Acids, Bases, pH, and Buffers

Goals

- Prepare a naturally occurring dye from red cabbage to use as a pH indicator.
- Measure the pH of several substances using cabbage indicator and a pH meter.
- Calculate pH from the $[H^+]$ or the $[OH^-]$ of a solution.
- Calculate the molar concentration and percentage of acetic acid in vinegar.
- Observe the changes in pH as acid or base is added to buffered and unbuffered solutions.
- Calculate pH from the $[H^+]$ or the $[OH^-]$ of a solution.

Text References

Review the following before performing this laboratory.

Timberlake; *General, Organic, and Biological Chemistry: Structures of Life*, Third Edition

Sections 10.1 to 10.4; Pages 281 to 298

or

Timberlake; *Chemistry: An Introduction to General, Organic, and Biological Chemistry*, Tenth Edition

Section 8.6; Pages 304 to 306

Discussion

An acid is a substance that dissolves in water and donates a hydrogen ion, or proton (H^+), to water. In the laboratory we have been using acids such as hydrochloric acid (HCl) and nitric acid (HNO_3).

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$

hydronium ion

You use acids and bases every day. There are acids in oranges, lemons, vinegar, and bleach. In this experiment we will use acetic acid (CH_3CO_2H). Acetic acid is the acid in vinegar that gives it a sour taste.

A base is a substance that accepts a proton. Some household bases include ammonia, detergents, and oven-cleaning products. Some typical bases used in the laboratory are sodium hydroxide (NaOH) and potassium hydroxide (KOH). Most of the common bases dissolve in water and produce hydroxide ions, OH^-.

$$NaOH \rightarrow Na^+ + OH^-$$

An important weak base found in the laboratory and in some household cleaners is ammonia. In water, ammonia reacts to form ammonium and hydroxide ions:

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

In a neutralization reaction, the protons (H^+) from the acid combine with hydroxide ions (OH^-) from the base to produce water (H_2O). The remaining substance is a salt, which is composed of ions from the acid and base. For example, the neutralization of HCl by NaOH is written as

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

If we write the ionic substances in the equation as ions, we see that the H^+ and the OH^- form water.

$$H^+ + Cl^- + Na^+ + OH^- \rightarrow Na^+ + Cl^- + H_2O$$

$$H^+ + OH^- \rightarrow H_2O$$

In a complete neutralization, the amount of H^+ will be equal to the amount of OH^-.

A. pH Color Using Red Cabbage Indicator

The pH of a solution tells us whether a solution is acidic, basic, or neutral. On the pH scale, pH values below 7 are acidic, equal to 7 is neutral, and values above 7 are basic. Typically, the pH scale has values between 0 and 14.

pH scale

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

← *acidic* → *neutral* ← *basic* →

Many natural substances contain dyes that produce distinctive colors at different pH values. By extracting (removing) the dye from red cabbage leaves, a natural indicator can be prepared. Adding the red cabbage solution to solutions of a variety of acids and bases will produce a series of distinctive colors. When the red cabbage solution is added to a test sample, the color produced can be matched to the colors of the pH reference set to determine the pH of the sample. A pH meter can also be used to measure pH.

B. Measuring pH

The concentration (moles/liter, indicated by brackets [ ]) of H_3O^+ or OH^- can be determined from the ionization constant for water (K_w). In pure water, $[H_3O^+] = [OH^-] = 1 \times 10^{-7}$ M at 25ºC.

$$K_w = [H_3O^+][OH^-] = [1 \times 10^{-7}][1 \times 10^{-7}] = 1 \times 10^{-14}$$

If the $[H_3O^+]$ or $[OH^-]$ for an acid or a base is known, the other can be calculated. For example, an acid has a $[H^+] = 1 \times 10^{-4}$ M. We can find the $[OH^-]$ of the solution by solving the K_w expression for $[OH^-]$:

$$[OH^-] = \frac{1 \times 10^{-14}}{[H_3O^+]} = \frac{1 \times 10^{-14}}{1 \times 10^{-4}} = 1 \times 10^{-10}\ M$$

The pH of a solution is a measure of its $[H_3O^+]$. It is defined as the negative log of the hydrogen ion concentration.

$$pH = -\log [H_3O^+]$$

Therefore, a solution with a $[H_3O^+] = 1 \times 10^{-4}$ M has a pH of 4.0, and is acidic.

A solution with a $[H_3O^+] = 1 \times 10^{-11}$ M has a pH of 11.0, and is basic.

C. Effect of Buffers on pH

The pH of the blood is maintained between 7.35 and 7.45 by buffers in the body. If blood pH goes above or below that range, it can destroy the cells in the blood. Buffers maintain the pH of a solution by reacting with and neutralizing small amounts of acids or bases. Many buffers contain a weak acid and its salt. The weak acid reacts with excess base, and the anion of the salt picks up excess H^+. It is the ability of a buffer to react with excess acid or base that maintains the pH of a solution. The pH of the blood is kept constant by the bicarbonate buffer, which is carbonic acid, H_2CO_3 (weak acid), and bicarbonate anion, HCO_3^- (salt). When base (OH^-) is added, it reacts with the weak acid in the buffer and produces bicarbonate ion and water:

$$H_2CO_3 + OH^- \rightarrow HCO_3^- + H_2O$$

When acid (H^+) enters the blood, it reacts with the HCO_3^- anion and re-forms carbonic acid:

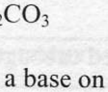
$$HCO_3^- + H^+ \rightarrow H_2CO_3$$

In this experiment, the effect of an acid and a base on the pH of a buffer and an unbuffered system will be determined.

Lab Information

Time:	$2\frac{1}{2}$ hr
Comments:	Students may be asked to bring a red cabbage to class.
	Share test tubes with your lab neighbors to prepare the pH reference solutions.
	Tear out the report sheets and place them beside the matching procedures.
Related Topics:	Acids, bases, pH, buffers

Dispose of all chemicals as directed by your lab instructor.

Experimental Procedures  *GOGGLES REQUIRED!*

A. pH Color Using Red Cabbage Indicator

Materials: Red cabbage leaves, 400-mL beaker, distilled water, Bunsen burner or hot plate or blender or food processor, 150-mL beaker, test tubes, two test tube racks, set of buffers with pH ranging from 1 to 13

A.1 **Preparing red cabbage indicator- 1.** There are two alternative procedures to produce a pH indicator from red cabbage. The first procedure involves boiling the cabbage leaves in water.

Section	Step	Procedure	Check when finished
A.1	1	Place 5 or 6 torn leaves from red cabbage in a 400-mL beaker.	
A.1	2	Add about 150–200 mL of distilled water to cover the leaves.	
A.1	3	Heat on a hot plate or using a Bunsen burner, but do not boil.	
A.1	4	When the solution has attained a dark purple color, turn off the burner and cool.	
A.1	5	Retain about 100 mL of the indicator (red cabbage) solution.	

A.2 **Preparing red cabbage indicator- 2.** The second procedure involves blending water with cabbage leaves in a high-speed kitchen blender.

Section	Step	Procedure	Check when finished
A.2	1	Place 5 or 6 torn leaves from red cabbage in a blender.	
A.2	2	Add about 150–200 mL of distilled water to cover the leaves.	
A.2	3	Blend the leaves and water together at high speed.	
A.2	4	Filter the resultant solution.	
A.2	5	Retain about 100 mL of the indicator (red cabbage) solution.	

A.3 **Preparing pH reference standards**

Section	Step	Procedure	Check when finished
A.3	1	Using a 150-mL beaker, obtain 50 mL of cabbage dye indicator.	
A.3	2	Arrange 13 test tubes in two test tube racks. You may need to combine your test tube set with your neighbor's set. (Your instructor may prepare a pH reference set for the entire class.)	
A.3	3	Pour 3–4 mL of each buffer in a separate test tube to create a set with pH values of 1–13. Caution: Low pH values are strongly acidic; high pH values are strongly basic. Work with care.	
A.3	4	To each test tube, add 2–3 mL of the cooled red cabbage solution. If you wish a deeper color, add more cabbage solution. Shake test	

		tube to mix.	
A.3	5	Describe the colors of the pH solutions.	
A.3	6	Keep this reference set for the next part of the experiment.	

B. Measuring pH

Materials: Shell vials or test tubes, samples to test for pH (shampoo, conditioner, mouthwash, antacids, detergents, fruit juice, vinegar, cleaners, aspirin, etc.), cabbage juice indicator from part A, pH meter, calibration buffers, wash bottle, Kimwipes™

B.1 **Using red cabbage indicator to measure pH**

Section	Step	Procedure	Check when finished
B.1	1	Place 3–4 mL of a sample in a shell vial (or a test tube).	
B.1	2	Add 2–3 mL of red cabbage solution.	
B.1	3	Describe the color and compare to the colors of the pH reference set. The pH of the buffer in the reference set that gives the best color match is the pH of the sample.	
B.1	4	Record.	
B.1	5	Repeat steps 1 to 4 for various samples	

Using a pH meter to measure pH. Your instructor will demonstrate the use of the pH meter and calibrate it with a known pH buffer

Section	Step	Procedure	Check when finished
B.2	1	After you determine the pH of a sample using the red cabbage solution, take the sample to a pH meter, and record the pH.	
B.2	2	Rinse off the electrode with distilled water.	
B.2	3	Repeat steps 1 and 2 for various samples.	

C. Effect of Buffers on pH

Materials: Buffer with a high pH (9–11), buffer with a low pH (3–4), droppers, shell vials or test tubes, 0.1 M NaCl, 0.1 M HCl, 0.1 M NaOH, pH meter, cabbage juice indicator from part A

Effect of Adding Acid

C.1 **Making up the samples**

Section	Step	Procedure	Check when finished
C.1	1	Place 10.0 mL of H_2O into a shell vial or test tube.	

C.1	2	Place 10.0 mL of 0.1 M NaCl into a shell vial or test tube.	
C.1	3	Place 10.0 mL of a buffer with a high pH into a shell vial or test tube.	
C.1	4	Place 10.0 mL of a buffer with a low pH into a shell vial or test tube.	
C.1	5	Add 2–3 mL of cabbage indicator to each.	
C.1	6	Describe the color.	
C.1	7	Determine the pH of each sample using the pH reference set or pH meter, or both.	
C.1	8	Record.	

C.2 **Adding acid and measuring the pH**

Section	Step	Procedure	Check when finished
C.2	1	Add 5 drops of 0.1 M HCl (acid) to each of the 4 test tubes.	
C.2	2	Mix each of the test tubes by shaking.	
C.2	3	Determine the pH in each of the test tubes.	
C.2	4	Record the pH for each of the test tubes.	
C.2	5	Add 5 more drops of 0.1 M HCl to each of the test tubes.	
C.2	6	Record any color change in the indicator in each of the test tubes.	
C.2	7	Determine the final pH in each of the test tubes.	

C.3 **Identifying buffers**

Section	Step	Procedure	Check when finished
C.3	1	Determine whether the pH changed significantly in any of the solutions.	
C.3	2	Identify the solutions that are buffers.	

Effect of Adding Base

C.4 **Making up the samples**

Section	Step	Procedure	Check when finished
C.4	1	Place 10.0 mL of H_2O into a shell vial or test tube.	
C.4	2	Place 10.0 mL of 0.1 M NaCl into a shell vial or test tube.	
C.4	3	Place 10.0 mL of a buffer with a high pH into a shell vial or test tube.	

C.4	4	Place 10.0 mL of a buffer with a low pH into a shell vial or test tube.	
C.4	5	Add 2–3 mL of cabbage indicator to each.	
C.4	6	Describe the color.	
C.4	7	Determine the pH of each sample using the pH reference set or pH meter, or both.	
C.4	8	Record.	

C.5 **Adding base and measuring the pH.**

Section	**Step**	**Procedure**	**Check when finished**
C.5	1	Add 5 drops of 0.1 M NaOH (base) to each of the 4 test tubes.	
C.5	2	Mix each of the test tubes by shaking.	
C.5	3	Determine the pH in each of the test tubes.	
C.5	4	Record the pH for each of the test tubes.	
C.5	5	Add 5 more drops of 0.1 M HCl to each of the test tubes.	
C.5	6	Record any color change in the indicator in each of the test tubes.	
C.5	7	Determine the final pH in each of the test tubes.	

C.6 **Identifying buffers**

Section	**Step**	**Procedure**	**Check when finished**
C.6	1	Determine whether the pH changed significantly in any of the solutions.	
C.6	2	Identify the solutions that are buffers.	

Report Sheet

Date ______________________ Name ______________________

Section ______________________ Team ______________________

Instructor ______________________ ______________________

Pre-Lab Study Questions

1. What does the pH of a solution tell you?

2. What is neutralization?

3. What is a buffer?

4. Is a solution with a pH of 12 acidic or basic?

5. Is a solution with a pH of 2 acidic or basic?

6. If you add acid or base to a buffer, how do you predict that the pH will change?

7. If you add acid or base to water, how do you predict that the pH will change?

Report Sheet

Date ____________ Name ____________
Section ____________ Team ____________
Instructor ____________

A. pH Colors Using Red Cabbage Indicator

pH	Colors of Acidic Solutions
1	
2	
3	
4	
5	
6	

pH	Color of Neutral Solutions
7	

pH	Colors of Basic Solutions
8	
9	
10	
11	
12	
13	

B. Measuring pH

Substance	Color with Indicator	pH Using Indicator	pH Using pH Meter	Acidic, Basic, or Neutral?
Household cleaners				
vinegar				
ammonia				
Drinks, juices				
lemon juice				
apple juice				

Report Sheet

Substance	Color with Indicator	pH Using Indicator	pH Using pH Meter	Acidic, Basic, or Neutral?
Detergents, shampoos				
shampoo				
detergent				
hair conditioner				
Health aids				
mouthwash				
antacid				
aspirin				
Other items				

Questions and Problems

Q.1 Complete the following table:

$[H_3O^+]$	$[OH^-]$	pH	Acidic, Basic, or Neutral?
1×10^{-6}			
		10.0	
	1×10^{-3}		
			Neutral

Q.2 The label on the shampoo claims that it is pH balanced. What do you think "pH balanced" means?

Report Sheet

Q.3 A solution has a $[OH^-] = 1 \times 10^{-5}$ M. What are the $[H_3O^+]$ and the pH of the solution?

Q.4 A sample of 0.0020 mole of HCl is dissolved in water to make a 2000-mL solution. Calculate the molarity of the HCl solution, the $[H_3O^+]$, and the pH. For a strong acid such as HCl, the $[H_3O^+]$ is the same as the molarity of the HCl solution.

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$

C. Effect of Buffers on pH

Effect of adding 0.1 M HCl

Solution	C.1 **Initial pH**	C.2 **pH after 5 drops HCl**	**pH after 10 drops HCl**	C.3 **pH change**	**Buffer?**
H_2O					
0.1 M NaCl					
High pH buffer					
Low pH buffer					

Effect of adding 0.1 M NaOH

Solution	C.4 **Initial pH**	C.5 **pH after 5 drops NaOH**	**pH after 10 drops NaOH**	C.6 **pH change**	**Buffer?**
H_2O					
0.1 M NaCl					
High pH buffer					
Low pH buffer					

Report Sheet

Questions and Problems

Q.5 Which solution(s) showed the greatest change in pH? Why?

Q.6 Which solutions(s) showed little or no change in pH? Why?

Q.7 Is a buffer supposed to keep the pH of a solution at 7 (neutral)?

Q.8 Normally, the pH of the human body is fixed in a very narrow range between 7.35 and 7.45. A patient with an acidotic blood pH of 7.3 may be treated with an alkali such as sodium bicarbonate. Why would this treatment raise the pH of the blood?