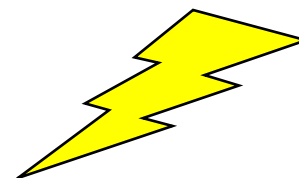


Electron Charge Lab

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Abstract

Students pass a charge between two copper plates in a copper sulfate solution to determine the charge on one electron. Copper ions are reduced at the negative electrode. From the mass of Cu plated, students are able to calculate the charge on one electron, 1.60×10^{-19} C.

Preface

Last year I worked with Mark Wightman to resolve a problem I had powering an Electron Charge (EC) lab. Mark teaches history and psychology, and also enjoys working with digital electronics. The EC lab is a wonderful way to teach students the mole concept. Unfortunately, the expensive power supplies we used continually shorted-out when students completed the circuit. Furthermore, as the day progressed, more of the power supplies failed to operate correctly due to over heating. Mark decided to try an old PC power supply in place of our scientific power supplies. The results were so accurate and reliable; we decided to share our idea with other science teachers. The new power sources revived the EC lab. The EC lab has become one of the best activities of the year. Furthermore, we were able to reuse old power supplies that were going to be sent to a landfill. Computer power supplies work well in the science lab to power light bulbs, electrochemical cells and motors on wave tanks. Computer power supplies produce very low voltages and offer a very steady current flow. With so many old computers being thrown out, these power supplies are easy to obtain and modify for use in the science laboratory.

A model for meeting the national and state standards in science education begins with quality investigations. Quality investigations challenge students to reason through a process using concepts from many disciplines. Students are challenged to read, write and communicate their findings in a clear and concise manner. In addition, students are

challenged to connect mathematical concepts with chemical and physical concepts. The Electron Charge Lab is an effective activity for teaching students how to conduct scientific inquiry. Students engage in scientific inquiry when they question the results of their own investigations. National standards in science education emphasize the teaching of inquiry-based activities. The EC lab offers students an opportunity to engage in an activity that directly addresses these standards. Students question the mole concept and the accuracy of Avogadro's number (6.02×10^{23}). The calculations students perform during the EC lab convince even the most skeptical student that Avogadro's number is an accurate prediction for the number of atoms in a mole.

Teaching is a craft where skilled professionals seek ideas that will lead to learning opportunities for their students. Teachers are constantly challenged to create a setting where students can engage in extended investigations. The use of computer power supplies to power the EC lab, demonstrates a commitment by these authors to develop a quality investigation that support student inquiry.

Introduction

Electrochemistry deals with the relation of the flow of electric current to chemical changes. It also deals with the conversion of chemical to electrical energy and electrical to chemical energy. The two main branches of electrochemistry are electrolysis and the electrochemical cell. During electrolysis, electrical energy is converted to chemical energy. During the operation of an electrochemical cell, the reverse takes place; chemical energy is converted to electrical energy.

In this lab we will calculate the experimental charge on one electron. We will set up an electrochemical cell with copper electrodes. A circuit will be constructed that allows a constant amount of current to pass through the cell. The charge on an electron may be calculated by plating copper ions for a specific amount of time. One ampere is equal to one coulomb per second.

$$\text{One Ampere} = \frac{\text{One Coulomb (C)}}{\text{Second}}$$

Therefore, the charge administered to the plate is equal to the current multiplied by the time in seconds. A digital multimeter will be used to measure the current level throughout the experiment. A computer power system will be used that delivers a steady 5.00 volts at less than 1.00 ampere of current. Computer power supplies give excellent current readings over long periods of time with very little over heating of the circuit. These power supplies are very inexpensive and can be found in any desktop computer. A built in fan cools the power supplies. As the load on the fan increases the fan spins faster minimizing over heating effects.

The computer power supplies were removed from old PC 286 computers being thrown away. Each power supply was screwed down to a wooden block. A plywood box was built around the power supply to shield the wires from student tampering. Holes were drilled in the front panel of the plywood box to support banana plug connectors. The connectors were purchased on-line from Mendelson Electronics Company (www.meci.com). Five volt and twelve volt wires from the power supply were soldered to the connectors inside the box. An automobile fender light-bulb assembly from a locate junk yard was use as an on/off indicator so students would know when the power supply was working. Two twelve-volt wires from the power supply were soldered to the automobile bulb and the bulb housing was fastened into the front plate of the box. As the power supply encounters more resistance in the circuit, voltage sensors in the power supply increase or decrease the current to maintain a constant voltage. Also, voltage and temperature sensors cause the fan to spin faster reducing over heating problems encountered with previous power supplies. When the light bulb is off, the circuit is open and no plating can take place. Figures 1A and 1B shows the power supply inside the plywood box. Figure 2 shows the unit in operation during the lab activity.

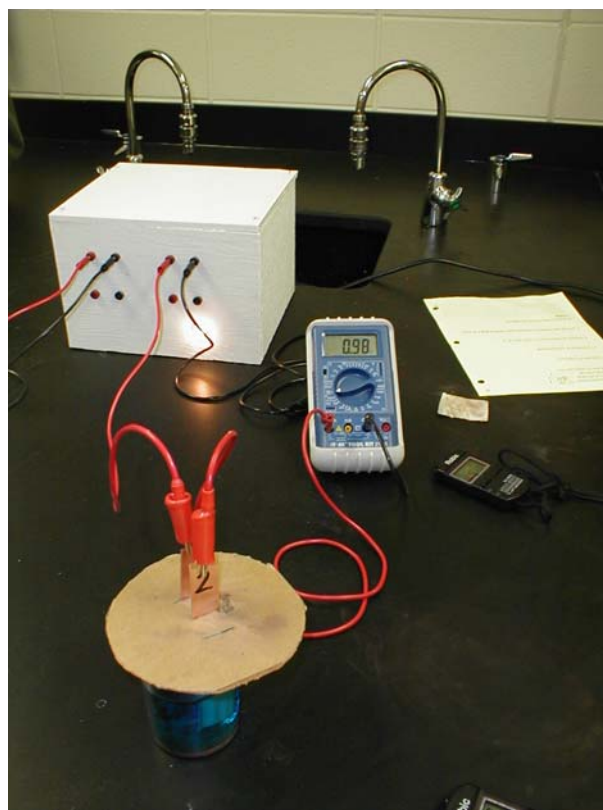
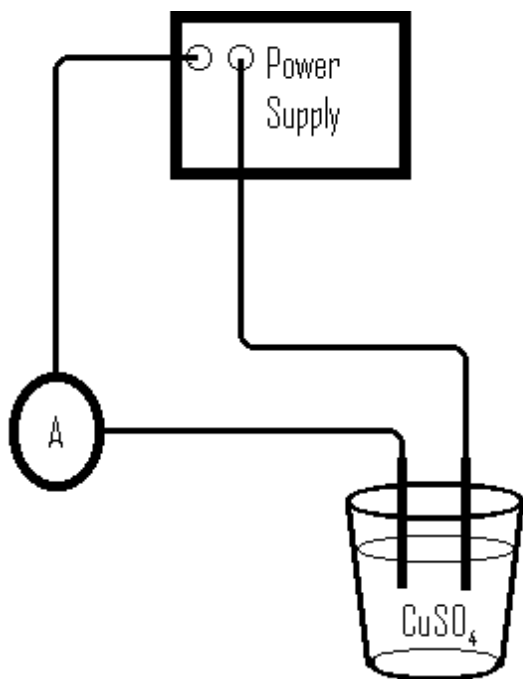
Figure 1A: Computer Power Supply (Front Panel)



Figure 1B: Computer Power Supply (Inside Front Panel)



Figure 2: Circuit Diagram and Lab Set Up



Purpose

Experimentally determine the charge on an electron and compare your observed value with the expected value.

Safety

Lab goggles are required for this lab and should be worn during the plating process.

Procedure

- 1) Mass the center copper electrode and record its value in the data table.
- 2) Set up the circuit shown in the diagram. Fill the glass cup about three-quarters full of copper (II) sulfate solution. (Ten milliliters of 0.1 M sulfuric acid has been added to 1 L of the copper (II) sulfate solution to enhance the conductivity of the solution.)

- 3) Turn on the power supply and rotate the voltage knob until the meter reads one ampere. Continue to watch the ammeter to be sure the needle continues to read one ampere for the entire experiment.
- 4) Allow the plating process to continue for 15 minutes.
- 5) After 15 minutes turn off the power supply and carefully remove the negative electrode. The electrode should appear a bright copper color indicating that copper has been plated to the electrode. Allow the negative electrode to dry then mass the electrode on the digital balance. Record the new mass in the data table and complete the calculations that follow.

Results

Figure 3 shows the calculations completed from one lab group. The calculations were broken down into steps so students could see how the mole concept is used to experimentally calculate the elementary charge on one electron. The 1994 Advanced Placement Chemistry Exam written by The College Board included a question related to the calculations outlined in figure 3. Problem number 63 states: "What is the maximum mass of copper that could be plated out by electrolyzing aqueous CuCl_2 for 16.0 hours at a constant current of 3.00 amperes?" This question challenges students to complete the calculations from the Electron Charge Lab in reverse. The elementary charge on one electron is given as $1.60 \times 10^{-19} \text{ C}$ in the reference materials provided to students with the AP Chemistry exam. Students must apply what they understand about the mole concept and electrochemistry to solve this multiple-choice question on the AP Chemistry exam. The percent of students who selected the correct answer from the five answers listed was only 15% based on statistics from The College Board. Clearly few students were able to complete this calculation successfully during the exam in 1994.

Figure 3: Student Calculations

Calculations (Source: Beth and Nathan's Data, Period 5, Chemistry)

Mass of Plate #1 before plating: 22.475 g Mass of Plate #2 before plating: 22.286 g

Mass of Plate #1 after plating: 22.720 g Mass of Plate #2 after plating: 22.046 g

Mass of Cu on Plate #1 = 0.245 g Mass of Cu removed from plate #2: 0.240 g

Record the Ampere Reading: 0.75 A Plating Time: 900 s

1) *Convert grams of Cu plated to moles of Cu.*

$$\frac{0.245\text{g Cu}}{1} \times \frac{1\text{mol}}{63.5\text{g Cu}} = 3.86 \times 10^{-3} \text{mole Cu}$$

2) *Convert moles of Cu to atoms of Cu.*

$$3.86 \times 10^{-3} \text{mole Cu} \times 6.02 \times 10^{23} \text{atoms Cu} = 2.32 \times 10^{21} \text{atoms Cu}$$

3) *Convert atoms of Cu^{2+} to total electrons plated.*

$$2.32 \times 10^{21} \text{atoms Cu} \times 2 = 4.65 \times 10^{21} \text{electrons}$$

4) *Calculate the total charge on the plate for 15 minutes (900 s) with the ampere reading on the meter.*

$$\text{Current} = \frac{\text{Charge}}{\text{Time}} = \text{Charge} = (\text{Amps})(\text{Time}) = (0.83\text{A})(900\text{s}) = 747 \text{C}$$

5) *Divide total charge on the plate by the total electrons plated to calculate the charge on one electron.*

$$\frac{\text{Charge}}{\text{Total Electrons}} = \frac{747\text{C}}{4.65 \times 10^{21}} = 1.61 \times 10^{-19} \text{C}$$

6) *Calculate your percent error based on the accepted value.*

$$\frac{|\text{Observed} - \text{Expected}|}{\text{Expected}} \times 100 = \frac{1.61 \times 10^{-19} - 1.60 \times 10^{-19}}{1.60 \times 10^{-19}} \times 100 = 0.625\% \text{ error}$$

Electron charge data was collected for eight chemistry classes. The data was entered by each lab group into an Excel spreadsheet so an average charge to mass ratio count be calculated. Figure 4 shows the results from the electron charge lab. Figure 5 shows Sophie and Jessica observe the plating of Cu ions during the Electron Charge Lab.

Figure 4: Electron Charge Data

STUDENT CHARGE DATA FOR EIGHT CHEMISTRY CLASSES 2001

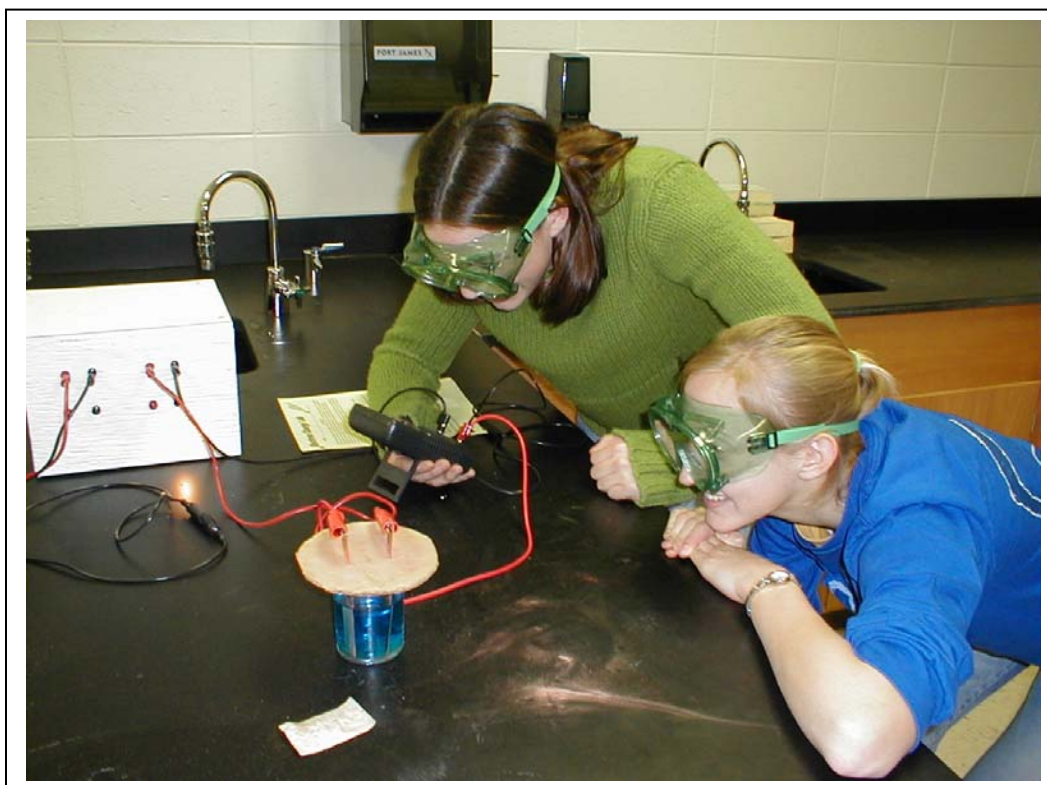
Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8		
1.58	1.34	1.57	1.67	1.40	1.62	1.50	1.62		
1.78	1.50	2.41	1.35	1.61	1.48	1.56	1.72		
1.15	1.52	1.65	1.79	1.55	1.48	1.56	1.08		
1.57	1.37	1.59	1.56	1.53	2.32	1.59	1.66		
1.50	2.04	4.58	1.27	1.55	1.03	1.52	2.57		
1.48	1.57	2.45	0.39	1.30	1.59	1.38	1.16		
1.50	8.63	1.54	1.11	1.46	1.33	1.58	1.58		
1.41	1.47	1.60	1.63	1.37	1.38	1.35	1.60		
1.53	0.65	1.67		1.58	1.62	1.84	1.65		
1.52	1.62	0.37			1.38	1.51			
0.86					1.38				
Class Avg	1.44	2.17	1.94	1.35	1.48	1.51	1.54	1.63	Overall Average

All values to the power of 10^{-19}

The class average value for the charge on one electron is 1.63×10^{-19}

The accepted book value for the charge on one electron is 1.60×10^{-19}

Figure 5: Sophie and Jessica observe Conducting the Electron Charge Lab



Evaluation

Students are evaluated on the Electron Charge Lab by completing a lab report they turn in for a grade. This report must include all the calculations with the proper units for students to receive full credit. Students are also given a question on their mole concept exam that includes data from the lab. Each student must calculate the elementary charge using the data that is provided in the question.

Conclusion

Each lab group observed the charge on an electron. The charge value was experimentally calculated by measuring the flow of electrons through an electrochemical cell. These results show a 5.6% error (1.51×10^{-19} C) when compared to the book value of 1.6×10^{-19} C. The computer power supplies provided a steady voltage across the cell leading to an accurate reading for the average current passing through the cell.

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