Cyclic Voltammetry Quantification of Iron in Ferrous Sulfate Supplements: A Method of Successive Addition to One Solution.

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ABSTRACT

There is a growing interest in the introduction of cyclic voltammetry to upper-level undergraduate chemistry students. This work presents a simple buffer-free cyclic voltammetry experiment for the quantification of elemental iron in ferrous sulfate supplements using standard addition to a single solution. The various student learning outcomes highlighted in this work include the introduction to the basic principles of cyclic voltammetry, the construction of a calibration curve based on the Randles−Sevcik equation, obtaining a linear regression equation using Microsoft excel, acid digestion of drug supplements, and quality assurance through a statistical evaluation of experimental data. This laboratory experiment also emphasizes the advantages of using the method of a standard addition to a single solution.

INTRODUCTION

The role of elemental iron in living organisms is implicated in critical metabolic processes such as hemoglobin and myoglobin synthesis, cell proliferation and regulation, and DNA synthesis. [1-3] About one-fifth of iron in the body is stored in an intracellular protein called ferritin, with seventy percent stored in hemoglobin.[3,4] Chronically low iron levels either through blood loss, pregnancy, or inadequate iron intake can cause iron depletion over time, resulting in iron deficiency anemia.[5,6] Iron intake through food fortification or medicinal supplementation has been shown to be effective in preventing and treating iron deficiency anemia.[5-7] Excess iron intake, on the other hand, has been linked to the etiology of a variety of chronic diseases, including cancer, diabetes, and cardiovascular disease.[8] Ferrous sulfate supplements are often prescribed to prevent or treat iron deficiency anemia.[9-12] It is administered orally as a liquid, tablet, or capsule.[13] In the context of possible low iron intake or overload, the validation of the actual amount of iron contained in ferrous sulfate supplements is imperative.

Trace element analysis of metals including iron has been an integral part of most undergraduate chemistry laboratory experiments.[13-15] These experiments exploit a myriad of analytical techniques and instrumentation, also providing students the opportunity to work with real-life samples. Cyclic voltammetry offers a versatile electroanalytical technique for both qualitative and quantitative studies of redox active specie.[16-20] It can be used to determine the diffusional coefficient and reduction potentials of an analyte for qualitative purposes.[17-18] The concentration of a redox active specie in a Nernstian system is proportional to peak current (Equation 1) allowing for the quantitative determination of analyte concentration. [17,18]

$$\boldsymbol{i_p = 2.69\ x\ 10^5 n^{3/2} A D^{1/2} C V^{1/2}} \qquad (1)$$

where $\boldsymbol{i_p}$ *is the maximum or peak current, n is the number of electrons transferred in the redox reaction, A is the area of the working electrode in cm*^{2}*. C is concentration in mol/cm*^{3} *of the electroactive species at the surface of the electrode. V is the scan rate in V/s, and D is the diffusion coefficient of the electroactive species.*

The authors present a simple yet an engaging laboratory experiment that uses cyclic voltammetry to determine the amount of iron in an over-the-counter ferrous sulfate supplement.

EXPERIMENT

Equipment

All CV experiments were performed in a glass cell vial using a BASi Epsilon Potentiostat, and a C-3 Cell stand (along with BASi software) (MF-1208). A three-electrode system consisting of a 1.60 mm diameter gold working electrode (MF-2014), a - Ag/AgCl (3M NaCl) reference electrode (MF-2052), and a platinum wire auxiliary electrode (MW-

1032). Electrode polishing pads and a polishing glass plate (MF-2128) (MF-1043, BASi). All electrochemical equipment listed in this section were obtained from BASi Research Products, Inc.

Chemicals

Nature Made ferrous sulfate (65) mg iron supplement tablets were purchased from a local store. Hydrochloric acid (HCl) and ferrous sulfate ($FeSO_4 \cdot 7H_2O$) were purchased from Sigma-Aldrich, and 0.01 µm Alumina powder from Buehler.

Procedure

This experiment is intended to be completed by a group of two or three students in a three-hour lab session. As a pre-laboratory assignment, each student is required to create an excel spreadsheet for data collection and calculations. Each group is given 4-5 iron supplement tablets which are pulverized, and acid-digested using ~ 100 mL 1.0 M HCl. This step is followed by gravity filtration of digested samples into a 200 mL volumetric flask. Excess 1.0 M HCl is added to the 200 mL mark. 50 mM $FeSO_4 \cdot 7H_2O$ in 1.0 M HCl was used as a standard for quantifying the amount of iron in each tablet. The supporting electrolyte for the cyclic voltammogram experiment was the 1.0 M HCl used for acid digestion and the standard solution.

Hazards

Acid digestion of samples should be done under a fume hood. The acid digestion setup should be approved by the instructor before proceeding. Protective eye goggles, gloves, and the appropriate apparel should be worn while performing this laboratory experiment. Ferrous sulfate can cause eye and skin irritation. All laboratory-provided iron supplement tablets should not be ingested.

Cyclic voltammetry experiment

Prior to the CV experiment, each group is required to clean their working electrodes. A three-electrode system is set up with a C-3 cell filled with 10 mL of the digested sample solution, a gold working electrode, a Ag/AgCl reference electrode, and a platinum wire as the auxiliary electrode (Figure 1). Triplicate CV runs of the analyte were obtained followed by incremental addition of the standard to the sample (Figure 2). Students are encouraged to clean the surface of the working electrode in between runs to avoid fouling the electrode. Both cathodic and anodic peak currents should respond linearly with increasing analyte concentration. Any deviation observed may be corrected by additional electrode polishing. All CVs were collected at a s scan rate of 200 mV/s over a potential range of – 300 mV to 800 mV.

Figure 1. A three-electrode set up for the cyclic voltammetry experiment showing a BASi Epsilon Potentiostat, a 1.60 mm diameter gold working electrode, a platinum wire auxiliary electrode and a Ag/AgCl (3M NaCl) reference electrode. The C-3 cell is filled with 10 mL of the digested iron supplement tablets.

RESULTS AND DISCUSSIONS

The cyclic voltammograms for the incremental addition of 50 mM $FeSO_4 \cdot 7H_2O$ to the digested iron supplement tablets are shown in Figure 2. The chemical reversibility of a redox reaction at the surface of a working electrode is established if the anodic to cathodic peak current ratio is 1. As shown in the sample student results, the anodic to cathodic peak ratio of 0.9682 confirms chemical reversibility of the Fe^{2+}/Fe^{3+} redox couple at the electrode surface (Table 1). The cathodic and anodic peak potentials occurred at 440 and 540 mV respectively. A sample standard addition calibration curve with an R^2 value of 0.9985 is shown in Figure 2. The choice of which peak current to use for the calibration curve is left at the discretion of each student. The concentration of iron in the digested samples is obtained using the calibration curve, and the associated uncertainty (2) is calculated with the aid of the Excel LINEST function. Each student submits a note card containing the amount of iron calculated in mg and the associated relative error. Our collated students' results for the mass of iron in these over-the-counter ferrous sulfate supplements was 60.1 ± 3.0 mg compared to 65.0 mg shown on the ferrous sulfate ion supplement label.

Table 1: Sample student experimental data and calculations.

Quantification of iron in over-the-counter iron supplement tablet using cyclic voltammetry							
v_i = 10.00 mL	$(v_s + v_i)$ mL	$s_i\left(\frac{v_s}{v_i}\right)$/M	i_p/mA	i_pm/A	i_p/mA	Mean (i_p) mA	$i_p * \left(\frac{v_s+v_i}{v_i}\right)$/mA
s_i = 50.0 mM	10.00	0.0000	0.1274	0.1317	0.1363	0.1318	0.132
	12.00	0.0100	0.1554	0.1535	0.1511	0.1533	0.184
	14.00	0.0200	0.1567	0.1626	0.1581	0.1591	0.223
	16.00	0.0300	0.1682	0.1668	0.177	0.1707	0.273
	18.00	0.0400	0.1733	0.1780	0.1793	0.1769	0.3184
Calculations							
Concentration (mM)		$28._8$			Anodic peak current i_{p_a}		0.126
Uncertainty in the x intercept (mM)		$1._1$			Cathodic peak current i_{p_c}		0.132
Mass of five Fe tablets (mg)		322			$i_{p_\mathrm{a}} / i_{p_\mathrm{c}}$		0.955
Mass of one Fe tablet (mg)		64.4			Anodic peak Voltage (E_{p_a})/mV		543
Mass of Fe per tablet printed on label (mg)		65.0			Cathodic peak Voltage (E_{p_c})/mV		443
Relative % Error		0.9			$(E_{p_\mathrm{c}} - E_{p_\mathrm{c}})$		100. mV

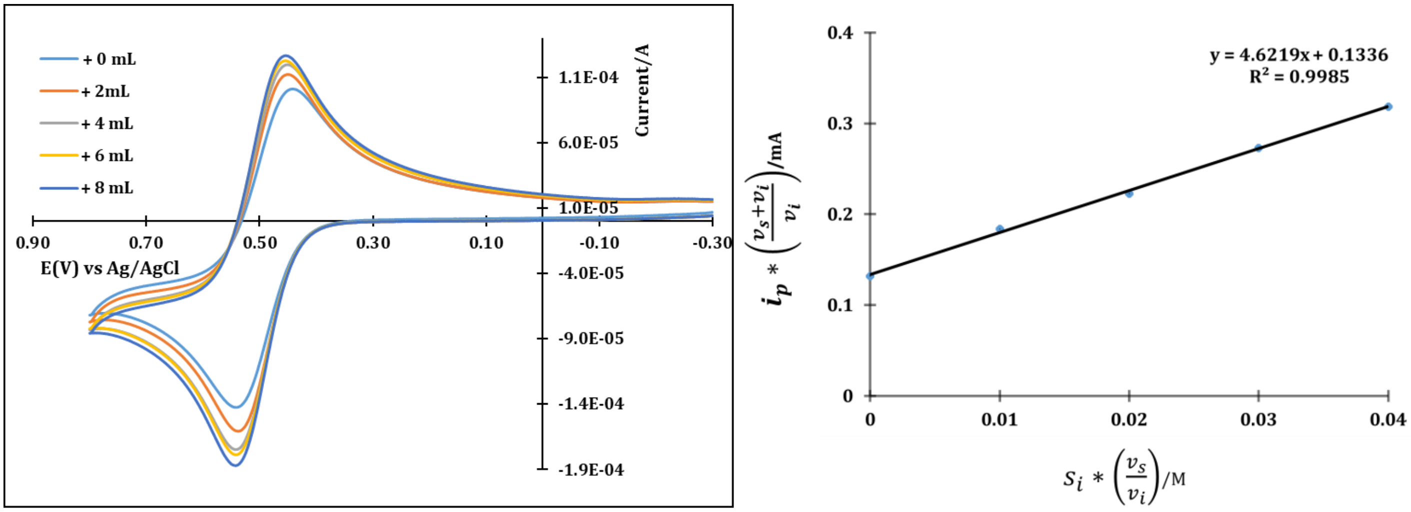

Figure 2. Sample student data showing cyclic voltammograms of the digested iron tablets with incremental addition (0 mL – 8 mL) of ferrous sulfate standard at a scan rate of 200 mV/s and the corresponding standard addition calibration curve. S_i is the concentration of the standard, v_s denotes the volume of standard added, and v_i is the volume of the digested ferrous sulfate tablets in the electrochemical cell.

$$u_x = \frac{S_y}{m}\sqrt{\left(\frac{1}{n} + \frac{\bar{y}}{m^2\,\Sigma(x_i - \bar{x})^2}\right)} \qquad (2)$$

u_x is the standard uncertainty in the x intercept, S_y is the standard deviation of y values and m is the absolute value of the slope. N denotes the number of data points used for the calibration curve and x_i represents the individual x values.[21]

CONCLUSIONS

We have presented a simple cost-effective cyclic voltammetry experiment for the quantification of over-the-counter iron supplement tablets. This experiment is suitable for both junior and senior undergraduate chemistry students. Some of the learning outcomes presented include the introduction to cyclic voltammetry and the basic features of a reversible cyclic voltammograms. Other learning outcomes include statistical evaluation and presentation of experimental data. The low sample volume requirement using the method of standard addition to a single solution is also highlighted.

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