare?" Blended liver and potato solutions were tested using the Preliminary Activity protocol.

With its lower total pH change, 1.7, blended liver was found to have greater buffering ability than egg white, with its total pH change of 3.6. Blended liver solution is acidic, whereas egg white solution is basic.

Investigating a Phosphate Buffer System

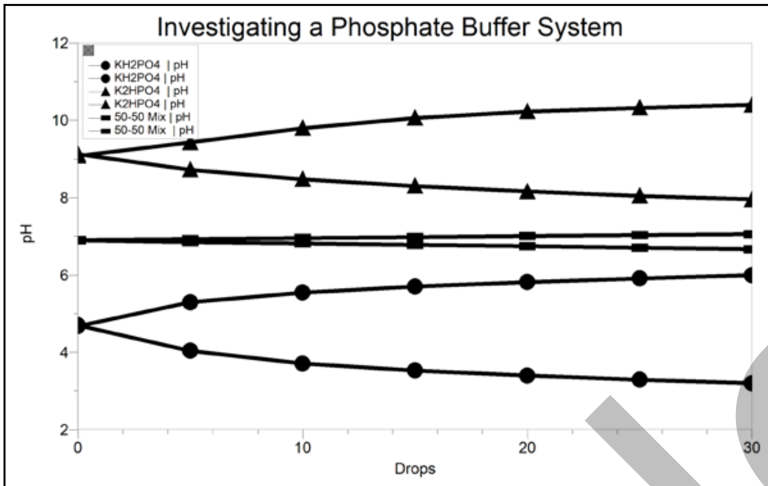

Figure 5 *Comparing the buffering actions of system components*

Table 4: A Phosphate Buffer System										
		pH after number of drops added								
Material	Added	0	5	10	15	20	25	30	ΔpH	Total
KH_2PO_4	acid	4.70	4.04	3.71	3.52	3.40	3.29	3.20	–1.50	2.8
	base	4.68	5.30	5.54	5.70	5.82	5.91	5.99	1.31	
K_2HPO_4	acid	9.13	8.72	8.48	8.30	8.16	8.05	7.95	–1.18	2.5
	base	9.08	9.43	9.80	10.06	10.23	10.32	10.40	1.32	
50–50 mix	acid	6.90	6.85	6.82	6.78	6.74	6.71	6.6	–0.24	0.4
	base	6.90	6.93	6.95	6.98	7.01	7.03	7.06	0.16	

These results address the question, “How do the buffering actions of monobasic sodium phosphate (KH_2PO_4), dibasic sodium phosphate (K_2HPO_4), and a 50–50 mixture of KH_2PO_4 and K_2HPO_4 solutions compare?” The solutions were tested using the Preliminary Activity protocol.

The small total pH change for the 50–50 mixture (by mass) of 0.4 pH units, compared to the 2.8 and 2.5 pH unit total changes for monobasic sodium phosphate and dibasic sodium phosphate, respectively, indicates the buffering advantage of the mixture.

This phosphate buffer system is a common biological buffer. It consists of dihydrogen phosphate ions ($H_2PO_4^-$) as the hydrogen-ion donor (acid) and hydrogen phosphate ions (HPO_4^{2-}) as the hydrogen-ion acceptor (base). These two ions are in equilibrium as indicated by the following chemical equation:

$$H_2PO_4^-(aq) \longleftrightarrow H^+(aq) + HPO_4^{2-}(aq)$$

A commonly stated pH range for this phosphate buffer system is 5.8–8.0. This buffer system is used elsewhere in this book. Phosphate buffer is one of the materials used in Investigation 8, Analysis of Enzymes using Tyrosinase, and in Investigation 12, Photosynthesis by Chloroplasts. Its use is suggested in the Sample Results of Investigation 6, Testing Catalase Activity, and Investigation 11, Fermentation with Yeast.

Investigating the Citric Acid–Sodium Citrate Buffer System

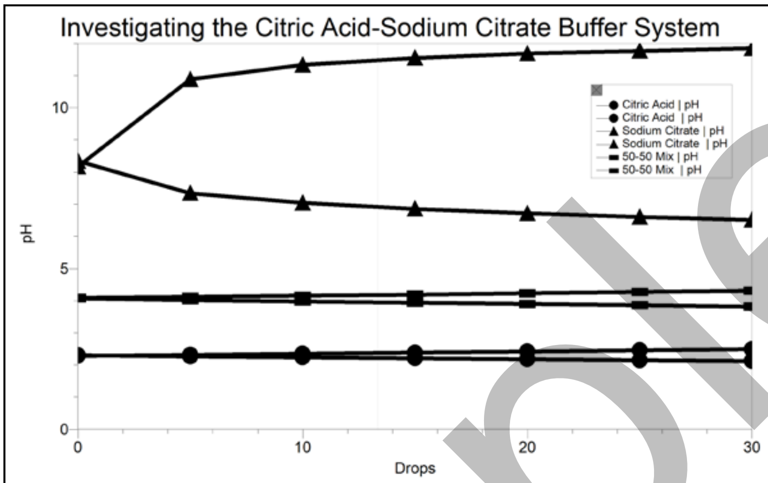

Figure 6 *Comparing the buffering actions of system components*

Table 5: The Citric Acid–Sodium Citrate Buffer System										
		pH after number of drops added								
Material	Added	0	5	10	15	20	25	30	ΔpH	Total
Citric acid	acid	2.30	2.27	2.24	2.21	2.18	2.15	2.12	–0.18	0.4
	base	2.29	2.32	2.35	2.39	2.42	2.46	2.49	0.20	
Sodium citrate	acid	8.34	7.34	7.04	6.85	6.71	6.60	6.51	–1.83	4.5
	base	8.17	10.88	11.33	11.54	11.68	11.77	10.84	2.67	
50–50 mix	acid	4.07	4.02	3.98	3.94	3.90	3.86	3.82	–0.25	0.5
	base	4.09	4.12	4.15	4.19	4.23	4.27	4.31	0.22	

These results address the question, “How do the buffering actions of citric acid, sodium citrate, and a 50–50 mixture of citric acid and sodium citrate solutions compare?” The solutions were tested using the Preliminary Activity protocol.

The total pH change for the 50–50 mixture (by mass) of 0.5 pH units was much smaller than the 4.5 pH unit total change for sodium citrate. The total pH change of 0.4 pH units for citric acid, however, was even smaller. A commonly stated pH range for the citric acid–sodium citrate buffer system is 3.0–6.2.

Citric acid solution, with sodium hydroxide added to adjust pH, is another useful buffer.

Additional Buffering Results

Table 6: Additional Results										
		pH after number of drops added								
Material	Added	0	5	10	15	20	25	30	ΔpH	Total
Bufferin®	acid	3.2	3.2	3.2	3.2	3.2	3.3	3.3	0.1	0.8
	base	3.2	3.4	3.6	3.7	3.8	3.9	4.1	0.9	
Aspirin	acid	3.1	2.8	2.7	2.6	2.5	2.5	2.4	–0.7	1.3
	base	3.0	3.1	3.2	3.3	3.5	3.5	3.6	0.6	
Alka-Seltzer®	acid	7.19	7.10	6.99	6.96	6.92	6.87	6.82	–0.37	1.7
	base	7.19	7.32	7.47	7.68	7.93	8.24	8.55	1.36	
NaCl	acid	6.22	3.24	2.80	2.59	2.46	2.36	2.28	–3.94	9.2
	base	6.22	10.20	10.76	11.02	11.26	11.41	11.52	5.30	
Laundry detergent	acid	9.41	8.92	8.43	8.00	7.63	7.32	7.08	–2.33	3.0
	base	9.41	9.63	9.77	9.87	9.94	10.02	10.07	0.66	
Shampoo	acid	6.12	3.65	3.06	2.82	2.67	2.56	2.46	–3.66	8.6
	base	6.15	10.19	10.61	10.79	10.94	11.03	11.07	4.92	
Soda water	acid	4.65	3.36	2.6	2.5	2.4	2.3	2.3	–2.4	3.3
	base	4.45	4.7	4.9	5.0	5.1	5.2	5.3	0.9	
Orange juice	acid	3.89	3.24	2.86	2.70	2.57	2.46	2.38	–1.51	7.3
	base	3.88	5.11	6.21	7.12	8.22	9.32	9.67	5.79	
Hard water (920 µS/cm)	acid	7.94	7.43	7.24	7.04	6.76	6.22	3.81	–4.13	7.0
	base	7.96	9.11	9.54	9.89	10.18	10.48	10.81	2.85	
Soft water (220 µS/cm)	acid	7.13	5.63	3.10	2.83	2.62	2.49	2.40	–4.73	9.2
	base	7.16	10.05	10.68	11.08	11.32	11.48	11.59	4.43	

TIPS

1. Try to make a 1% solution of the materials being tested. It is not too critical to be exact. Add 10 grams of material for each liter of solution.

2. The citrate and phosphate buffer system results shown in the Sample Results were obtained using 1% solutions, by mass. It would be best for advanced students to use 0.10 M solutions.

3. To prepare the 0.1 M NaOH solution, use 4.0 g of solid NaOH pellets per 1 L of solution. **HAZARD ALERT:** Corrosive solid; skin burns are possible; much heat evolves when added to water; very dangerous to eyes; wear face and eye protection when using this substance. Wear gloves. Hazard Code: B—Hazardous.

4. To prepare the 0.1 M HCl solution, use 8.6 mL of concentrated acid per 1 L of solution. **HAZARD ALERT:** Highly toxic by ingestion or inhalation; severely corrosive to skin and eyes. Hazard Code: A—Extremely hazardous.

5. Additional **HAZARD ALERT**. Citric acid, monohydrate, $C_6H_8O_7 \bullet H_2O$; Severe eye irritant. Hazard Code: D—Relatively non-hazardous. Note: Citric acid, anhydrous, $C_6H_8O_7$, does not have such an alert.

   The hazard information reference is: Flinn Scientific, Inc., *Chemical and Biological Catalog Reference Manual,* (800) 452-1261, www.flinnsci.com.

6. More information about the sensor used in this Investigation, as well as tips for optimal performance, can be found in the sensor's user manual available for download from the Vernier web site, www.vernier.com/sensors.

7. The plans that your students submit for approval should list laboratory safety concerns, including chemical safety concerns, and specify how they will address these safety concerns during their investigations.