

1. Conductivity of Aqueous Solutions

Introduction

Aqueous solutions of some substances will conduct electricity (Ebbing/Gammon, Section 4.1). These substances are called *electrolytes*. Other substances whose solutions will not conduct an electric current are called *nonelectrolytes*.

When an electrolyte is dissolved in water, ions are produced. Ions are responsible for conductivity. We will distinguish between two types of substances that produce ions in solution. *Strong electrolytes* form aqueous solutions that conduct electricity very easily. The conductivity is high because strong electrolytes in solution exist almost entirely as ions. *Weak electrolytes*, on the other hand, form solutions that are poorer conductors. In solution, weak electrolytes exist primarily as molecular substances, with only a few ions.

Purpose

The conductivities of solutions (or the electric current that flows through these solutions) will allow you to distinguish between strong electrolytes, weak electrolytes, and nonelectrolytes. You will also be able to distinguish between strong acids and bases and weak acids and bases. Finally, you will have the opportunity to dilute an acid and a base to a desired concentration.

Concept of the experiment

When a voltage (E) is applied across a conductor, the current (i) is controlled by the resistance (R) of the conductor. The exact relationship is given by Ohm's law, $E = iR$. This equation can be rearranged to give an equivalent relationship, $1/R = i/E$. The term $1/R$ is called the conductance; it has units of ohm^{-1} . This equation also shows that the conductance is directly proportional to the current at a constant voltage. Therefore, a measurement of the current is an indirect measurement of the conductance. Some laboratories may not have a conductivity apparatus. Therefore, do not be surprised if you are asked to measure current rather than conductance in this experiment.

The magnitude of each conductance (or current) that you measure will depend on the concentration of the ions in the solution and on their type. These two factors will dictate a pattern of conductances that will allow you to pick out the strong electrolytes, the weak electrolytes, and the nonelectrolytes.

Do not expect, however, that isomolar solutions (solutions that have the same molarity) of different strong electrolytes will have the same conductance. Although each solution will have a large conductance, each conductance will differ from the others. The reason lies in the differing mobilities of different ions. The abilities of different ions to move through the solution will not be identical. As a result, their conductances will differ even though their concentrations are the same.

Finally, we will note the existence of an *approximate* additivity rule. As an example, consider a dilute solution containing two strong electrolytes. We will stipulate that these substances do not react with each other. Consider, also, separate solutions of these electrolytes. The concentration of each electrolyte in its separate solution must be identical to its concentration in the mixture. Under these conditions, the conductance of the mixture will be approximately equal to the sum of the conductances of the separate solutions.

Additivity will not occur, however, when the two electrolytes react with each other. The reason is easy to understand. A chemical reaction will produce new substances with different characteristic conductances. In this experiment, a notably large deviation from additivity will allow you to pinpoint a case in which a chemical reaction has occurred.

A special note about molarity and dilution

In this experiment, you will encounter the symbol M . It stands for molarity with units of mol/L (Ebbing/Gammon, Section 4.7). Molarity is a measure of the concentration of a solution.

You will also encounter dilution—perhaps for the first time. Suppose you dilute (by adding water) a solution of known initial molarity (M_i) and known initial volume (V_i) to a solution with a final molarity (M_f) and final volume (V_f). The following equation (Ebbing/Gammon, Section 4.8) is applicable:

$$M_i \times V_i = M_f \times V_f$$

In this experiment, you will know M_i , M_f , and V_f . You will be able to calculate V_i from this equation. The difference, $V_f - V_i$, will tell you how much water to add to achieve the desired dilution (if it is assumed that the volume of the original solution and the volume of the water added are perfectly additive).

Procedure

Getting started

1. Your laboratory instructor may ask you to work with a partner.
2. Obtain an apparatus to measure either conductance or current.

CAUTION: Handle the apparatus with care to avoid electric shocks.

3. Prepare 0.10 M solutions of acetic acid ($\text{HC}_2\text{H}_3\text{O}_2$) and ammonia (NH_3) according to the directions you devised in the Prelaboratory Assignment.

CAUTION: Handle the 6 M solutions of acetic acid and ammonia with caution. Work in an area with very good ventilation. A hood is preferred. Do not mix these substances. If you spill one of these substances on you, wash the contaminated area thoroughly and report the incident to your laboratory instructor. You may need further treatment.

Making the measurements

1. Use a 50-mL beaker for each of the following measurements. Rinse it and dry it after each measurement.
2. Compare the conductances of 20 mL of distilled water, 20 mL of tap water, and 20 mL of ethyl alcohol (C_2H_5OH). The volumes should be measured in a graduated cylinder. Record the results from each measurement.
3. Measure the conductances of 0.10 *M*, 0.050 *M*, and 0.020 *M* solutions of HCl. These solutions should be prepared according to the directions you prescribed in the Prelaboratory Assignment. Make sure that each solution is mixed thoroughly before you measure the conductance.
4. Add 10 mL of 0.10 *M* HNO_3 to the beaker from the clean, dry graduated cylinder. Add 10 mL of distilled water. Swirl gently to mix. Calculate and record the new concentration. Measure and record the conductance.
5. Repeat Step 4, substituting, in turn, 0.10 *M* KOH, 0.10 *M* KCl, 0.10 *M* KNO_3 , and 0.10 *M* $Ca(NO_3)_2$ for 0.10 *M* HNO_3 .
6. Repeat Step 4, substituting, in turn, your 0.10 *M* NH_3 and your 0.10 *M* $HC_2H_3O_2$ for 0.10 *M* HNO_3 .
7. Measure and record the conductance of a solution containing 10 mL of 0.10 *M* HCl and 10 mL of 0.10 *M* KNO_3 .
8. Measure and record the conductance of a solution containing 10 mL of 0.10 *M* HNO_3 and 10 mL of 0.10 *M* KCl.
9. Measure and record the conductance of a solution containing 10 mL of 0.10 *M* NH_3 and 10 mL of 0.10 *M* $HC_2H_3O_2$.
10. Calculate and record the new concentration of each substance in Steps 7, 8, and 9.

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5. How will you prepare the following solutions from 6.0 *M* solutions of acetic acid and ammonia? Give exact details. Assume that a 10-mL graduated cylinder (in which volumes can be read to the nearest 0.1 mL) and a 100-mL graduated cylinder are available.

a. 80 mL of 0.10 *M* HC₂H₃O₂

b. 80 mL of 0.10 *M* NH₃

6. What special safety precautions must be observed during this experiment?

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Date: Student name:
Course: Team members:
Section:
Instructor:

Results

Substance or Solution	Concentration (M)	Conductance or Current
Distilled water	X	.....
Tap water	X	.....
C ₂ H ₅ OH	X	.....
HCl	0.10	.....
HCl	0.050	.....
HCl	0.020	.....
HNO ₃	.....	.....
KOH	.....	.....
KCl	.....	.....
KNO ₃	.....	.....
Ca(NO ₃) ₂	.....	.....
NH ₃	.....	.....
HC ₂ H ₃ O ₂	.....	.....

Mixture	Concentration (M)	Conductance or Current
HCl + KNO ₃	HCl .....	.....
	KNO ₃ .....	.....
HNO ₃ + KCl	HNO ₃ .....	.....
	KCl .....	.....
HC ₂ H ₃ O ₂ + NH ₃	HC ₂ H ₃ O ₂ .....	.....
	NH ₃ .....	.....

Questions

1. a. Use your measured conductances (currents) for isomolar solutions of the substances you tested and the conductances (currents) for pure water and ethyl alcohol to distinguish between strong electrolytes (SE), weak electrolytes (WE), and nonelectrolytes (NE).

H ₂ O	KNO ₃
C ₂ H ₅ OH	KOH
HCl	Ca(NO ₃) ₂
HNO ₃	HC ₂ H ₃ O ₂
KCl	NH ₃

- b. Use these results to classify the acids and bases as either strong acids (SA), weak acids (WA), strong bases (SB), or weak bases (WB).

HCl	KOH
HNO ₃	NH ₃
HC ₂ H ₃ O ₂	

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2. Use your experimental results to make inferences, where possible, about the following points.
 - a. The effect of the concentration of an electrolyte on the conductance (current)

 - b. The cause of the differences in the conductances (currents) of isomolar solutions of KNO_3 and $\text{Ca}(\text{NO}_3)_2$

 - c. The presence of ionic impurities in ordinary tap water

 - d. The presence of molecular impurities in ordinary tap water

3. For each of the mixtures of electrolytes, compare the conductance (current) of the mixture with the sum of the conductances (currents) of the separate electrolytes. If a gross violation of the additivity rule occurs, offer an explanation for the increased or decreased conductance (current) and give an equation for the reaction. It may be helpful for you to read the section on neutralization in your textbook (Ebbing/Gammon, Section 4.4) before you formulate your answer.

