A Numerical Exercise To Teach Electrochemical Impedance Using Electric Circuit Simulation Software

ARTICLE *in* JOURNAL OF CHEMICAL EDUCATION · NOVEMBER 2013

Impact Factor: 1.11 · DOI: 10.1021/ed4004595

1 AUTHOR:

A.A. Moya

Universidad de Jaén

37 PUBLICATIONS **314** CITATIONS

JOURNAL OF CHEMICAL EDUCATION

Technology Report

pubs.acs.org/jchemeduc

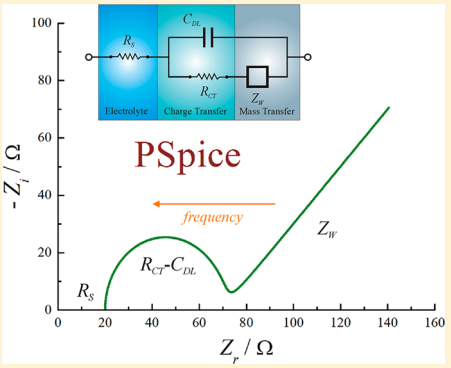
A Numerical Exercise To Teach Electrochemical Impedance Using Electric Circuit Simulation Software

Antonio A. Moya*

Departamento de Física, Universidad de Jaén, Edificio A-3, Campus Universitario de Las Lagunillas, 23071 Jaén, Spain

Supporting Information

ABSTRACT: A numerical exercise to teach electrochemical impedance at university level by using the electric circuit simulation program, PSpice, is presented. The demo or student version of this software is available for free on the Internet. A study of the usual electrochemical impedances by means of numerical tables and graphics can be done by the students on a personal computer. This exercise can be incorporated into an electrochemistry course to help students understand the concept of electrochemical impedance.



KEYWORDS: *Upper-Division Undergraduate, Analytical Chemistry, Physical Chemistry, Computer-Based Learning, Computational Chemistry, Electrochemistry*

Electrochemical impedance spectroscopy is a powerful technique used to characterize many electrical properties of electrochemical systems. For example, it is a used to study the kinetics of charge transfer at electrodes and to measure the conductivity of electrolyte solutions.[1] The standard measurement technique is to perturb the system with a single-frequency sine current (voltage) and to measure, using a frequency response analyzer, the resulting system electric voltage (current) at that frequency. The use of equivalent electric circuits to model and interpret the impedance of physicochemical systems is a classic topic in electrochemistry courses.[2] These equivalent electric circuits employ simple electrical elements such as resistors or capacitors and frequency-dependent elements such as constant-phase elements. These equivalent electric circuits provide useful models of experimental situations.

NUMERICAL EXERCISE

The fundamentals of electrochemical impedance spectroscopy are explained in textbooks,[2−4] and the importance of this technique is increasing in the electrochemical labs. However, university students often have difficulty understanding the concept of the electrochemical impedance as well as the mathematical expressions and the diagrams to analyze the experimental results, as has been pointed out in this *Journal*.[5−7] This lack of understanding is especially problematic when it is necessary to use complex variable algebra to describe the impedance of frequency-dependent electric elements. After the instructor explains the fundamentals of electrochemical impedance and reviews simple electric circuits, a numerical exercise consisting of the computer simulation of the impedance spectra can be used to improve the students' understanding of electrochemical impedance and the quality of their learning.[5,6] As such, the simulation of electric circuits becomes an attractive tool,[8] complementary to the lab techniques, to help instructors teach electrochemical impedance at university level. This type of software takes advantage of the fact that electrochemistry instructors and students are generally familiar with electric circuits.

SIMULATION SOFTWARE

PSpice is a popular software for the numerical simulation of electric and electronic circuits, and a free demo or student version of this software is available on the Internet.[9] A numerical study of the usual electrochemical impedances by means of tables and graphics can be easily done by the university students on a personal computer. A single input file describing the circuit by means a very simple language is submitted to the PSpice program, which returns the simulation results in table form in an output file and also in graphics form.[10] The output file can be read in ASCII format by most commercial graphic or spreadsheet packages such as Excel, although it is optional. After introducing the values for the parameters of the circuit, PSpice program allows students to obtain the magnitude or modulus, phase, and real and imaginary parts of the impedance for each value of the frequency. With these data, the students can build impedance diagrams, such as Bode or Nyquist, or carry out calculations from the output tables.

Published: November 20, 2013

dx.doi.org/10.1021/ed4004595 | *J. Chem. Educ.* 2013, 90, 1699−1700

IN-CLASS EXERCISES

Two sessions of 1 h each are enough for the students to do the numerical exercise. The first session includes a theoretical introduction and the simulation of the impedance spectra by the instructor. The data can be analyzed in the second session. The software has been used in university classes corresponding to the chemistry curriculum. It constitutes a powerful tool to generate impedance diagrams and analyze the role of the different parameters involved, allowing students to develop skills in identifying electrochemical impedance diagrams. Sample activities and questions are available in the Supporting Information.

ASSOCIATED CONTENT

Supporting Information

Theoretical introduction on the fundamentals of electrochemical impedance; examples of input files for PSpice; sample activities and questions. This material is available via the Internet at http://pubs.acs.org.

AUTHOR INFORMATION

Corresponding Author

*E-mail: aamoya@ujaen.es.

Notes

The authors declare no competing financial interest.

REFERENCES

(1) Orazem, M. E.; Tribollet, B. *Electrochemical Impedance Spectroscopy*; Wiley: Hoboken, NJ, 2008.
(2) Bard, A. J.; Faulkner, L. R. *Electrochemical Methods: Fundamentals and Applications*; Wiley: New York, 2001; Chapter 10, pp 368−416.
(3) Brett, C. M. A.; Oliveira Brett, A. M. *Electrochemistry: Principles, Methods and Applications*; Oxford University Press: Oxford, 2005; Chapter 11, pp 224−251.
(4) Oldham, K. B.; Myland, J. C.; Bond, A. M. *Electrochemical Science and Technology*; Wiley: Chichester, U.K., 2012; Chapter 15, pp 303−328.
(5) Arnau, F.; Cabot, P. L.; Cortés, M.; Costa, J. M. Faradaic impedance diagramas: A computer electrochemical experiment. *J. Chem. Educ.* **1987**, *64*, 792−793.
(6) García-Jareño, J. J.; Benito, D.; Sanmatías, A.; Vicente, F. Simulation of impedance spectra. A computational and electrochemical exercise for university students. *J. Chem. Educ.* **2000**, *77*, 738−739.
(7) Gelderman, K.; Lee, L.; Donne, S. W. Flat-band potential of a semiconductor: Using the Mott-Schottky equation. *J. Chem. Educ.* **2007**, *84*, 685−688.
(8) Sadik, O. A.; Cheung, M. C. Computer simulation of electronic circuits used in chemical instrumentation. *J. Chem. Educ.* **2001**, *78*, 658−662.
(9) Cadence Design Systems. http://www.cadence.com (accessed Oct 2013); Electronics Lab http://www.electronics-lab.com (accessed Oct 2013).
(10) Tuinenga, P. W. *SPICE: A Guide to Circuit Simulation and Analysis Using PSpice*; Prentice Hall: Englewood Cliffs, NJ, 1992.