JOURNAL OF CHEMICAL EDUCATION

Laboratory Experiment

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Solution Preparation and Conductivity Measurements: An Experiment for Introductory Chemistry

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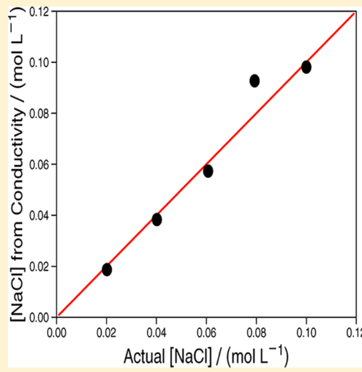
Supporting Information

ABSTRACT: The aim of this general chemistry laboratory exercise is to teach students how to prepare solutions of known concentration from a solid (NaCl) and by dilution from a stock solution. After preparing the solutions, the students perform conductivity measurements to check the accuracy of the concentrations. Using Kohlrausch's law and the conductivity data, they back-calculate the concentration. The students also measure the conductivity of a weak electrolyte (CH_3COOH) solution at the same concentration as the NaCl solution to better understand the difference between a strong and a weak electrolyte.



KEYWORDS: *First-Year Undergraduate/General, Physical Chemistry, Laboratory Instruction, Collaborative/Cooperative Learning, Hands-On Learning/Manipulatives, Aqueous Solution Chemistry, Conductivity, Solutions/Solvents*

In introductory chemistry courses, types of electrolytes and their solution concentrations form the fundamental building blocks of aqueous solution chemistry lectures. During the lectures, students learn to calculate the concentration of solutions, and the concept of conductivity is introduced as a measure of the number of free ions in solution. However, it was not until the early 1990s that the need for the students to learn to prepare solutions was emphasized.[1,2] Since then, M. R. Wang's work can be listed as the only study done on teaching solution preparation.[3] Wang's students prepared solutions from a solid and by dilution and used these solutions for the Briggs–Rauscher oscillation reaction as a tool to check for the accuracy of the prepared solutions. In this laboratory exercise, we use conductivity measurements to determine the accuracy of concentration of solutions prepared by the students. The aim of this laboratory exercise is to teach the students how to prepare solutions and to introduce them to the relationship between conductivity and solution concentration.

EXPERIMENT OVERVIEW

Students use two approaches to prepare solutions in a volumetric flask: from a solid and by dilution of a stock solution. Sodium chloride (NaCl), a strong electrolyte, and acetic acid (CH_3COOH), a weak electrolyte, are chosen as solutes. After preparing the solutions, the students measure the conductivity of each solution. A drawback for conductivity measurements may be the cost of providing an instrument for each student pair. In our lab, a single portable conductivity meter is used to perform all the measurements for five student pairs without compromising lab time. Home-made conductivity meters can also be used given enough time for instrument preparation.[4,5] All conductivity measurements are normalized to a standard temperature of 25 °C. This laboratory exercise takes 1 h of laboratory time. The students use their data to turn in a formal laboratory report in one week's time.

BACKGROUND

The conductivity of a solution is proportional to the number of ions in unit volume and , therefore, can be used to determine the concentration of an electrolyte solution. According to Kohlrausch's law, the conductivity of a solution of a strong electrolyte (at low concentrations, $c < 10^{-2}$ M) is related to concentration,

$$\Lambda = \Lambda_0 - K\sqrt{c} \quad (1)$$

where Λ is molar conductivity in S cm^2 mol^{-1}, Λ_0 is the limiting molar conductivity in S cm^2 mol^{-1}, K is a non-negative constant in S cm^2 mol^{-1} M$^{-1/2}$, and c is the molar concentration in M. Molar conductivity is defined as the measured conductivity of an electrolyte solution (κ in mS cm^{-1}) divided by the molar concentration of the electrolyte (c)

$$\Lambda = \frac{\kappa}{c} \quad (2)$$

ANALYSIS

There are two ways that the students can determine the accuracy of the concentration of their NaCl solutions. The first way involves inserting the concentration (c) in eq 1, solving for

Published: November 8, 2013

Table 1. The Conductivities of NaCl Solutions Prepared by the Students from Solid NaCl

Aimed Concentration/M	Mass of NaCl from Balance/g	Actual Concentration[a]/M	$\kappa_{measured}$/(mS/cm)	$\kappa_{theoretical}$/(mS/cm)	Percent Error (%)
0.0200	0.118	0.0202	2.13	2.30	−7.4
0.0400	0.235	0.0402	4.17	4.36	−4.4
0.0600	0.355	0.0607	6.02	6.34	−5.0
0.0800	0.464	0.0793	9.20	8.03	+14.6
0.100	0.586	0.100	9.66	9.82	−1.6

[a]There is a ± 0.0002 M uncertainty due to balance and volumetric flask.

the conductivity (κ), and finding the percent error in their conductivity measurement. The second way involves back-calculating concentration from eq 1 by iteration and determining the percent error in their solution concentration.

The comparison of conductivities of NaCl and CH_3COOH solutions at the same concentration also gives the students a better understanding of the concepts of a strong and weak electrolyte.

■ PRELABORATORY EXERCISES

This is the first experiment of the semester; therefore, one week before this experiment, students go through a safety training and watch a demonstration performed by the instructors in the laboratory. The students are introduced to the basic laboratory glassware, real-time redox, acid−base and precipitation reactions, and to the instruments they are going to use during the semester. As a prelaboratory exercise for this experiment, a conductivity meter is used to perform conductivity measurements for laboratory deionized water and for a list of solutions used in the work of Nyasulu et al. and referred to as "other solutions".[6] The collected data are discussed with the students. Thus, prior to the solution preparation experiment, the students are familiar with the conductivity meter and units of conductivity.

■ EXPERIMENTAL PROCEDURE

Apparatus and Materials

Portable conductivity meter, balance (±0.001g), volumetric flask (100 mL), pipet (5 mL), pipet bulb, funnel, stirring rod, beaker (100 mL), sodium chloride (NaCl), 1.00 M acetic acid (CH_3COOH) solution, deionized water.

Part A. Preparation of 100 mL NaCl Solutions from Solid NaCl

Each student group is asked to calculate the mass (in grams) of solid NaCl to be weighed to prepare one of the following solutions: 0.0200, 0.0400, 0.0600, 0.0800, and 0.100 M NaCl. Students follow the procedures in the laboratory handout to prepare the solutions and measure the conductivity of the resulting solution using the conductivity meter.

Part B. Preparation of 100 mL 0.0024 M NaCl Solution Using Stock NaCl Solutions Prepared in Part A

Students are asked to calculate the volume (in mL) of stock NaCl solutions needed to prepare 0.0024 M NaCl solution. The volume of the stock solution needed is measured with a volumetric pipet. Students follow the laboratory procedures in the handout to prepare the solutions and measure the conductivity of the resulting solution using the conductivity meter.

Part C. Preparation of 100 mL CH_3COOH Solutions Using 1.00 M Stock CH_3COOH Solution

CH_3COOH solutions (0.020, 0.040, 0.060, 0.080, and 0.100 M) are prepared using 1.00 M stock CH_3COOH solution. Students are asked to calculate the volume (in mL) of stock solution needed to prepare the solutions above. The volume of the stock solution needed is measured with a volumetric pipet.

■ HAZARDS

NaCl and CH_3COOH solutions prepared by the students do not have significant hazard. Leftover solutions are disposed down the drain with large quantities of water.

■ RESULTS AND DISCUSSION

All the data presented here were collected by five pairs of students in the laboratory. Table 1 shows the data for Part A of the experiment. For most of the concentrations, the mass of NaCl taken from the balance was different from the calculated value. Therefore, the students determined the "actual concentration" by using the mass of NaCl from the balance. As it can be seen from Table 1, the "actual concentration" is (virtually) the same as the aimed concentration. The data for Part B is listed in Table 2. In both tables, the students determined the theoretical conductivities of the solutions from eq 1 using 126.4 S cm^2 mol^{-1} for Λ_0 and 89.1456 S cm^2 mol^{-1} $M^{-1/2}$ for K for NaCl.[7] For Table 2, the theoretical conductivity value at 0.0024 M NaCl is 0.293 mS cm^{-1}. The students' data on percent errors show no trend. For discussion, students can write only about their two data points and almost all clearly see the decrease of conductivity with decreasing NaCl concentration.

Table 2. The Conductivities of 0.0024 M NaCl Solutions Prepared by the Students by Dilution from Stock Solutions

Stock Solution Concentration/M	Volume/mL	$\kappa_{measured}$/(mS/cm)	Percent Error[a] (%)
0.0202	12.0	0.268	−8.5
0.0402	6.0	0.282	−3.8
0.0607	4.0	0.279	−4.8
0.0793	3.0	0.314	+7.2
0.100	2.4	0.293	0

[a]The theoretical conductivity of 0.0024 M NaCl solution calculated from eq 1 is 0.293 mS/cm.

Students used Excel (Microsoft, 2007) to back-calculate the concentrations of NaCl solutions from eq 1 using their conductivity data. Table 3 lists the percent error of the concentration of the prepared solutions. There is no definite trend in the percent error data. The accuracy of the prepared solutions' concentrations can be clearly seen from Figure 1. Figure 1 is a plot of NaCl concentration back-calculated using conductivity data and eq 1 versus NaCl solution concentration

Table 3. The Back-Calculated Concentration Values of NaCl Solutions Prepared by the Students from Solid NaCl

Actual Concentration/M	$\kappa_{measured}$/(mS/cm)	Back-Calculated Concentration/M	Percent Error (%)
0.0202	2.13	0.0187	−7.4
0.0402	4.17	0.0383	−4.7
0.0607	6.02	0.0573	−5.6
0.0793	9.20	0.0927	+16.9
0.100	9.66	0.0981	−1.9

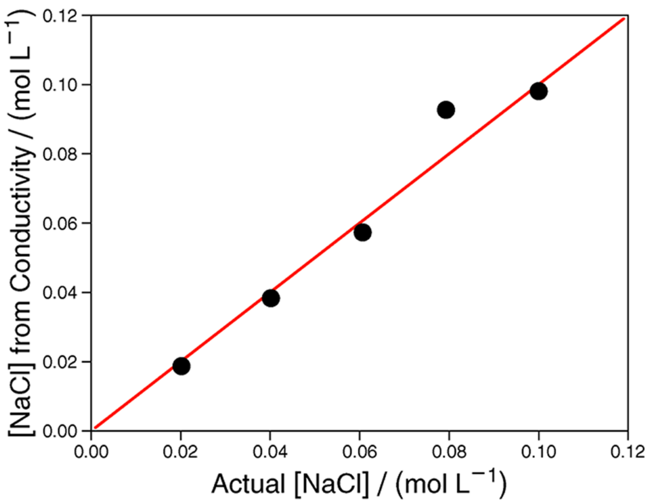


Figure 1. The accuracy of NaCl solutions prepared from solid NaCl.

prepared by the students or "actual concentration". The red line shows the data points when the back-calculated concentration is the same as the "actual concentration".

Students also compared the conductivity values of CH_3COOH solutions with NaCl solutions at the same concentration as shown in Table 4. The conductivities of CH_3COOH solutions were less than the conductivities of NaCl solutions. In their reports, the students discussed the cause of the difference by writing down dissociation equations for NaCl and CH_3COOH and stating that CH_3COOH is a weak electrolyte.

Table 4. Comparison of Conductivities of CH_3COOH and NaCl Solutions

	CH_3COOH	NaCl
Aimed Concentration/M	$\kappa_{measured}$/(mS/cm)	$\kappa_{measured}$/(mS/cm)
0.020	0.240	2.13
0.040	0.348	4.17
0.060	0.429	6.02
0.080	0.492	9.20
0.100	0.551	9.66

SUMMARY

In this laboratory experiment, students learn how to prepare solutions from a solid and by dilution from stock solution and how to perform conductivity measurements to check the accuracy of their solution preparation. To see the effect of concentration on conductivity, each student group prepares one stock solution from solid NaCl and a 0.0024 M solution diluted from the stock solution. After doing the experiment in the laboratory, students write a lab report, where they need to back-calculate the concentrations of the NaCl solutions from their conductivity measurements. Students also prepare CH_3COOH solutions at the same concentration as NaCl solutions, by dilution from a stock solution and observe the differences in conductivity between a strong and a weak electrolyte.

ASSOCIATED CONTENT

Supporting Information

Instructor notes and student handout. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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