TÜRK FEN EĞİTİMİ DERGİSİ
Yıl 1, Sayı 2, Aralık 2004

Journal of
TURKISH SCIENCE EDUCATION
Volume 1, Issue 2, December 2004

http://www.tused.org

A fast and Simple Way for the Determination of Avogadro Number and Faraday Constant

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ABSTRACT

In an illuminating experiment suitable for the first grade undergraduate and high school students, we tried to determine the Avogadro number considering accuracy and time. A voltage of 2.54 volt was applied to the circuit by immersing two zinc plate electrodes in $ZnSO4.7H_2O$ solution of 0,1M. When this voltage was applied, there was a current of 0,140 Amp in the circuit. The Avogadro number was evaluated, with an error of $\pm$ 0,07, by weighting the mass increase in the cathode at the end of a 1200-minute time period. Pedagogically, this activity interrelates the studies of electrochemistry and electrolysis in an efficient laboratory activity.

Keywords: Laboratory Instruction, Electrochemistry, Chemical Education Research, Laboratory Equipment / Apparatus, metals.

INTRODUCTION

Today, for most teachers and students, how the Avogadro number is calculated is the subject of great interest. This number is frequently referred as “Avogadro’s Number”, and the term “Loschmidt’s Number” is then reserved for the number of molecules in a cubic centimeter of a gas under standard conditions. However, these designations are often used interchangeably and are confusing. Avogadro’s important hypothesis on the identity of the number of molecules in equal volumes of different gases at the same pressure and temperature was formulated in 1811, and it is associated with his name but Avogadro made no quantitative estimates of neither of the above-mentioned constants. The first actual estimate of the number of molecules in one cubic centimeter of a gas under standard conditions was made in 1865 by Loschmidt. As a result of this, the number of molecules (atoms) in a gram molecule (atom) was calculated.

This number is frequently referred to as “Avogadro’s Number”,the term “Loschmidt’s Number” being then reservsd for the number of molecules in a cubic centimeter of a gas under standard conditions. Unfortunately, these designations are often interchanged. Avogadro’s important hypothesis on the identity of the numbers of molecules in equal volumes of different gases at the same pressure and temperature was formulated in 1811, and is appropriately associated with his name; but Avogadro made no quantitative estimate of either of the abovementioned constants. The first actual estimate of the number of molecules in one cubic centimeter of a gas under standard conditions was made in 1865 by Loschmidt, and from this the number of molecules (atoms) in a gram molecule (atom) was later evaluated. From the quantitative view-point, it thus seems preferable to speak of "Loschmidt's number per gram-molecule (atom)," and of "Loschmidt's number per cubic centimeter," as is consistently reviewed in the German scientific literature. This terminology avoids ambiguity and has been adopted here (Virgo, 1933).

There was no clear agreement on what the number should be called until 1933. Virgo informs that more than eighty separate determinations had been made to discover the true value of the number "as it is a basic atomic constant and perhaps it's most probable value is of great importance in atomic physics." The best modern values for what we now call "Avogadro's Number" are the result of the x-ray diffraction measurement of lattice distances in metals and salts. The earliest attempts of using this method are reviewed in Virgo's study. Calculations reflecting these methods are often found in modern general chemistry text-books (Davis, Peck & Whitten 2000).

For many years how the Avogadro number was estimated has been wondered by most teachers and students. For this purpose, the Avogadro number has been tried to be determined by means of electrolysis experiments. Recently, many researchers have focused on the subject of determining the Avogadro number (Brittany, Mitchell, Roulhac, Thomes, & Stumpo, 2000; Szafran, Pike & Foster, 1993; Singh, Pike & Szafran, 1995; Abraham, Pavelich, 1991; Roberts, Hollenberg & Postma, 1997; Waterman, Thompson, 1995; Bell, 1993;).,In this work, an electrolysis experiment found in the literature (Beran, 1994) has been modified to improve the metal plating by preventing the plated material from being lost as a result of poor bonding.

The exact mass of the plated metal can be used to obtain an accurate determination of Avogadro's number (N), and Faraday's constant (F) depending on the interpretation of the experimental data.

The quantitative relationships between electricity and chemical change were first described by Michael Faraday (Mortimer, 1979). Later in 1832, he illustrated that the weight of a chemical substance liberated at an electrode was directly proportional to the amount of current passing through the cell. In 1833, he stated that the weights of different substances produced by a given amount of current were proportional to the equivalent weights of the substance. In the following two sections, the principle of this method and the experimental processes will be discussed in detail.

PRINCIPLE OF THE METHOD

Similar to all electrolytic cells, a power supply is also used to drive the chemical changes on the electrodes. Two zinc plates are immersed in a beaker containing the corresponding metal ion electrolyte, in this case Zn^{2+} from a $ZnSO_4$ solution. A zinc plate electrode, the anode, undergoes oxidation according to

$$Zn(s) \rightarrow Zn^{2+}_{(aq)} + 2é$$

Another zinc plate electrode, the cathode, undergoes reduction according to

$$Zn^{2+}_{(aq)} + 2é \rightarrow Zn_{(s)}$$

The mass of the cathode electrode before electrolysis and after electrolysis are m_i and m_f, respectively. The differences ($m_f - m_i$) represent quantity of zinc accumulated on the cathode.

To determine the mass of plated metal accurately, it is necessary that the plated metal adhere firmly to the cathode. In order to achieve this goal the experiment has been modified. First, the pre-weighed electrode functions as the anode for a short time period, t_1 (time at anode), before functioning as the cathode for a longer period, t_2. Since the current, I , is kept constant, the net plating time, t_2-t_1, is proportional to the net gain in plated mass, m, the difference between the total mass gained at the electrode while it functions as the cathode during t_2, and the mass lost at the electrode while it is the anode during t_1.

The electrical charge that flows through the system during electrolysis, q, can be calculated using equation (1)

$$q = I_{(A)} x t_{(s)} \qquad (1)$$

Avogadro's number, N_o, can then be calculated using equation (2)

$$N_o = \frac{q.M}{n.m.q_e} \qquad (2)$$

Here, M is the atomic weight of the metal, n is the number of electrons in the half-reaction, and q_e is the charge on one electron. Faraday's constant, F , can be calculated using equation (3)

$$F = \frac{q.M}{n.m} \qquad (3)$$

EXPERIMENTAL PROCEDURE

The zinc plates (or wires) used as the electrode that would have a net gain in mass were prepared by rounding off the square corners with a scissors before weighing. In addition, the plates were cleaned by wiping lightly with a cloth dampened in a dilute solution of a weak acetic or citric acid, and then dried in a warm oven.

A metal plate will contain stress areas, at the sharp borders where it was cut; a wire will have stress areas at places where it was bent. These defects will cause the plated metal to adhere as long hairy strands owing to the high electric field at these locations. This was avoided by using the electrode functioning first as the anode, then as the cathode. The stress areas, having a higher positive charge density (with higher potential energy), dissolve relatively faster than other areas, into Zn^{2+} ions to relieve the excess positive charge. This results in a less stressed electrode surface ready for plating. In the course of longer electrolysis period, some metal pieces fall off at the anode without dissolving. This causes more mass than expected to be lost at the anode. The corresponding mass plated at the cathode is more reliable since it does not have this problem. The electrolysis apparatus is shown in Figure 1 and electrolysis results are shown in Table 1.

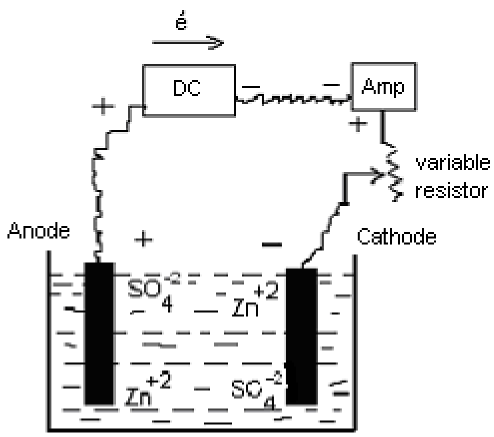

Figure 1. Electrolysis apparatus.

Tablo 1. *Results from the Electrolysis Experiment*

Parameter	Trial 1	Trial 2	Trial 3	Mean Values
Electrolysis time (t/s)	1200	1200	1200	1200
Current (I / A)	0.140	0.140	0.140	0.140
Mass increase in the cathode (m/g)	0.0565	0.0555	0.0570	0.0563
Atomic weight (Zn) (M / g mol^{-1})	65.370	65.370	65.370	65.370
Electronic charge, q_e / 10^{-19} C $electron^{-1}$	1.602	1.602	1.602	1.602
Faraday's constant (F / 10^4 C mol^{-1} $electron^{-1}$)	9.71	9.89	9.55	9.71
Avogadro's number (N / 10^{23} atoms mol^{-1})	6.09	6,17	6,01	6,09

RESULT AND DISCUSSION

The value of q was calculated using the values obtained from the experiments and employing the equation 1. Current (I) and time (t) in electrolysis were adjusted to 0,140 ampere and 1200 s, respectively. Number of the electron transferred in the electrolysis cell is 2 (n =2). The values of Avogadro number and Faraday constant were calculated by using average experimental results and using equations (4) and (5).

$$N_o = \frac{q.M}{n.m.q_e} = \frac{(0.140 amper)(1200 s)(65.370\, g/mol)}{(2\, é/atom)(0.0565 g)(1.602x10^{-19}\, C/é)} = 6.06x10^{23}\, atomZn/molZn \qquad (4)$$

$$F = \frac{q.M}{n.m} = \frac{(168C)(65.370\, gZn/molZn)}{(2\, mol\acute{e}/molZn)(0.0565 gZn)} = 9.71x10^4\ C/mol\ electron \quad (5)$$

The obtained Avogadro number was found to be in good agreement with the standard Avogadro number, 6.02 x $10^{23,}$ and the standard deviation was $\pm$ 0.07 x 10^{23}. The average value of F for these trials was 9.71 x 10^4 C /mol electron, which agrees well with the accepted value of 9.6487 x 10^4 C / mol electron. The percent error was 0.50 %, and the standard deviation was $\pm$ 0.0613 x 10^4.

CONCLUSION

Science involves complex and abstract concepts which are difficult to understand for some students. It is argued that practical work provides understanding of the fascination of science facilitates problem-solving, increases motivation which has a well-know importance on effective learning environment. Therefore, teachers' experiences, skills and ideas have great importance in science education.

Despite the fact that Avogadro number is an essential number used in teaching mol concepts and gas laws, there are no illustrations and information in Turkish high schools' chemistry textbooks about how this number was determined. The activities in this study explaining how the Avogadro number is determined could be a valuable part of high school and university chemistry textbooks. However, there is no well known and easy any of determining the Avogadro's number in the classroom, although several methods are described in the literature. For on effective teaching the abstract concept several teaching approaches are suggested.

There are several methods and techniques for an effective chemistry education. Laboratory method is one of the best teaching methods. It requires using all senses. Laboratory activities provide students an active learning environment. However, root learning is still dominating our education system. It is widely accepted that "doing" is the best way of learning. It is for this reason that experimental studies are part of the science education research and widely accepted around the world. The experiment in this study shows how a metal can be plated without the need of abrasives. The plating adheres on a relatively smoother surface and the current is easier to control during the experiment. This improves the accuracy of the data and, therefore, N_o. The experiment presents no significant hazards, the electrolyte solution can be reused, and the experiment can be adapted to semi-micro scale by reducing the size of the container, therefore minimizing wastes.

IMPLICATIONS FOR TEACHING

This experiment presents no significant hazards, however safety goggles should be worn when working with chemicals. Zinc plates or zinc wire from an electrical shop can be used.

Finally, if either a zinc plate or wire were unavailable, the electrodes can be substituted with commonly available metals (Fe, Cu or Ni) and their appropriate electrolyte solutions.

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