Acid-Base Studies

PURPOSE

To measure pH's of a variety of solutions and mixtures and to account for the results obtained.

GOALS

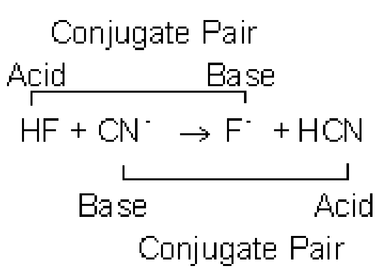
1 To use pH paper and a pH electrode to measure the pH of a given solution.

2 To become familiar with the pH scale.

3 To observe pH changes produced upon addition of acid or base to a solution.

INTRODUCTION

Many substances can be classified as acids or bases. There are three ways to describe acids and bases: the Arrhenius definition, the Brønsted definition, and the Lewis definition. Here we will consider only the Brønsted definition. In this theory, an **acid is a proton (H^+) donor** and acids can usually be recognized because protons that can be transferred are written first in the chemical formula. For example, acetic acid has the formula $HC_2H_3O_2$. Although it contains four protons, only one is acidic. A **base is a proton (H^+) acceptor.** Protons have positive charge, so their acceptors usually have negative charge, i.e., most anions are bases. A very common base that is not an anion is ammonia NH_3. An Brønsted acid-base reaction is the transfer of a proton from the acid to the base to form their conjugate acid-base pairs. Conjugate acid-base pairs differ by exactly one proton. Thus, the conjugate base of an acid is obtained by removing one H^+, so the conjugate base of HF is the F^- ion. The conjugate acid of a base is obtained by adding one H^+ to the base, so the conjugate acid of CN^- is HCN. Brønsted acid-base reactions contain two conjugate acid-base pairs and nothing else.



The acidity of a Brønsted acid is a measure of the extent to which the acid reacts with the weak base H_2O to produce its conjugate base and H_3O^+ ions, the conjugate acid of water. The greater the extent of this reaction, the larger the equilibrium constant is for the reaction. This equilibrium constant is defined as the acid dissociation constant or K_a of the acid. The larger the K_a, the stronger the acid is. The general form of the acid dissociation reaction and K_a are shown below in equation 1.

$$HA + H_2O \rightleftharpoons A^- + H_3O^+ \qquad K_a = \frac{[A^-][H_3O^+]}{[HA]} \tag{1}$$

The basicity (or alkalinity) of a Brønsted base is a measure of the extent to which a Brønsted base reacts with water to produce its conjugate acid and OH^- ions, the conjugate base of water. The equilibrium constant for the reaction of a base with water is given the symbol K_b. The general from for this chemical reaction and K_b are shown below in equation 2.

$$A^- + H_2O \rightleftharpoons HA + OH^- \qquad K_b = \frac{[HA][OH^-]}{[A^-]} \tag{2}$$

The acidity of an aqueous solution is therefore measured by the concentration of H_3O^+, and the basicity by the concentration of OH^-. Most solutions we deal with are aqueous solutions, and these concentrations are important characteristics. We have seen that water behaves both as an acid (Reaction 1) and a base (Reaction 2), so it should not be surprising that it can react with itself.

$$H_2O + H_2O \rightleftharpoons H_3O^+ + OH^- \qquad K_w = [H_3O^+][OH^-] \tag{3}$$

Hydronium and hydroxide ion concentrations can be very small. For example, the K_w = 1.0 x 10^{-14} at 298K, so in pure water at 298 K, $[H_3O^+]$ = $[OH^-]$ = 1.0 x 10^{-7} M. Negative exponents are avoided by defining the pH:

$$\text{pH} = \text{¡s:minus¿}\log[H_3O^+] \tag{4}$$

The pH of pure water is -log(1.0 x 10^{-7}) = 7.0. Solutions in which $[H_3O^+] = [OH^-]$ are said to be neutral, so neutral solutions have a pH of 7.0 at 298 K. Solutions in which $[H_3O^+] > [OH^-]$ are acidic and pH < 7. Solutions in which $[OH^-] > [H_3O^{1+}]$ are basic or alkaline and pH > 7. Thus, the acidity or basicity of an aqueous solution can be determined from its pH. Equation 4 can be solved for the hydronium ion concentration to obtain Equation 5.

$$[H_3O^+] = 10^{\text{-pH}} \tag{5}$$

Thus, a pH of 2.2 implies that $[H_3O^+] = 10^{-\text{pH}} = 10^{-2.2} = 0.006$ M.

The acidity or basicity of a solution can be determined by measuring its pH or with an indicator. pH electrodes are electrochemical cells whose voltage is pH sensitive. When the electrode is placed in a solution, a voltage is developed between the electrode and the solution. The voltage is converted to a pH value that can be read directly. An acid-base indicator is a weak acid whose conjugate base is a different color. When the indicator is placed in an acidic solution, it is converted to the acid form and takes that color, but when it is placed in a basic solution, it is converted to the base and takes on the color of the base.

pH paper is a strip of paper with an indicator on it. The color of the indicator changes with pH, so the approximate pH of a solution can be determined by placing a small amount of the solution on the paper.

In Part A of this lab, you will calibrate a pH electrode and check the calibration with 3 buffer solutions. In Part B, you will use pH electrodes to determine the pH of several acid-base solutions commonly found in a chemistry laboratory to become familiar with the pH scale. In Part C, you will use pH paper to determine whether several common household chemicals are acidic, basic, or neutral. In Part D, you will use a pH electrode to follow the pH change of an acidic solution as a basic solution is added to it.

EQUIPMENT

1 30 mL beaker

1 10 mL graduated cylinder

1 glass stir rod

7 medium test tubes

1 test tube rack

1 pH electrode in pH 7.00 buffer

1 MicroLab interface

1 MicroLab pH measurement instruction sheet

1 pH paper

1 plastic work surface

1 deionized water squirt bottle

REAGENTS

0.010 M HCl

0.0010 M HCl

0.00010 M HCl

0.010 M $HC_2H_3O_2$

0.010 M NaOH

0.0010 M NaOH

0.010 M NH_3

pH 4.00 buffer

pH 7.00 buffer

pH 10.00 buffer

~2 drops vinegar

~2 drops bleach

~2 drops ammonia

~2 drops vitamin C

~2 drops lemon juice

~2 drops baking soda

~2 drops dishwasher detergent

~2 drops carbonated water

~2 drops baking powder

SAFETY

HCl, NaOH, $HC_2H_3O_2$ and NH_3 are corrosive. They can attack the skin and cause permanent damage to the eyes. If any of these solutions splash into your eyes, use the eyewash station immediately. Hold your eyes open and flush with water for at least 15 minutes. If contact with skin or clothing occurs, flush the affected area with water for at least 15 minutes. Have your lab partner notify your teaching assistant and the lab director about the spill and exposure.

HCl, $HC_2H_3O_2$ and NH_3 solutions give off highly irritating vapors. Do not inhale them. Work with concentrated solutions under the hood at your bench so vapors do not build up in the lab. If you do inhale enough vapor to have a problem, move to fresh air. Have your lab partner notify your teaching assistant and the lab director about the inhalation.

Acid-base reactions are highly exothermic. They can cause water to boil and splash hot, corrosive solution out of the vessel in which they were mixed. Do not directly combine solutions with concentrations greater than 0.1 M. Use caution when pouring solutions or disposing of them.

The chemicals used in this experiment are very dilute so gloves will not be available. Remember to wash your hands with soap and water when the experiment is completed.

WASTE DISPOSAL

All solutions can be discarded down the sink drain followed by flushing with plenty of water. When disposing of concentrated solutions, pour them slowly while the water is running.

PRIOR TO CLASS

Please complete WebAssign prelab assignment. Check your WebAssign Account for due dates. Students who do not complete the WebAssign prelab are required to bring and hand in the prelab worksheet.

LAB PROCEDURE

Please print the worksheet for this lab. You will need this sheet to record your data.

In this experiment, you will be using pH electrodes. They have electrodes with a thin glass bulb at the tip. **They break easily and are costly to replace.** Be careful not to shove the electrode into the bottom of a test tube or drop the electrode. There is a protective guard around the tip, which should remain in place at all times. The guard will not protect against careless treatment. Please use extreme care when using this equipment. When the pH electrode is not in use, it should be stored in the pH 7 buffer solution.

Part A: Calibration of a pH Electrode

1 Open the MicroLab program.

2 Make sure the pH electrode is plugged into the interface.

3 Calibrate the pH electrode using the MicroLab instructions provided in the lab.

4 After the calibration is complete, configure the MicroLab program to collect data as described in the instructions provided in the lab.

5 After the calibration and configuration are complete, measure the pH of each of the three buffer solutions of pH = 4.00 (red), pH = 7.00 (yellow), and pH = 10.00 (blue). Record the value in the digital display into WebAssign as a record of how accurately the probe is calibrated. Make sure the electrode is immersed in the solution and allow for a few seconds equilibration.

Part B: pH Measurements of Some Common Acid and Base Solutions.

1 Number seven test tubes 1 - 7.

2 Fill each test tube $\sim$ 1/4 - 1/2 full with solutions 1 - 7 listed in Data Table A.

3 Use a pH electrode to measure the pH of each solution and record them in Data Table A. *Rinse the pH electrode thoroughly with deionized water between each measurement.*

4 Discard the solutions and rinse each of the test tubes.

Data Table A: pH Measurements of Some Common Acid and Base Solutions.

Question 1: Based on your observations in Data Table A, classify each of the following as a strong acid, strong base, weak acid or weak base.

a HCl

b $HC_2H_3O_2$

c NaOH

d NH_3

Question 2:

a What happened to the pH when the 0.010 M HCl was diluted to 0.0010 M?

b What happened to the pH when the 0.010 M NaOH was diluted to 0.0010 M?

c State a general rule about what happens to the pH of acidic or basic solutions when they are diluted with pure water.

Part C: Acidity and Basicity of Some Household Chemicals

1 Place ten small strips of pH paper on the plastic work surface provided.

2 Put one or two drops of each of the solutions listed in Data Table B on a separate piece of paper. Because ammonia vapors will react with the pH paper, *add ammonia (NH_3) last!* The bleach will oxidize the pH paper quickly; be sure to observe the initial color change of the pH paper.

3 Observe and record your results in Data Table B.

Data Table B: Acidity and Basicity of Some Household Chemicals

Question 3:

a List all of the household chemicals that you found to be acidic.

b List all of the household chemicals that you found to be basic.

c List all of the household chemicals that you found to be neutral.

Part D: Acid-Base Reactions

1 Measure 10.0 mL of 0.010 M HCl in a 10 mL graduated cylinder and place in a clean 30 mL beaker.

2 Use a pH electrode to measure the pH. Record this value in Data Table C as 0.0 mL NaOH.

3 Rinse the graduated cylinder used in Step 1 thoroughly and dry.

4 Measure 3.0 mL of 0.010 M NaOH and add it carefully to the HCl solution in the beaker and stir. Record the pH of the new solution in Data Table C as 3.0 mL NaOH.

5 Add an additional 3.0 mL of 0.010 M NaOH to the beaker, stir, and record the pH in Data Table C as 6.0 mL NaOH. The total volume in the beaker should now be 16 mL.

6 Add a final 6.0 mL of 0.010 M NaOH to the beaker and record the pH in Data Table C as 12.0 mL NaOH. The total volume should now be 22 mL.

7 Return the pH electrode to the pH 7 buffer solution and close the MicroLab software.

8 Discard the solution, wash and dry all your glassware and return it to the set-up area where you found it.

Data Table C: HCl + NaOH

Question 4: Based on your observations in Data Table C, classify each of the resulting solutions as acidic, basic or neutral.

a HCl + 0.0 mL NaOH

b HCl + 3.0 mL NaOH

c HCl + 6.0 mL NaOH

d HCl + 12.0 mL NaOH

9 Before leaving, go to a computer in the laboratory and enter your results in the InLab assignment. If all results are scored as correct, log out. If not all results are correct, try to find the error or consult with your teaching assistant. When all results are correct, note them and log out of WebAssign. The InLab assignment must be completed by the end of the lab period. If additional time is required, please consult with your teaching assistant.