Name _____ Class _____ Date _____

Skills Practice

Hydronium Ion Concentration and pH

For pure water at 25°C, the hydronium ion concentration, $[H_3O^+]$, is 1.0×10^{-7} M or 10^{-7} M.

In *acidic* solutions, the hydronium ion concentration is *greater* than 1×10^{-7} M. For example, the H_3O^+ concentration of a 0.00 001 M hydrochloric acid (HCl) solution is 1×10^{-5} M.

In *basic* solutions, the hydronium ion concentration is *less* than 1×10^{-7} M. The hydronium ion concentration in a basic solution can be determined from the equation for K_w when the hydroxide ion concentration, $[OH^-]$, is known.

(1) $$K_w = [H_3O^+][OH^-] = 1 \times 10^{-14}\ \text{mol}^2/\text{L}^2$$

(2) $$[H_3O^+] = \frac{1 \times 10^{-14}\ \text{mol}^2/\text{L}^2}{[OH^-]}$$

Therefore, the concentration of H_3O^+ in a 0.000 01 M NaOH basic solution is

$$[H_3O^+] = \frac{1 \times 10^{-14}\ \text{mol}^2/\text{L}^2}{[OH^-]} = \frac{1 \times 10^{-14}\ \text{mol}^2/\text{L}^2}{0.000\ 01\ \text{mol/L}} = \frac{1 \times 10^{-14}\ \text{mol}^2/\text{L}^2}{1 \times 10^{-5}\ \text{mol/L}}$$
$$= 1 \times 10^{-9}\ \text{mol/L}$$

The pH of a solution is defined as the negative of the common logarithm of the hydronium ion concentration. Therefore, for a 1×10^{-5} M HCl solution,

(3) $$\text{pH} = -\log [H_3O^+]$$
$$= -\log (1 \times 10^{-5}) = 5$$

For a 1×10^{-5} M NaOH solution, from equation **2**,

$$[H_3O^+] = \frac{1 \times 10^{-14}\ \text{mol}^2/\text{L}^2}{1 \times 10^{-5}\ \text{mol/L}} = 1 \times 10^{-9}\ \text{mol/L}$$

$$\text{and pH} = -\log (1 \times 10^{-9}) = 9$$

Values for pH that are greater than 7 indicate a basic solution. The higher the pH above the value of 7, the stronger the base and the smaller the hydronium ion concentration.

OBJECTIVES

Use pH paper and standard colors to determine the pH of a solution.

Determine hydronium ion concentrations from experimental data.

Describe the effect of dilution on the pH of acids and sodium hydroxide.

Relate pH to the acidity and basicity of solutions.

Name _____ Class _____ Date _____

Hydronium Ion Concentration and pH *continued*

MATERIALS

- 0.033 M H_3PO_4
- 0.10 M CH_3COOH
- 0.10 M HCl
- 0.10 M NaCl
- 0.10 M Na_2CO_3
- 0.10 M $NaHCO_3$
- 0.10 M NaOH
- 0.10 M NH_3, aqueous
- 0.10 M CH_3COONH_4
- 10 mL graduated cylinder
- 50 mL graduated cylinder
- 250 mL beaker
- deionized water
- glass plate
- glass stirring rod, 25 cm long
- pH papers, wide and narrow range
- test tubes 9
- white paper, small sheet
- test tube rack

  **Always wear safety goggles and a lab apron to protect your eyes and clothing.** If you get a chemical in your eyes, immediately flush the chemical out at the eyewash station while calling to your teacher. Know the locations of the emergency lab shower and the eyewash station and the procedures for using them.

 **Do not touch any chemicals.** If you get a chemical on your skin or clothing, wash the chemical off at the sink while calling to your teacher. Make sure you carefully read the labels and follow the precautions on all containers of chemicals that you use. If there are no precautions stated on the label, ask your teacher what precautions you should follow. Do not taste any chemicals or items used in the laboratory. Never return leftovers to their original containers; take only small amounts to avoid wasting supplies.

 **Call your teacher in the event of a spill.** Spills should be cleaned up promptly, according to your teacher's directions.

 **Never put broken glass in a regular waste container.** Broken glass should be disposed of properly.

Name _____ Class _____ Date _____

Procedure

1. Place the glass plate on the sheet of white paper. Place a strip of wide-range pH paper and a strip of narrow-range pH paper on the glass plate.
2. Obtain samples of all of the solutions listed in **Data Table 1.** To find the pH of each solution, dip a clean stirring rod into each solution and apply a drop of the solution first to the wide-range pH paper and then to the narrow-range pH paper. **Figure A** shows the correct technique. Compare the color produced by each solution with the colors on the charts included with the pH papers. Be sure to rinse and dry the stirring rod before you test each solution. Record your results in **Data Table 1.**

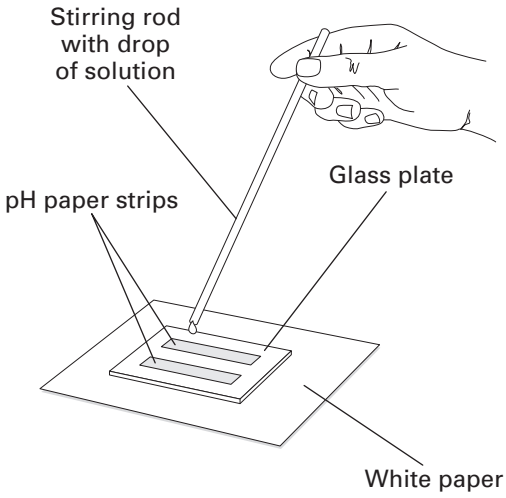

Figure A

3. Using the 10 mL graduated cylinder, measure 5.0 mL of 0.10 M HCl. Dilute it to 50 mL in the 50 mL graduated cylinder with deionized water added from the 10 mL graduated cylinder. Stir the solution with a stirring rod. Transfer 5.0 mL of the diluted solution to a labeled test tube. Using the 10 mL graduated cylinder, measure and save 5.0 mL of the diluted solution from the 50 mL graduated cylinder. Empty the 50 mL graduated cylinder into a waste container, and rinse it with deionized water.
4. Repeat step **3** two more times, starting with the 5.0 mL of *diluted* solution you just made and measured in the 10 mL graduated cylinder.

Data Table 1

0.1 M solution	pH	0.1 M solution	pH
HCl		NaCl	
CH_3COOH		Na_2CO_3	
H_3PO_4		$NaHCO_3$	
NaOH		CH_3COONH_4	
NH_3			

Name _____ Class _____ Date _____

5. Repeat steps **3** and **4** for 0.10 M NaOH and 0.10 M CH_3COOH. Record your results for each test in **Data Table 2.**

DISPOSAL

6. Clean all apparatus and your lab station. Return equipment to its proper place. Dispose of chemicals and solutions in the containers designated by your teacher. Do not pour any chemicals down the drain or in the trash unless your teacher directs you to do so. Wash your hands thoroughly after all work is finished and before you leave the lab.

Data Table 2

Concentration (M)	HCl	NaOH	CH_3COOH
0.10			
0.010			
0.0010			
0.000 10			

Analysis

1. Organizing Data List the solutions in order of decreasing acid strength using your results from step **2.**

_____

_____

_____

_____

2. Organizing Data Calculate the theoretical pH values for the concentrations prepared in steps **3–5.** Record these values below.

HCl	Calculated pH	NaOH	Calculated pH
0.10 M		0.10 M	
0.010 M		0.010 M	
0.0010 M		0.0010 M	
0.000 10 M		0.000 10 M	

Name _____ Class _____ Date _____

3. **Analyzing Results** What effect does dilution have on the pH of (a) an acid and (b) a base?

a. _____

_____

b. _____

_____

Conclusions

1. **Predicting Outcomes** Solutions with a pH of 12 or greater dissolve hair. Would a cotton shirt or a wool shirt be affected by a spill of 0.1 M sodium hydroxide? Explain.

_____

_____

_____

_____

_____

_____

_____

Skills Practice

Hydronium Ion Concentration and pH

Teacher Notes

TIME REQUIRED 60 min

SKILLS ACQUIRED

Collecting data
Communicating
Experimenting
Identifying patterns
Interpreting
Organizing and analyzing data
Predicting

RATING Easy 1 2 3 4 Hard

Teacher Prep–3
Student Set-Up–3
Concept Level–3
Clean Up–3

THE SCIENTIFIC METHOD

Make Observations Students observe the effects of adding drops of various solutions to pH paper.

Analyze the Results Analysis questions 1 and 2

Draw Conclusions Analysis question 3 and Conclusions question 1

Communicate the Results Analysis questions 1 to 3 and Conclusion question 1

MATERIALS

Wear safety goggles, a face shield, impermeable gloves, and a lab apron when you prepare the NaOH, HCl, H_3PO_4, NH_3, and CH_3COOH solutions. For all except NaOH and H_3PO_4, work in a hood known to be in operating condition, with another person nearby to call for help in case of an emergency. Be sure you are within a 30 s walk from a safety shower and an eyewash station known to be in good operating condition.

To prepare 1.0 L of 0.033 M phosphoric acid, H_3PO_4, observe the required safety precautions. Slowly stir 2.0 mL of concentrated H_3PO_4 into enough deionized water to make 1.0 L of solution.

To prepare 1.0 L of 0.1 M acetic acid, CH_3COOH, observe the required safety precautions. Slowly stir 6.0 mL of glacial acetic acid into enough deionized water to make 1.0 L of solution.

To prepare 1.0 L of 0.1 M hydrochloric acid, HCl, observe the required safety precautions. Slowly stir 9.0 mL of concentrated HCl into enough deionized water to make 1.0 L of solution.

To prepare 1.0 L of 0.1 M sodium chloride, NaCl, dissolve 6.0 g of solid NaCl in enough deionized water to make 1.0 L of solution.

To prepare 1.0 L of 0.1 M sodium carbonate, Na_2CO_3, dissolve 5.0 g of solid Na_2CO_3 in enough deionized water to make 1.0 L of solution.

To prepare 1.0 L of 0.1 M sodium hydrogen carbonate, $NaHCO_3$, dissolve 8.0 g of solid $NaHCO_3$ in enough deionized water to make 1.0 L of solution.

To prepare 1.0 L of 0.1 M sodium hydroxide, NaOH, observe the required safety precautions. Slowly stir 4.0 g of solid NaOH in enough deionized water to make 1.0 L of solution.

To prepare 1.0 L of 0.1 M aqueous ammonia, NH_3, observe the required safety precautions. Slowly stir 7.0 mL of concentrated $NH_3(aq)$ into enough deionized water to make 1.0 L of solution.

To prepare 1.0 L of 0.1 M ammonium acetate, CH_3COONH_4, dissolve 8.0 g of solid CH_3COONH_4 in enough deionized water to make 1.0 L of solution.

Best results are obtained by using Panapeha brand pH strips. Each strip contains six squares for color matching and covers pH values of 1–14. Also available are EM brand pH strips, which contain four squares per strip. EM paper is available in wide and narrow range.

SAFETY CAUTIONS

Read all safety precautions, and discuss them with your students.

- Safety goggles and a lab apron must be worn at all times.
- In case of an acid or base spill, first dilute it with water. Then mop up the spill with wet cloths or a wet cloth mop while wearing disposable plastic gloves. Designate separate cloths or mops for acid and base spills.

DISPOSAL

Combine all solutions containing H_3PO_4 and adjust the pH to between 5 and 9 using 1.0 M potassium hydroxide, KOH. (Do not use sodium hydroxide, NaOH, because the EPA does not want sodium hydrogen phosphates in the water.) Then pour the adjusted solution down the drain. Combine all other solutions and adjust the pH to between 6 and 8, and pour the adjusted solution down the drain.

TIPS AND TRICKS

Show students how to test the solutions and compare the test paper with the pH wide-range and narrow-range standards. Caution them to avoid poor results by thoroughly cleaning and drying the stirring rod between tests.

Name _____ Class _____ Date _____

Skills Practice

Hydronium Ion Concentration and pH

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(2) $$[H_3O^+] = \frac{1 \times 10^{-14}\ \text{mol}^2/\text{L}^2}{[OH^-]}$$

Therefore, the concentration of H_3O^+ in a 0.000 01 M NaOH basic solution is

$$[H_3O^+] = \frac{1 \times 10^{-14}\ \text{mol}^2/\text{L}^2}{[OH^-]} = \frac{1 \times 10^{-14}\ \text{mol}^2/\text{L}^2}{0.000\ 01\ \text{mol/L}} = \frac{1 \times 10^{-14}\ \text{mol}^2/\text{L}^2}{1 \times 10^{-5}\ \text{mol/L}}$$
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$$\text{and pH} = -\log (1 \times 10^{-9}) = 9$$

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OBJECTIVES

Use pH paper and standard colors to determine the pH of a solution.

Determine hydronium ion concentrations from experimental data.

Describe the effect of dilution on the pH of acids and sodium hydroxide.

Relate pH to the acidity and basicity of solutions.

Name _____ Class _____ Date _____

Hydronium Ion Concentration and pH *continued*

MATERIALS

- 0.033 M H_3PO_4
- 0.10 M CH_3COOH
- 0.10 M HCl
- 0.10 M NaCl
- 0.10 M Na_2CO_3
- 0.10 M $NaHCO_3$
- 0.10 M NaOH
- 0.10 M NH_3, aqueous
- 0.10 M CH_3COONH_4
- 10 mL graduated cylinder
- 50 mL graduated cylinder
- 250 mL beaker
- deionized water
- glass plate
- glass stirring rod, 25 cm long
- pH papers, wide and narrow range
- test tubes 9
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Name _____ Class _____ Date _____

Procedure

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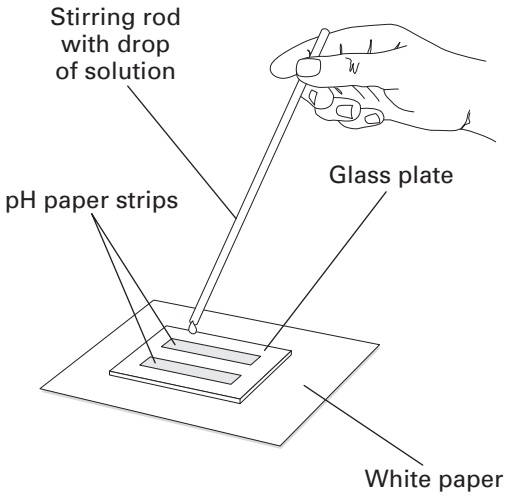

Figure A

3. Using the 10 mL graduated cylinder, measure 5.0 mL of 0.10 M HCl. Dilute it to 50 mL in the 50 mL graduated cylinder with deionized water added from the 10 mL graduated cylinder. Stir the solution with a stirring rod. Transfer 5.0 mL of the diluted solution to a labeled test tube. Using the 10 mL graduated cylinder, measure and save 5.0 mL of the diluted solution from the 50 mL graduated cylinder. Empty the 50 mL graduated cylinder into a waste container, and rinse it with deionized water.
4. Repeat step **3** two more times, starting with the 5.0 mL of *diluted* solution you just made and measured in the 10 mL graduated cylinder.

Data Table 1

0.1 M solution	pH	0.1 M solution	pH
HCl	1	NaCl	7
CH_3COOH	3	Na_2CO_3	11
H_3PO_4	1.5	$NaHCO_3$	8
NaOH	13	CH_3COONH_4	7
NH_3	11		

Name _____ Class _____ Date _____

Hydronium Ion Concentration and pH *continued*

5. Repeat steps **3** and **4** for 0.10 M NaOH and 0.10 M CH_3COOH. Record your results for each test in **Data Table 2.**

DISPOSAL

6. Clean all apparatus and your lab station. Return equipment to its proper place. Dispose of chemicals and solutions in the containers designated by your teacher. Do not pour any chemicals down the drain or in the trash unless your teacher directs you to do so. Wash your hands thoroughly after all work is finished and before you leave the lab.

Data Table 2

Concentration (M)	HCl	NaOH	CH_3COOH
0.10	**Students' answers will vary.**		
0.010			
0.0010			
0.000 10			

Analysis

1. Organizing Data List the solutions in order of decreasing acid strength using your results from step **2.**

HCl, H_3PO_4, CH_3COOH, CH_3COONH_4, $NaCl$, $NaHCO_3$, NH_3, Na_2CO_3, $NaOH$

2. Organizing Data Calculate the theoretical pH values for the concentrations prepared in steps **3–5.** Record these values below.

HCl	Calculated pH	NaOH	Calculated pH
0.10 M	**1**	0.10 M	**13**
0.010 M	**2**	0.010 M	**12**
0.0010 M	**3**	0.0010 M	**11**
0.000 10 M	**4**	0.000 10 M	**10**

Name _____ Class _____ Date _____

3. **Analyzing Results** What effect does dilution have on the pH of (a) an acid and (b) a base?

   a. **The pH of an acid increases as the solution is made more dilute.**

   b. **The pH of a base decreases as the solution is made more dilute.**

Conclusions

1. **Predicting Outcomes** Solutions with a pH of 12 or greater dissolve hair. Would a cotton shirt or a wool shirt be affected by a spill of 0.1 M sodium hydroxide? Explain.

A shirt made from wool, which is animal hair, will dissolve in the sodium hydroxide solution. This will happen because, according to the calculations for question 2, 0.1 M NaOH has a pH of 13.