Goals of this Experiment: The primary goal of this experiment is to get students to observe and identify the mass (and number of moles) of a metal that plates out at the cathode is directly proportional to the current passing through the cell and to the time that current passes. Also that the number of moles of a metal are inversely proportional to the number of electrons transferred by the metal. When these two proportionalities are combined Faraday's constant can be calculated.

Why ask questions? This is important because if you are always asking questions the students feel like they are figuring things out for themselves. As a teacher you want to try to reduce (not to zero) the number of times you must tell the student something. If you are asking a question and the student answers they are engaged, they have to use their understanding of the concept to explain things to you. And if the student cannot answer your question, try to come up with a different path (using a different line of questions) to get the student to figure things out for themselves. You are the expert, you need to act as a guide to get students to use their understanding of the concepts to figure things out for themselves. This takes PRACTICE. So do not worry if the first time does not work well. Think about your questions and try again with the next group of students. After doing this several times, you get better at it…I promise.

Goals of the Teacher: It is very important to remain engaged with the students so at certain points during the experiment you make sure, as a result of asking particular questions, that students are making the correct observations, obtaining the correct data, organizing that data the proper way, arriving at the correct proportionalities between current (amps), time (seconds), and number of electrons transferred, so students can eventually calculate Faraday's constant (96,500 $\frac{C}{mol\ e^-}$). In particular you must pay close attention to getting the students to, at some point, transition from thinking about amount of metal plating out on the cathode in terms of grams of the metal, to moles of the metal. If students do not do this at some point during the first three sets of experiments then you must guide them to doing that before the students finish the experiment. This transition is important because with out it the three sets of experiments cannot be connected to each other to pull out the inverse relationship between the number of electrons transferred. If students stay with grams as the measure of the amount of metal plating out on the cathode each set of experiments (1 – 5, 6 – 10 and 11 – 15) will only be internally consistent with the proportionality between amount of metal plating out and current (amps) * time (sec). However, students will not see that half as many moles of the metal are plated out when the metal ion has a 2+ charge, compared to when the metal has a 1+ charge. Additionally there is

also the molar mass issue that will not be obvious if students try to set up their proportionalities in terms of grams rather than moles.
So how do you get students to make this transition? I'm not exactly sure either, but how does this sound when talking to a student who has done all three experiment sets and shows you his/her proportionality and you notice that they are relating grams of the metal to amps*seconds in each set and they do not have the inverse proportionality between the moles of metal plating out and the number of electrons transferred.
Teacher: "Is the proportionality that you are showing me the same for all three sets of experiments?"
Student: "Yes it is."
Teacher: "Excellent, looking at your data (nicely organized in a data table with easily readable column headings) I see that same relationship. I'm wondering, did you see any relationship between the amount (do not say grams, use the word amount) of metal plating out at the cathode for your three different metals?"
Student: "Hmm, I do not think so? What kind of relationship?"
Teacher: "Well I was wondering (have the student look at their data), did the same amount of metal plate out at the cathode for all three metals for the same amount of amps and time?"
Student: "Well, looking at my data I measured the mass of each metal when the current was 2 amps and the time was 10 minutes, and I see that in each case the mass is different for each metal." (The student is looking at their data and they see that the mass of silver plated out is 1.34 g: the mass of iron plated out is 0.35 g and the mass of zinc plated out is 0.41 grams.) NOTE: If the student does not have this data, you might be able to point to data that other students have collected and written on the board.
Teacher: "Ok, I see that too, do you see a simple relationship between the mass of each metal plating out with the same amount of current for the same amount of time?"
Student: "Hmm, I am not sure. I do not know. Well maybe the smaller the molar mass the smaller the amount of mass of the metal that plates out."
Teacher: "Well that is an excellent observation! But that is not exactly what I was looking for....I'm wondering what the three half-reactions look like for the three metals? Can you write those for me?"
Student: "Yes I can! (the student writes those: $Ag^+ + 1e^- \rightarrow Ag$: $Fe^{2+} + 2e^- \rightarrow Fe$: $Zn^{2+} + 2e^- \rightarrow Zn$).
Teacher: "Based on the questions you answered after doing the Demonstration experiment, what particle flows through the wire from the anode to the cathode?"
Student: "Electrons!"
Teacher: "Good, I agree, so how would you read that half- reaction? Tell me the relationship between electrons and the amount of metal that plates out in each half reaction."

Student: "Well, one atom of silver ion picks up one electron and one atom of silver plates out. (Or maybe the student says) One mole of silver ions pick up one mol of electrons to plate out one mole of silver atoms. Or the student might say one mole of electrons must be transferred to plate out one mole of solver"
Teacher: "Good, you did not say 1 gram of silver ions pickup/react with one gram of electrons to produce one gram of silver atoms. Or That is very good that is how I read that equation one mol of silver plates out for every mole of electrons transferred. Mol, hmmm, mol. Do you think moles are a better measure of the amount of the metal that plates out at the cathode?
Student: "Possibly!?"
Teacher: "I think you should follow that up. Why not add a column for moles of the metal that plate out, and then compare the moles that plate out in those three experiments where you had the same time and current and see if anything pops out. When you do that if you have any questions, come back and check with me."

Electrochemical Cells Part II

Problem Statement: What affects the amount of metal plated out on the cathode in an electrolytic cell?

Checkout a computer from the Technology TA. For this investigation you will use a simulation located at http://media.pearsoncmg.com/bc/bc_0media_chem/chem_sim/electrolysis_fc1_gm_11-26-12/main.html. You may also go to the Syllabus link on the CHEM 1515 web site to more easily access this site. At this link you will see three tabs titled: Overview; Learner Outcomes and Experiment. Review the Overview and the Learner Outcomes, then click on the Experiment tab and click on the Run Demonstration button. In the Demonstration mode you will learn what features of the simulation can be changed and how to change those features. After running the Demonstration you will go to the Experiment Mode where you will setup each experiment so that you can collect evidence that will allow you to answer the Problem Statement.

Based on the Demonstration answer the following questions.

1a. At which metal strip does oxidation occur? Write the half reaction that occurred at this metal strip (anode).

Oxidation occurs at the positive metal strip, or the left-hand metal strip, also known as the anode.

Cu^{2+}*(aq)* + $2e^-$ → Cu(s)

b) At which metal strip does reduction occur? Write the half-reaction that occurred at this metal strip (cathode).

Reduction occurs at the negative metal strip, or the right-hand metal strip, also known as the cathode.

Cu(s) → Cu^{2+}*(aq)* + $2e^-$

c) briefly describe how the mass of the anode and cathode changed during the experiment.

After starting the demonstration experiment, the mass of the anode decreases as time passes, and mass of the cathode increase.

d) How many electrons are transferred in the reaction per Cu^{2+}*(aq)* ion? How many electrons are transferred in the reaction per mol of Cu^{2+}*(aq)* ion?

2 electrons are transferred for each Cu^{2+}*(aq)* ion.
2 moles of electrons are transferred for each mol of Cu^{2+}*(aq)* ion th.at are reduced at the cathode.

This is very important that they notice the number of electrons transferred. It will be useful to ask students later when they are looking at other metals, how many electrons were transferred. Is it the same number as for copper, it is not, oh that is interesting, isn't it?

d) Based on your observations is the relationship between the amount of time the experiment proceeds and the amount of metal that is plated out at the cathode directly proportional, inversely proportional, or not related? Briefly, what evidence do you have to support your choice.

The amount of metal that plates out on the cathode is directly proportional to the amount of time that passes when the power source is on.

2a. Define the term *electric current*.

Electric current is the flow of electrons (electric charge) through a wire as a result of a voltage difference.

b) What particle(s) are pushed out of the power supply and through the wire connected to the right-hand electrode and are pulled by the power supply through the wire connected to the left-hand electrode?

Electrons flow

b) From careful observation of the Microscopic View describe how these particles move/flow through the electrochemical circuit.

Electrons left behind on the anode when the metal atom is oxidized are pulled by the power supply. The electrons on the surface of the anode feel a repulsion to other electrons so when extra electrons appear on the surface of the anode they push electrons already in the anode away towards the power supply. As a result of this push electrons are available on the surface of the cathode to reduce a metal ion in solution that is near the surface of the cathode. It is important to say that the electrons released on the anode are NOT the same two electrons that appear on the cathode to reduce a metal ion.

Figure I shows the initial view of the experimental apparatus.

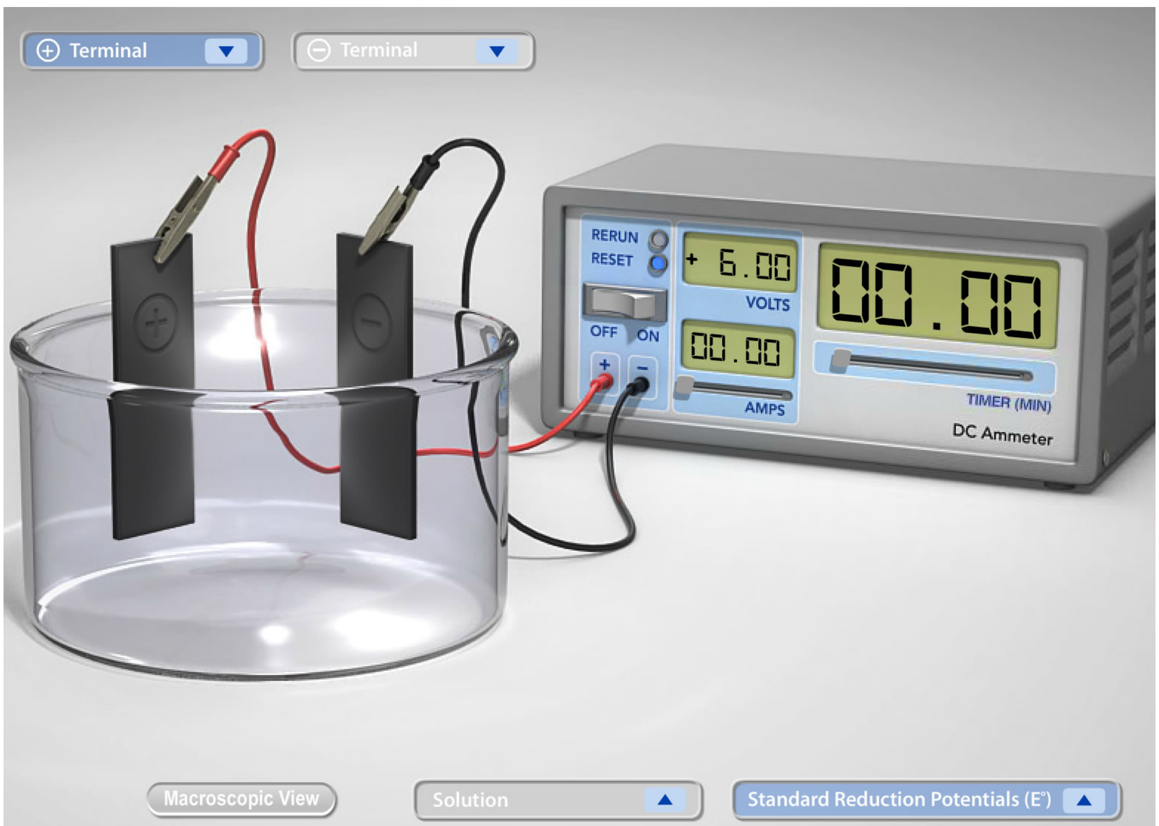

Figure I. Equipment setup showing; the Power Supply where the voltage (held constant in this simulation), current and time are controlled; two metal strips (electrodes) that are connected to the Power Supply with electrical wires coated with a plastic material; and a glass container that will hold the aqueous solution of a metal ion. Dropdown menus allow the choice: of the metal for each metal strip, the aqueous solution in the glass container, a view of the particulate level at important locations in the electrolytic cell, and a list of reduction half-reactions.

Find three other students and form a group of four. Each member of the group should have a computer and be connected to the simulation web site.

NOTE: Each member of the groups of four should be doing the Demonstration. If the number of students are not divisible by four than groups of three are OK. I think trying to do group(s) of five will mean someone(s) is not doing or contributing much.

Data Collection:

A. Perform 4 to 6 experiments using silver as the metal for both the left-hand metal strip and the right-hand metal strip, in a solution of silver (I) nitrate to determine what affects the amount of silver plated out on the cathode and lost from the anode. Discuss, as a group, what data you are going to collect and agree on a data table to organize the data. Record the data in your data table, and your data is collected write your data on one of the boards in the laboratory.

Have the students come up with their own amps and time values. You should have the groups share with the other groups what time and amps each group is doing so as to cover a large range of current and times, but also to obtain verification that the data is correct. So if there are six groups of four in the class pairs of groups should do the same time and current, but there should be 15 different current and time values that are reported.

A1. Data Table for Experiments 1 – 5 with Silver.

While I want students to setup their own table here is what I am thinking. You should advise the groups to show you their tables before proceeding too far into the data collection. Do not ask them about columns for moles yet unless someone asks you.

Experiment #	**Change in mass (anode)**		**Change in mass (cathode)**		**Time (seconds)**	**Current (amps)**

NOTE: The two blank columns will eventually be used to enter the amounts at the anode and cathode in terms of moles. Students might have other columns.

B. Perform two more sets of 4 to 6 experiments using at least two additional metals as the anode and as the cathode in a solution of that metal ion to determine what affects the amount of the metal plated out on the cathode and lost from the anode. Decide what data you are going to collect and agree on a data table to organize the data. When your data is collected write your data on one of the boards in the laboratory. Briefly describe each of these experimental setups in sufficient detail that another student would be able to use the description to setup the identical experiment and collect the same data.

B1. Describe the experimental setup for Experiments 6 - 10:

For this portion groups should pick a second metal (probably a metal that has a 2+ ion). They should describe their setup in terms of the metal. For example if the students select iron for this metal. They would describe:
In this second set of experiments the anode is iron, the cathode is iron and the solution in the glass bowl is 1 M iron (II) nitrate. For the current and amps we used the same 5 combinations as we did in the first set of experiments with silver in Data Collection part A.

B2. Data Table for Experiments 6 – 10 with metal ______.

The table should look similar to the table used for silver in part A

C1. Describe the experimental setup for Experiments 11 - 15:

See comment in B1.

C2. Data Table for Experiments 11 – 15 with metal ______.

See comment in B2.

II. Data Analysis and Interpretation

A. Based on Experiments 1 – 5 (the first set of experiments with silver) what relationship(s) did you discover. What evidence do you have to support the relationship(s). You should write a mathematical proportionality to summarize the relationship(s).

For evidence the students should identify should include: In Exp #1 and #2 I doubled the current, but held the time constant and the mass of silver doubled. In Exp #3 and #4 I double the time and kept the current (amps) constant and the mass of silver also doubled. In Exp 5 I doubled the current and the time when compared to Exp #1 and observed that the mass of silver plated out on the cathode is four times the mass in Exp #1.

Therefore the relationship between mass, current and time is;

Grams Ag α amps * time (sec)

The mass of silver plated out on the cathode is directly proportional to the amps times the time.

So as you review each groups data be sure that any claims students make are supported by evidence. They will need one pair of experiments where the only current is changed, one pair where only time is changed and one pair where both time and current are changed. Hopefully they choose easy values.

B. Based on Experiments 6 – 10 (the second set of experiments with metal ____) what relationship(s) did you discover. What evidence do you have to support the relationship(s). You should write a mathematical proportionality to summarize the relationship(s).

For whatever metal the student selects:

For evidence the students should say something like in Exp #1 and #2 I doubled the current, but held the time constant and the mass of the metal doubled. In Exp #3 and #4 I double the time and kept the current (amps) constant and the mass of the metal also doubled. In Exp 5 I doubled the

current and the time, compared to Exp #1 and four times the mass of the metal plated out on the cathode.

The students should be writing:

Grams metal α amps * time (sec)

The mass of metal plated out on the cathode is directly proportional to the amps times the time.

So as you review each group's data be sure that any claims students make are supported by evidence. They will need one pair of experiments where the only current is changed, one pair where only time is changed and one pair where both time and current are changed. Hopefully they choose easy values.

C. Based on Experiments 11 – 15 (the third set of experiments with metal ____) what relationship(s) did you discover. What evidence do you have to support the relationship(s). You should write a mathematical proportionality to summarize the relationship(s).

For whatever metal the student selects:

The students should be writing:

For evidence the students should say something like in Exp #1 and #2 I doubled the current, but held the time constant and the mass of the metal doubled. In Exp #3 and #4 I double the time and kept the current (amps) constant and the mass of the metal also doubled. In Exp 5 I doubled the current and the time, compared to Exp #1 and four times the mass of the metal plated out on the cathode.

Grams metal α amps * time (sec)

The mass of metal plated out on the cathode is directly proportional to the amps times the time.

So as you review each group's data be sure that any claims students make are supported by evidence. They will need one pair of experiments where the only current is changed, one pair where only time is changed and one pair where both time and current are changed. Hopefully they choose easy values.

D. When comparing the results of Experiments 1 – 5 with the experimental results of Experiments 6 – 10 and 11 – 15 does/do an/any additional relationship(s) appear? If so what is the relationship(s) and what evidence do you have to support the relationship(s)?

When students consider the moles of the metal they can now make a comparison between Exp #1 - #5 and Exp #6 - #10 and Exp# 11 -#15. To see the relationship they need to pick an experiment from each set where the amps * time is the same. If they do not have a experiments that do that you may need to guide the students to coming up with that idea. That might be handled this way:

Teacher: "Did the proportionalities of moles of metal α amps * time (sec) fit both sets of experiments #1 - #5 and #6 - #10?

Student: "Yes!"

Teacher: "Excellent. I see from your data that that is the case. That within each set of data (Exp #1 - #5 and Exp #6 - #10) that there is a direct proportionality between the moles of metal plated and the amps * time. I wonder, is there any relationship between the two sets of experiments?"

Student: "I do not know."

Teacher: "Do you want to review the data to see if anything pops out at you?"

Student: "Sure." Some time later…"I guess I do not see anything, is there something I am missing?"

Teacher: Looks to see if there are pair of experiments one in Exp #1 - #5 and one in Exp #6 - #10 where the time and amps are the same. If that you will have to point that out, but not right away. Instead take the following approach..

Teacher: "I'm wondering what the two reduction half-reactions look like for these two metals? Can you write those for me?"

Student: "Yes I can! (the student writes those: $Ag^{+} + 1e^{-} \rightarrow Ag$ and $M^{2+} + 2e^{-} \rightarrow M$."

Teacher: "What is different about the two have reactions?"

Student: "well, in the silver half-reaction only one electron is transferred, but in the other half-reaction two electrons are transferred"

Teacher: "Yes! I agree. I see that also. I wonder if there is a way to keep everything the same for the silver experiments and for the other metal experiments, so the only difference is the number of electrons transferred?"

Student: " Let me think…yes I could keep the number of amps and the time the same for each metal and see what happens!"

Teacher: "That sounds like an interesting experiment, why don't you try that."

Moles of metal $\alpha \; \dfrac{1}{\#\ e^{-}\ \text{transferred}}$ **(based on the half-reaction)**

So for example if the metal in this set of experiments has a 2+ charge in solution the number of electrons transferred are 2, and when the amps and

time are the same as an experiment in the first set (#1 - #5) comparing the moles of metal plated out the moles of the metal in this set will be half the moles of silver. If the student selects aluminum, the number of moles of electrons transferred are 3 and the number of moles of aluminum plated are one-third the number of moles of silver.

That is the evidence that is need to claim the inverse relationship between moles of metal plated and moles of electrons transferred.

Again students can not make this connection until they realize/discover/are lead to the idea that they must consider the amount of metal that plates out on the cathode in terms of moles. So do not stress about this proportionality until after the data for the third set has been collected. But you will need to be looking at the data each group is collecting (check out the tabular form so you can quickly see what data the students are collecting.)

E. Combine all of the factors you identified in A – D into a single proportionality expression. Calculate a proportionality constant (called the Faraday) for the expression. What are the units for this constant?

When answering this question the students need to have all three relationships clearly determined.

Moles of metal α amps * time (sec)

Moles of metal $\alpha \; \dfrac{1}{\#\ e^-\ \text{transferred}}$ **(based on the half-reaction)**

So when they combine these they would have…

Moles of metal $\alpha \; \dfrac{\text{amps * time (sec)}}{\#\ e^-\ \text{transferred}}$

When they look at any one experiment in their three sets they can see that if they multiply the current times time (in seconds) and divide by the number of electrons transferred they do not get the number of moles plated. To do that they need to add a constant. Now where that constant goes, in the numerator or the denominator, the students may not know, and you will have to tell them. The constant should be in the denominator. Then they can check their experiments (at least several in each set) so they have evidence that they are getting the same constant….around 96,000 to 97,000. You will have to tell

them that an amp *sec is also a coulomb of charge so the constant is 96,500 $\frac{C}{mol\ e^-}$.

Application: Complete the online activity on your Personal Page.