Iowa Science Teachers Journal

Volume 3 | Number 2 Article 5

1965

# A Quantitative Study of the Conductivity of Solutions

Rex T. Morrison
*West Essex Regional High School*

# *A Quantitative Study* OF THE *Conductivity of Solutions*

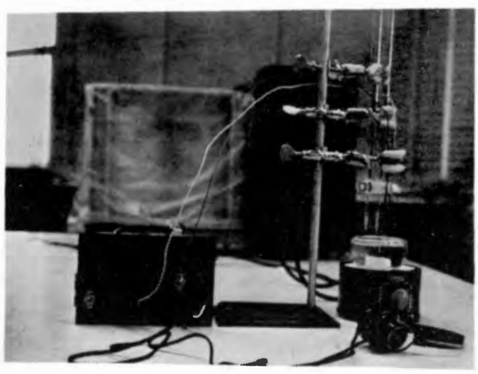
REX T. MORRISON

During the summer of 1963, the author had the privilege of attending an Advanced Placement Chemistry Institute in which the participants built some simple instruments useful in chemistry and studied their usual applications. The A. C. Conductivity Bridge built by the participants seemed to offer some advantages in presenting one of the demonstrations accompanying an experiment used in the Chem-Study course at Roosevelt High School in Des Moines, Iowa where the following activity was conducted.

**Morrison**

Experiment 17, found in **Chemistry —An Experimental Science Laboratory Manual** published by W. H. Freeman and Co., is the experiment referred to above. In this experiment, it is important to determine which acids and bases used were weak or strong electrolytes. Some foundation for this judgment is provided in an earlier demonstration in which the relationship of the presence of ions in a solution and its concomitant conductance of electricity was demonstrated in a semi-quantitative manner by use of an apparatus which could show conductance by the lighting of a two-watt neon glow bulb, and/or a ten-watt bulb, and/or a forty-watt bulb, or non-conductance by the lighting of none of the bulbs. This apparatus was suggested for the determination of conductance of the acid and basic solutions used in Experiment 17, and for the study of the change in conductance during the titration of a Ba $(OH)_2$ solution with $H_2SO_4$.

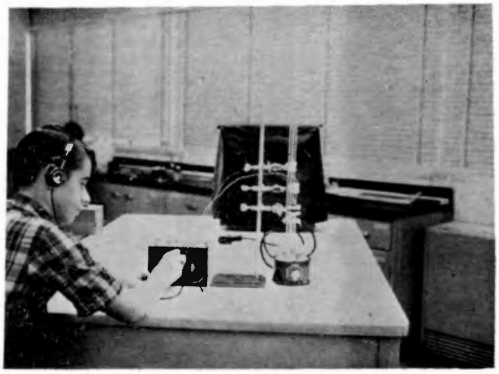
It was decided that the simple electrical theory of the A. C. Conductivity Bridge could be used as a



**The conductivity bridge, using alternating current, is housed in the box at the left. The ring stand supports the 2 platinum electrodes and the burettes for titration. A magnetic stirrer may also be used, as shown in the photograph.**

Rex Morrison received a B.S. degree in General Science from Parsons College, a B.S.P. degree in Pharmacy from Drake University, a M.S. degree in Science Education from Drake University in 1955, and has attended several N.S.F. Institutes in Chemistry since that time. He taught Chemistry at Roosevelt High School in Des Moines, Iowa for eight years before moving to West Essex Regional High School in North Caldwell, New Jersey where he is currently a teacher of Chem-Study Chemistry and Chairman of the Science Dept.

means of teaching some of the electrical units used in Ohm's Law relationships, and also as a background for later discussion of such instruments as the mass spectrograph, the teaching of Faraday's Laws of electrochemistry, and related material which follows closely on the presentation of acid-base theory in the Chem-Study course. It can also be used to show how more quantitative data on conductance can be obtained, thus building on the previous experience of the students with the simpler conductance apparatus. Therefore 0.0050M solutions of each acid and base used in Experiment 17 and the accompanying demonstration were prepared and their conductance was measured with the bridge. The bridge circuit, Fig. 4, and a reference to further details on its construction, Table 3, are available with this report. The simple theory of the bridge accompanies the circuit diagram. The calibration of the variable resistance was discussed and the use of the calibration curve to permit relative conductance calculations was explained. The dial reading of the variable resistance minus an intercept of



**Using earphones to detect when the conductance of the solution is optimum, a student takes a numerical reading directly from the dial of the conductivity bridge.**

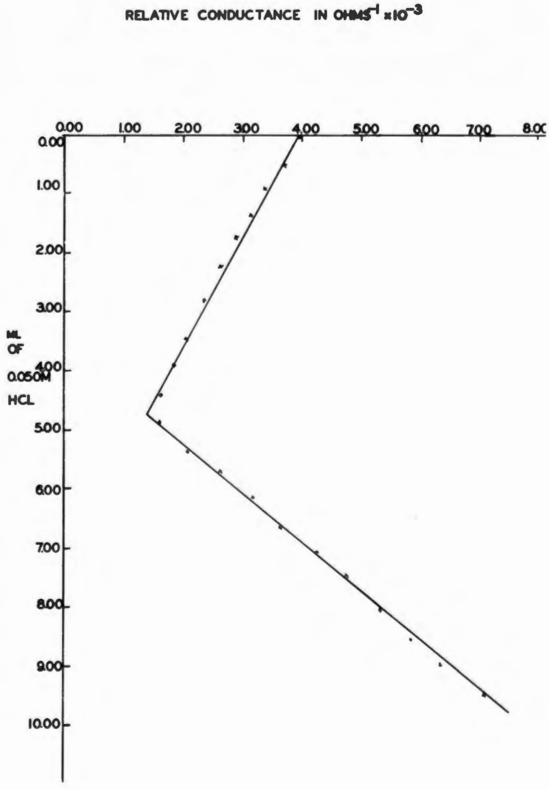



FIG.1
TITRATION OF 0.0050 M NAOH (50.0ML)
WITH 0.050M HCL

3.3 times the resistance per dial unit from the slope of the calibration curve gave the resistance of the cell. This cell has two small platinized Pt electrodes which must be kept under distilled water when not in use. The inverse of this resistance is the relative conductance. Use of a standard 0.010M KCl, solution makes possible the calculation of the cell constant for the cell if equivalent conductanees of solutions are desired by calculation from the specific conductance of a solution, k. The relationship used in this calculation is $\Lambda = (1{,}000/N)k$, in which $\Lambda$ is the equivalent conductance, N is the number of equivalents per liter, and k is the specific conductance. For comparative purposes, such as in the conductimetric titration performed, the relative conductances were used on the graphs.

In each class, the conductances of the solutions were measured to find which conducted well, and which to a much lesser extent, i. e., which were strong and which were weak electrolytes. Then, one of the three titrations was demonstrated to each class to familiarize them with the techniques involved. The data from all three were given to the students, and they were asked to write the equations for the reactions involved in the titrations. They were also directed to graph the relative conductance calculated from the given dial readings for each addition of titrant against the volume of titrant added. They were asked to explain in a brief paragraph why the graphs had the shape they did in view of the measured conductances of the solutions involved. The titrations performed were those of a strong base, 0.0050M NaOH, with a strong acid, 0.050M HCl, in which a soluble salt was formed. A second titration was that of a strong base, 0.0045M Ba $(OH)_2$, with a strong acid, 0.050M $H_2SO_4$, in which an insoluble

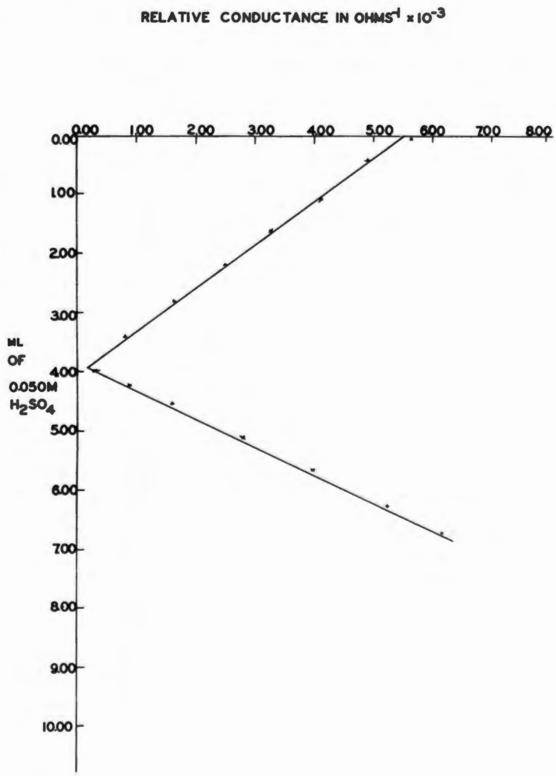



FIG. 2
TITRATION OF 50.00ML OF 0.0045M Ba $(OH)_2$ WITH 0.050 M $H_2SO_4$

salt was formed. The final titration demonstrated was that of a strong base, 0.0050M NaOH, with a weak acid, 0.050M $CH_3COOH$. A sample of data actually taken from these demonstrations is given in Table 2. Table 1 gives similar data for the conductances of the solutions used. The graphs of the data from Table 2 such as the students prepared are shown in Fig. 1, 2, and 3. A magnetic stirrer was used to achieve uniform mixing during the titration, although any method of stirring which does not disturb the electrodes would be satisfactory.

In conclusion, it was felt that though this procedure required more time than the simpler demonstration it replaced, the understanding of the ionic nature of solutions and the effect of this nature on their conductance was much more thoroughly understood by the students. Their appreciation of the role of instrumentation in science to obtain the quantitative data upon which the theories of solutions are based was also increased. The necessity to understand some simple electrical relationships and units used in electrical measurements increased the student's motivation for gaining a background which was of great assistance in developing later topics in which an understanding of these ideas was highly desirable. Better understanding of these topics seems to make the extra time requirement a worthwhile investment, although it also emphasizes the need for extra laboratory periods for scientific investigation in modern science courses.

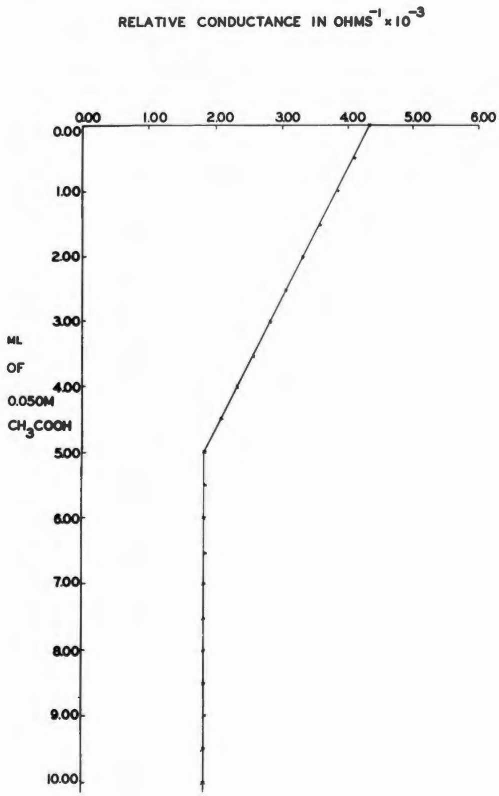



FIG. 3
TITRATION OF 50.0ML OF 0.0050M NAOH WITH 0.050M $CH_3COOH$

## TABLE 1

### Conductance of Various 0.0050M Solutions at 24°C

| Substance | Dial Position | Dial Reading | Relative Conductance x $10^{-3}$ $ohms^{-1}$ | *Cell Constant | Specific Conductance in $ohms^{-1}$ $cm^{-1}$ x $10^{-3}$ |
|---|---|---|---|---|---|
| 1. HCl | $P_1$ | 16.0 | 6.73 | 0.238 | 1.60 |
| 2. $HNO_3$ | $P_1$ | 15.5 | 7.00 | 0.238 | 1.66 |
| 3. $H_2SO_4$ | $P_1$ | 11.0 | 1.11 | 0.238 | 2.64 |
| 4. $CH_3COOH$ | $P_2$ | 25.0 | 3.94 | 0.238 | 9.39 x $10^{-2}$ |
| 5. NaOH | $P_1$ | 24.5 | 4.04 | 0.238 | 9.72 x $10^{-1}$ |
| 6. KOH | $P_1$ | 24.5 | 4.04 | 0.238 | 9.72 x $10^{-1}$ |
| 7. Ba $(OH)_2$** | $P_1$ | 15.0 | 7.31 | 0.238 | 1.74 |

* (The k, specific conductance, of 0.010M KCl at 25°C is 1.413 x $10^{-3}$ $ohms^{-1}cm^{-1}$ and at 24°C is 1.386 x $10^{-3}$ $ohms^{-1}cm^{-1}$. The k for distilled water at 25°C is 5.8 x $10^{-8}$ $ohms^{-1}cm^{-1}$. Conductance of 0.010M KCI at 24°C based on a dial reading of 18.0 at $P_1$ was 5.82 x $10^{-3}$ $ohms^{-1}$ on this cell which gave a cel lconstant of 0.238 from k — (1/A)L in which 1 is the length of the conductivity cell, A is the area between the electrodes, and L is the reciprocal of the measured resistance of the cell.)

** (The $Ba(OH)_2$ solution was only 0.0045M.)

$P_1$ FOR 0 TO 1,000Ω, $\frac{R_2}{R_1} = \frac{1K\Omega}{10K\Omega}$

$P_2$ FOR 0 TO 10Ω, $\frac{R_2}{R_1} = \frac{10K\Omega}{10K\Omega}$

$P_3$ FOR 0 TO 100Ω, $\frac{R_2}{R_1} = \frac{10K\Omega}{1K\Omega}$

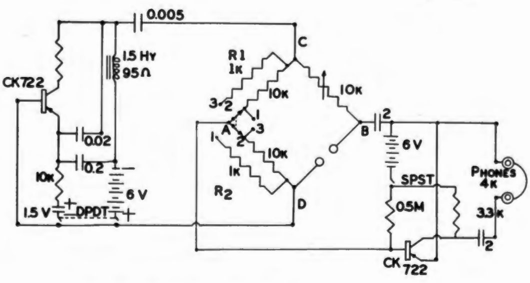



FIG. 4
A.C. CONDUCTANCE BRIDGE

J. CHEM. ED. 37, 244 (MAY 1960)

WHEN POINTS A AND B ARE AT THE SAME POTENTIAL, THERE IS NO SIGNAL THROUGH THE EARPHONES.

$$V = IR$$

| | |
|---|---|
| $V_{CA} = I_1 R_1$ | $V_{AD} = I_1 R_2$ |
| $V_{CB} = I_2 R_v$ | $V_{BD} = I_2 R_c$ |
| $V_{CA} = V_{CB}$ | $V_{AD} = V_{BD}$ |
| $I_1 R_1 = I_2 R_v$ | $I_2 R_2 = I_2 R_c$ |

$$\frac{I_1 R_1}{I_1 R_2} = \frac{I_2 R_v}{I_2 R_c}$$

$$R_c = \frac{R_2}{R_1} \cdot R_v$$

## TABLE 2

### Titration Data

Heading 1 — 0.0050M NaOH vs 0.050M HCl
Heading 2 — 0.0045M $Ba(OH)_2$ vs 0.050M $H_2SO_4$
Heading 3 — 0.0050M NaOH vs 0.050M $CH_3COOH$
All readings at $P_1$ except *, which are $P_2$.

Col. 1 — ml of acid added
Col. 2 — dial reading
Col. 3 — Relative Conductance in $ohms^{-1} \times 10^{-3}$

| Heading 1 | | | Heading 2 | | | Heading 3 | | |
|---|---|---|---|---|---|---|---|---|
| Col. 1 | Col. 2 | Col. 3 | Col. 1 | Col. 2 | Col. 3 | Col. 1 | Col. 2 | Col. 3 |
| 0.00 | 25.0 | 3.95 | 0.00 | 16.0 | 6.75 | 0.00 | 23.0 | 4.35 |
| 0.50 | 27.0 | 3.61 | 0.50 | 18.0 | 5.82 | 0.50 | 24.0 | 4.13 |
| 1.00 | 29.0 | 3.33 | 1.00 | 21.0 | 4.84 | 1.00 | 25.0 | 3.95 |
| 1.50 | 31.0 | 3.10 | 1.50 | 24.0 | 4.14 | 1.50 | 27.0 | 3.61 |
| 2.00 | 33.0 | 2.88 | 2.00 | 30.0 | 3.21 | 2.00 | 29.0 | 3.33 |
| 2.50 | 35.0 | 2.70 | 2.50 | 40.0 | 2.34 | 2.50 | 31.0 | 3.09 |
| 3.00 | 37.5 | 2.50 | 3.00 | 59.0 | 1.54 | 3.00 | 33.0 | 2.88 |
| 3.50 | 40.0 | 2.33 | 3.50 | 16.5* | 0.65 | 3.50 | 36.0 | 2.62 |
| 4.00 | 43.0 | 2.16 | 4.00 | 38.0* | 0.25 | 4.00 | 40.0 | 2.33 |
| 4.50 | 45.0 | 2.05 | 4.50 | 59.0 | 1.54 | 4.50 | 44.0 | 2.10 |
| 5.00 | 45.0 | 2.05 | 5.00 | 35.0 | 2.70 | 5.00 | 49.0 | 1.87 |
| 5.50 | 38.0 | 2.47 | 5.50 | 25.0 | 3.95 | 5.50 | 49.0 | 1.87 |
| 6.00 | 30.0 | 3.21 | 6.00 | 20.0 | 5.13 | 6.00 | 49.5 | 1.85 |
| 6.50 | 25.0 | 3.95 | 6.50 | 17.5 | 6.03 | 6.50 | 49.5 | 1.85 |
| 7.00 | 22.5 | 4.45 | 7.00 | 16.0 | 6.75 | 7.00 | 50.0 | 1.83 |
| 7.50 | 20.0 | 5.12 | 7.50 | 14.5 | 7.64 | 7.50 | 50.0 | 1.83 |
| 8.00 | 18.0 | 5.82 | 8.00 | 13.5 | 8.39 | 8.00 | 50.0 | 1.83 |
| 8.50 | 17.0 | 6.25 | 8.50 | 12.5 | 9.32 | 8.50 | 50.0 | 1.83 |
| 9.00 | 16.0 | 6.75 | 9.00 | 12.0 | 9.84 | 9.00 | 50.5 | 1.81 |
| 9.50 | 15.0 | 7.31 | 9.50 | 11.0 | 11.1 | 9.50 | 50.5 | 1.81 |
| 10.00 | 14.5 | 7.63 | 10.00 | 10.5 | 11.9 | 10.00 | 50.5 | 1.81 |

## TABLE 3

### Parts List — A. C. Conductance Bridge

| Quantity | Article | Cost |
|---|---|---|
| 1 | 10 kohm potentiometer—Type J-AB | $ 2.75 |
| 1 | 2 pole, 6 position non-shorting switch, Malory 3226J | 1.06 |
| 2 | Transistors, Raytheon CK 722 | 2.60 |
| 2 | Capacitors—2 microfarad | 1.16 |
| 1 | Capacitors—0.2 microfarad | .30 |
| 1 | Capacitor—0.02 microfarad | .28 |
| 1 | Capacitor—0.005 microfarad | .28 |
| 2 | 10 kohm deposited carbon resistor (± 1%, ½ w) | .83 |
| 2 | 1 kohm deposited carbon resistor (± 1%, ½ w) | .83 |
| 1 | 1 kohm resistor (± 10%, ½ watt) | .19 |
| 1 | 3.3 kohm resistor (± 10%, ½ watt) | .19 |
| 1 | 18 kohm resistor (± 10%, ½ watt) | .19 |
| 1 | 4 kohm headphones (Lafayette F-374) | 1.35 |
| 1 | DPDT switch | .60 |
| 2 | SPST switches | .64 |
| 1 | Dial plate for 10 kohm potentiometer | .45 |
| 2 | Platinum foil electrodes and wire | 2.29 |
| 2 | 6 V batteries | 2.14 |
| 1 | 1½ V battery—type NE | .11 |
| 1 | Transformer (Merit Coil and Transf. Corp.—C2973) | 1.35 |
| 10 | Banana plugs and knobs | 2.07 |
| | Miscellaneous: mounting panel and base, hardware, shipping costs | 3.35 |
| | | 25.11 |