Manitoba
Education, Citizenship and Youth

Chemistry – Grade 12
Unit 6 - Electrochemistry

DRAFT / Unedited Version

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Specific Learning Outcomes

C12-6-01: Develop an activity series experimentally. (2 hours)

C12-6-02: Predict the spontaneity of reactions using an activity series. (0.5 hours)

Skills and Attitudes Outcomes:

C12-0-S1 Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment
Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), emergency equipment.
GLO: B3, B5, C1, C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

Entry-Level Knowledge

Students were introduced to oxidation and reduction reactions in the first unit, Aqueous Solutions. Given an oxidation reduction reaction, students should now be able to identify the oxidation numbers of all the elements in a given reaction, identify the element being oxidized, the element being reduced as well as the oxidizing and reducing agents. Students should also be able to balance oxidation reduction reactions and have a good understanding of the concept of the conservation of electrons. If students are not able to adequately perform these tasks, they will have difficulty understanding this next section on electrochemistry. Teachers should review redox information from unit 1 as necessary.

It should be also noted that the following outcome was discussed in the introductory unit, *Aqueous Reactions*.
C12-1-12: Research practical applications of oxidation-reduction reactions.
If students were asked to research applications of oxidation-reduction, they should be given time to present their findings during this unit.

Teacher Notes

It is important to note that the standard reduction potential tables provided in both approved texts are not what some teachers might expect. The texts present the SI system standard reduction potentials in which the half reaction at the top is the lithium ion being reduced to the lithium atom and the fluorine reduction half reaction is placed at the bottom of the table. See the following reference.
http://www.iupac.org/didac/Didac%20Eng/Didac03/Content/R07.htm

As most chemistry texts currently found in Manitoba schools and at the advanced study level follow the non SI approach, an explanation has been made using the non SI table of Standard Electrode Potentials starting at the top with the reduction half reaction for Fluorine gas. The questions provided in the following discussion and subsequent answers will also use the same table. However, during the discussion that follows an explanation will be made for the SI Standard Electrode Potential Half Reactions starting with the reduction reaction of the lithium ion to the lithium metal.

Electrochemistry is ideally suited to discussions about what is occurring in the visual, molecular and symbolic modes of representation. As discussed previously, current research shows that for students to clearly understand chemical processes more completely, these modes of representation should be discussed and illustrated. This is especially true for electrochemistry where there are well recognized web sites that provide excellent animated explanations. Once students have experienced macroscopic changes in the laboratory, they should be asked to draw and explain what is happening on a molecular level. Any animations that the teacher can use to illustrate what is occurring on a molecular level will only increase

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student understanding of the processes involved. The animation from the University of Iowa State listed below is an excellent example of what animations are available to the chemistry teacher.

Animations

Department of Chemistry University of Iowa St
Reactions of Metals and Metal Ions Experiment (simulation)
This simulation lets the student discover the activity series by placing different metals in various aqueous solutions. The student can observe the simulation at the molecular level.
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/redox/home.html

Virtual Crezlab Qualitative Analysis
Displacement reaction between $CuSO_{4(aq)}$ and $Zn_{(s)}$
http://www.crescent.edu.sg/crezlab/webpages/pptReaction3.htm

Laboratory Investigation

For this outcome, students are required to perform an experiment or investigation that shows, qualitatively, how the activity series is derived. There is an excellent investigation that has been around for many years that uses reactions producing free halogens, Cl_2, Br_2, and I_2. Many texts including the approved texts usually provide a lab that includes the metals, Zn, Cu, Pb, and sometimes Ag with their corresponding ions. However, not many labs provide negative reduction reactions like $I_{2(s)} + 2e^- \rightarrow 2I^-_{(aq)}$. Using the halogen half reactions has an obvious advantage by providing larger selection of half-cell reactions. Such a lab has been provided in Appendix 1 together with explanations and reactions in the teacher form of the investigation (see Appendix 2).
As this investigation has been around for many years, it follows the non SI approach and generates a Standard Electrode Potential table with $Cl_{2(aq)}$, $Br_{2(aq)}$, $Ag^+_{(aq)}$, $I_{2(aq)}$, $Cu^{2+}_{(aq)}$, $Pb^{2+}_{(aq)}$, and $Zn^{2+}_{(aq)}$ written as reduction reactions. After the investigation is complete, students are able to create an electromotive series table of reduction reactions with species are arranged in decreasing ease of reduction. i.e. $Cl_{2\ (aq)}$ is the species that is the most easily reduced at the top of the table to $Zn^{2+}_{(aq)}$, the species that is the least easily reduced at the bottom of the table.

To provide a historical note, the free halogens in solution were originally tested with carbon tetrachloride, and then later with TTE (trichlorotrifluoroethane). Both of these liquids are now banned from schools and have been replaced with hexane, a safer organic solvent that provides the same test results as the other two dangerous solvents. Teachers might want to inform students that at one time, carbon tetrachloride was used extensively in the dry cleaning industry.

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Teacher Notes

Once an activity table has been established by the students, it can be used to predict the spontaneity of reactions. As students are not yet aware of the significance of the electrode potentials, it might be useful to cut off the potential values so as not to distract students.

A non SI table of Standard Electrode Potentials has been included in Appendix 3. Notes have been added to The table regarding such information as 'what species is the most easily reduced?', 'what species has the least affinity for electrons?', etc.

Most North American activity series are listed as Standard Reduction Potentials at 25˚C and ionic concentrations of 1 mole /L solution. European activity series are usually written as oxidation potentials.

Students should understand how the various species are organized on the table in terms of:

- Greatest / least affinity for electrons
- Most / least easily reduced / oxidized
- Strongest / weakest oxidizing / reducing agent

A number of examples have been provided based on the tables provided in the appendix:

1. What species is the strongest oxidizing agent?, Answer: F_2 (g)
2. What species is the least easily reduced?, Answer: Li^+ (aq)
3. What species is the weakest reducing agent?, Answer: F^- (aq)

These are a few of the possible questions students may be required to answer using the standard reduction potential table. Additional assessment questions have been provided later.

Based on the results of experiments with chemical reactions, not unlike the investigation performed by students, chemists discovered that certain species reacted spontaneously whereas others did not react. Students already know from prior knowledge (grade 10 chemistry unit) that alkali metals react to become positive ions, losing electrons in the process to become stable and having a similar electronic structure to the inert gases. Similarly, fluorine gas rapidly and readily gains electrons to become a stable ion in solution with the electronic structure of a stable inert gas with an octet of electrons in its outer energy level. These reactions form the top and bottom of a very important table for chemists. This table is based on the relative affinity of various species for electrons causing a reduction to occur in the ion charge of the species being reduced. See Appendix 3 for a non SI version of this table.

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Fluorine gas on the top left has a greater affinity for electrons than a species lower down on the left, the higher species will therefore undergo a reduction reaction as an oxidizing agent and a species lower down will be reversed to become an oxidation reaction.

e.g. F_2 will react with Cl^-, Ag^0, Cu^0, etc

e.g.

$$
\begin{array}{l}
F_2\,(g) + \cancel{2e^-} \rightarrow 2\,F^-(aq) \\
Cu^0\,(s) \rightarrow \cancel{2e^-} + Cu^{2+}\,(aq) \\
\hline
F_2\,(g) + Cu^0\,(s) \rightarrow 2\,F^-\,(aq) + Cu^{2+}\,(aq) \quad \text{net reaction}
\end{array}
$$

- F_2 has a greater affinity for electrons (actually the greatest affinity of all species)
- F_2 being reduced and is the oxidizing agent
- Cu^0 is being oxidized and is the reducing agent

Journal Writing

Have students:

- research to find out where the name ‘electromotive series’ originated
- discuss the importance of the ‘electromotive series’
- relate position on the table to chemical reactivity as discussed in grade 10 science or grade 11 chemistry

Visual Displays

Have students draw representations of the reactants and products or redox reactions and show how the transfer of electrons occurs in solution.

Suggestions for Assessment

Laboratory Skills

Students should exhibit appropriate lab skills at all times during the lab period. Rubric checklists are available in the appendix for assessment of skills.

Paper and Pencil Tasks

A. Have students predict the spontaneous / nonspontaneous reactions between metal and ionic species using the Standard Reduction Potential tables provided.

1. A zinc metal strip is placed into a 1.0 mol/L solution of copper (II) nitrate

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Answer: The species available for reacting are: Zn^0 (aq), Cu^{2+} (aq), and NO_3^- (aq)

Zn^0 (aq) + Cu^{2+} (aq) + NO_3^- (aq) → ??????

NO_3^- (aq) ions will not react unless the solution is acidic. See table in appendix 3.
Cu^{2+} (aq) + $2e^-$ → Cu^0 (s)
Zn^{2+} (aq) + $2e^-$ → Zn^0 (s)

According to the table, Cu^{2+} has a greater affinity for electrons than Zn^{2+} and so Cu^{2+} will attract electrons to become reduced in the process to Cu^0. This causes Zn^0 to give up electrons and become oxidized to Zn^{2+}.

The 2 reactions are:

Cu^{2+} (aq) + $2e^-$ → Cu^0 (s)
Zn^0 (s) → $2e^-$ + Zn^{2+} (aq)
Cu^{2+} (aq) + Zn^0 (s) → → Cu^0 (s) + Zn^{2+} (aq) Net reaction and spontaneous

2. An aluminum strip of metal is placed into a 1.0 mol/ solution of silver nitrate

Answer: The species available for reacting are: Al^0 (s), Ag^+ (aq), and NO_3^- (aq)

Al^0 (s) + Ag^+ (aq) + NO_3^- (aq) → ??????

NO_3^- (aq) ions will not react unless the solution is acidic. See table in appendix 3.
Ag^+ (aq) + $1e^-$ → Ag^0 (s)
Al^{3+} (aq) + $3e^-$ → Al^0 (s)

According to the table, Ag^+ has a greater affinity for electrons than Al^{3+} and so Ag^+ will attract electrons to become reduced in the process to Ag^0. This causes Al^0 to give up electrons and become oxidized to Al^{3+}.

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The 2 reactions are:

$3[Ag^+(aq) + 1e^- \rightarrow Ag^0(s)]$
$Al^0(s) \rightarrow 3e^- + Al^{3+}(aq)$
$3Ag^+(aq) + Al^0(s) \rightarrow 3Ag^0(s) + Al^{3+}(aq)$

The first reaction is multiplied by 3 to balance the electrons lost and gained.

Net reaction and spontaneous

B. Have students use a redox tables to answer the following questions:

e.g. Answer the following questions about these species: Au^{3+} $Cr^0(s)$ Sr^{2+} Br^-

a)	the most easily reduced, i.e. strongest oxidizing agent	Au^{3+}
b)	the greatest affinity for electrons	Au^{3+}
c)	the least easily oxidized	Cr^0
d)	the most easily oxidized	Br^-
e)	which will oxidize Sn^{2+} to Sn^{4+}	Au^{3+}
f)	which will reduce $F_2(g)$ to $2F^-(aq)$	Br^- and Cr^0

C. In an investigation, similar to the one you did in class, strips of gold, silver, and tin were placed in beakers containing their ions and the following results obtained:

1) $Sn^0(s) + Ag^+(aq) \rightarrow$ metallic Ag deposited
2) $Au^{3+}(aq) + Sn^0(s) \rightarrow$ metallic Au deposited
3) $Au^0(s) + Ag^+(aq) \rightarrow$ no reaction

Arrange the ions used the investigation in order of decreasing tendency to attract electrons. (i.e. the species with the greatest affinity for electrons would be at the top)

Answer: Reaction one tells us that for the reaction to proceed as written, Ag^+ must have a greater affinity for electrons than Sn^{2+}, therefore Ag^+ must be above Sn^{2+} on a table that has the species with the greatest affinity for electrons at the top.

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Similarly reaction 2 tells us that for the reaction to proceed as written, Au^{3+} has a greater affinity for electrons than Sn^{2+}, therefore Au^{3+} must be above Sn^{2+} on a table that has the species with the greatest affinity for electrons at the top.

NOTE the reverse logic in this explanation that is of interest.

IF reaction 3 had produced products than using the same logic as in the previous 2 reactions, Ag^{+} would have been above Au^{3+} !!. However, the reaction did **not** go and so the reverse is true or Au^{3+} is above Ag^{+} .
The complete list of reactions or species having the greatest affinity for electrons would be as follows:
Au^{3+}, then Ag^{+}, then Sn^{2+}

OR $Au^{3+} + 3e^{-} \rightarrow Au^{0}(s)$
$Ag^{+} + 1e^{-} \rightarrow Ag^{0}(s)$
$Sn^{2+} + 2e^{-} \rightarrow Sn^{0}(s)$

D. Challenge question
Substances A, B, C, D, & E are metals that form positive ions. Ions of metal A react with metal E but not with metal C. However, metal C does react with solutions containing ions of metal D and B. Metal D will not react with ions of metal B.
List the METAL IONS placing the best oxidizing agent at the top.

Answer: Now students are becoming more familiar with logic used to arrange the various species, a shorter explanation will now be used. We will assume the easiest case where the metal ions are 1+

$A^{+} + E^{0} \rightarrow$ Rxn. Therefore A^{+} over E^{+}
$A^{+} + C^{0} \rightarrow$No rxn Therefore C^{+} over A^{+}
$D^{+} + C^{0} \rightarrow$ Rxn Therfore D^{+} over C^{+}
$B^{+} + C^{0} \rightarrow$ Rxn Therefore B^{+} over C^{+}
$B^{+} + D^{0} \rightarrow$ No rxn Therefore D^{+} over B^{+}

The species according to the best oxidizer first would be: D^{+}, B^{+}, C^{+}, A^{+}, E^{+}

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Learning Resources Links

Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005

Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005
Table 21.1 Activity Series of Metals (oxidation process) (664) (opposite of what is mentioned in teacher notes-stresses the reduction process)

Laboratory Manual Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005
46 Oxidation-Reduction Reactions (275)

Small-Scale Chemistry Laboratory Manual, Prentice Hall Chemistry, Waterman and Thompson, Pearson Education / Prentice-Hall, 2005
34 Determination of an Activity Series (241)

Chemistry 12 College Preparation, Davies *et* al, Thomson Nelson, 2004
5.3 Activity Developing an Activity Series of Metals (385)

Chemistry in Microscale 2nd edition, Book 1, Ehrenkranz and Mauch, Kendall / Hunt, 1996
Metal Reactivities (80)

Specific Learning Outcome

C12-6-03: Outline the historical development of voltaic (galvanic) cells.
Include: contributions by Alessandro Volta, Luigi Galvani (1 hour)

Skills and Attitudes:

C12-0-R1 Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, and other resource people
GLO: C2, C4, C6

C12-0-R2 Evaluate information obtained to determine its usefulness for information needs.
Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…
GLO: C2, C4, C5, C8

C12-0-R3 Quote from or refer to sources as required and reference information sources according to an accepted practice.
GLO: C2, C6

C12-0-N1 Explain the roles of theory, evidence, and models in the development of scientific knowledge
GLO: A1, A2

C12-0-N2 Describe, from a historical perspective, how the observations and experimental work of many individuals led to modern understandings of matter.
GLO: A1, A4

C12-0-N3 Describe how scientific knowledge changes as new evidence emerges and/or new ideas and interpretations are advanced.
GLO: A1, A2

Teacher Notes

Voltaic cells are electrochemical cells used to convert chemical energy into electrical energy. Voltaic cells are also called galvanic cells after Luigi Galvani.

Some information has been presented below about Galvani and Volta, however, it would be beneficial for students to conduct research themselves.

Luigi Galvani (1737-1798)-discovered that muscle contraction occurred from electrical stimulation. He believed that electricity was a natural entity which was produced only in animals. It had been found that a charge applied to the spinal cord of a frog could generate muscular spasms throughout its body. Charges could make frog legs jump even if the legs were no longer attached to a frog. While cutting a frog leg, Galvani's steel scalpel touched a brass hook that was holding the leg in place. The leg twitched. Further experiments confirmed this effect, and Galvani was convinced that he was seeing the effects of what he called animal electricity, the life force within the muscles of the frog.

Alessandro Volta (1745-1827) Italian physicist, studied under Galvani. Volta didn’t think that electricity was exclusive to animals so he set out to disprove Galvani’s hypothesis. In 1800, after extensive experimentation, he developed the voltaic pile, the original electric battery. The original voltaic pile consisted of a pile of zinc and silver discs and between alternate discs, a piece of cardboard that had been soaked in saltwater. A wire connecting the bottom zinc disc to the top silver disc could produce repeated sparks. No frogs were injured in the production of a voltaic pile. This disproved Galvani’s idea that animal electric fluid. The debate between Galvani and Volta was considered one of the more interesting episodes in the history of science.

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Research
Have students research the historical development of the voltaic (galvanic) cell and report their findings either individually or in small groups. The following Websites could be useful:

http://www.corrosion-doctors.org/Biographies/GalvaniBio.htm
http://www.energyquest.ca.gov/scientists/galvani.html
http://www.ieee-virtual-museum.org/collection/people.php?id=1234675&lid=1
http://www.italian-american.com/volta.htm

Net Research
The following URL shows some of the history of the electrochemical cell together with images of some of the original voltaic cells.
http://physics.kenyon.edu/EarlyApparatus/Electricity/Electrochemical_Cell/Electrochemical_Cell.html

Check the following URL for a very clear explanation of various electrochemical cells.
http://www.funsci.com/fun3_en/electro/electro.htm

In this URL there is a mouse rollover diagram that shows very the various parts of an electrochemical cell.
http://chimge.unil.ch/En/redox/1red13.htm

Activity/Demonstration
Have students build a lemon battery (see *Lemon Battery* p.662 Chemistry (Pearson) or *Discovery Battery* p.663 Chemistry Matter and Change).

Students can replicate Volta's experiment and make a voltaic pile. Have them alternate nickels and pennies and soaked pieces of cardboard (in salt water) and connect a lead from the bottom of the pile to the top of the pile. They can demonstrate how an electric current is generated. Students can place a zinc disc on the

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bottom of the pile, with an electrolyte-soaked filter paper in the middle and a copper disc on top (this "sandwich" is called an "element"). After building a stack of the six elements, and being careful that the solution does not drip down the side of the stack (this can cause a short circuit), two cables with alligator clips – one at the bottom and one at the top – can be used to measure the voltage between the bottom zinc disc and the top copper disc. It is possible to use the voltaic pile to try to power a small LCD clock, thermometer, or calculator.

Suggestions for Assessment

Paper and Pencil Tasks
Describe how electrochemistry is involved in producing energy in batteries.
(Science Notebook p.294 Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005)

Laboratory Skills
If students were asked to recreate Volta's experiment in the lab as either a demonstration or as an activity, lab skills would be assessed using the lab skill checklist available in the appendix.

Class Discussion
Brainstorm a list of items that require some type of battery.

Student presentation
Have students present their findings on the historical development of voltaic cells. A presentation rubric in the Appendix can be used to assess student presentations.

Journal Writing
Have students answer the following question:
What would be the effect of not having any kind of electrochemical cell? How would our lives change?

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After net research or student presentations, students could describe the research done by any of the scientists responsible for the development of electrochemical cells.

Visual Displays
Diagram and illustrate Volta’s voltaic pile. Explain why it produces an electric current.
These visual diplays would be assessed using the Visual Display rubrics provided in the Appendix.

Learning Resources Links

Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005

Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005
Voltaic Cells (Ch. 21) (665) shows Volta’s electric piles

Specific Learning Outcomes

C12-6-04: Explain the operation of a voltaic (galvanic) cell using at the visual, molecular and symbolic levels. Include: writing half-cell reactions, overall reaction and shorthand (line) notation. (1 hour)

C12-6-05: Construct a functioning voltaic (galvanic) cell and measure its potential. (1 hour)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-S4 Select and use scientific equipment appropriately and safely.
Examples: volumetric glassware, balance, thermometer…
GLO: C1, C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-A1 Demonstrate confidence in their ability to carry out investigations in chemistry.
GLO: C2, C5

Entry-Level Knowledge

One fourth of the grade 9 science course was devoted to the Nature of Electricity. In this detailed study of electricity, students related the particle model of electricity to atomic structure (outcome S1-3-04), constructed diagrams for electrical circuits (outcome S1-3-13), and used appropriate instruments to measure voltage (specific learning outcome S1-3-14). As a result, students will have prior information concerning electrical circuits; however, a review should be done.

Demonstration / Discrepant Event

A good demonstration to start the class is for the teacher to walk in drinking orange juice. After taking a sip, the teacher pours the remaining juice into a beaker in which there are two electrodes: one of magnesium metal and the other of copper. Both electrodes are connected to a large display clock. The clock starts running and the comment from the teacher is “we are now on the clock and we can begin the class”. An alternative demonstration might be to have a copper penny and a piece of clean zinc metal stuck into a lemon connected to either a voltmeter or a similar clock. The following URL provides some detail for the lemon clock.
http://www.funsci.com/fun3_en/electro/electro.htm#2

Teacher Notes

Students should be asked to explain the operation of electrochemical cells using the three modes of representation: visual (macroscopic), particulate (microscopic), and then symbolic.
An inspection of the approved texts as well as each of the suggested reference texts by Chang, Zumdahl and Silberberg shows that each text illustrates clear particulate diagrams of electrochemical cell processes.

After this section is presented, students should understand that a chemical reaction can be used to create an electric current. A voltaic cell is an apparatus that uses a spontaneous redox reaction to produce electrical energy. According to the law of conservation of energy, energy cannot be created nor destroyed; it is simply converted from one form of energy into another. In a voltaic cell, the chemical energy from a spontaneous redox reaction is converted into electrical energy.

Specific Learning Outcomes

C12-6-04: Explain the operation of a voltaic (galvanic) cell using at the visual, molecular and symbolic levels.
Include: writing half-cell reactions, overall reaction and shorthand (line) notation. (1 hour)

C12-6-05: Construct a functioning voltaic (galvanic) cell and measure its potential. (1 hour)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-S4 Select and use scientific equipment appropriately and safely.
Examples: volumetric glassware, balance, thermometer…
GLO: C1, C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-A1 Demonstrate confidence in their ability to carry out investigations in chemistry.
GLO: C2, C5

There are many chemical and electrical processes that occur in an electrochemical cell. Students must be able to explain the reactions in both half cells in terms of electron flow, anion flow, and cation flow.

The animations that have been recommended below will provide students with an appreciation of microscopic events and subsequent symbolic representations.

Students should first construct a spontaneous, working voltaic cell based on their understanding of the electromotive series discussed in outcomes C12-6-01 and C12-6-02. Students should have access to voltmeters, wire, alligator clamps, U tubes, cotton wool, a number of common metals together with 1.0 mol/L solutions of their ions, and a 1.0 mol/L solution of sodium, potassium, or ammonium nitrate to use in their salt bridge.

Have students write out the spontaneous reaction, identify the reduction reaction, the oxidation reaction, the two half cell reactions still using the redox table presented in previous outcomes. When spontaneity is confirmed by the teacher, each group of students should then construct their cell and measure the voltage across the electrodes.

Teachers should note that students will not likely achieve the predicted net E_{cell} voltage. According to the Nernst Equation, the maximum voltage is dependent on concentration and assumes that temperature is constant. Immediately after the connections are made concentrations will change. The reactant ions will decrease as they are used up and the product ions will increase as they are produced. Le Chatelier's Principle will then cause a stress on the system and attempt to reestablish equilibrium by the reverse reaction and reducing the net cell voltage. At this point, students should be asked what conditions would cause the equilibrium to shift forward and increase voltage.

A concentration gradient would occur at each electrode causing both an excess of one ion and a shortage of other ions for the net reaction.

Each of the approved texts provides a procedure for a good student investigation. The Pearson text provides a clearer particulate view of the processes occurring in the cell.

Specific Learning Outcomes

C12-6-04: Explain the operation of a voltaic (galvanic) cell using at the visual, molecular and symbolic levels. Include: writing half-cell reactions, overall reaction and shorthand (line) notation. (1 hour)

C12-6-05: Construct a functioning voltaic (galvanic) cell and measure its potential. (1 hour)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

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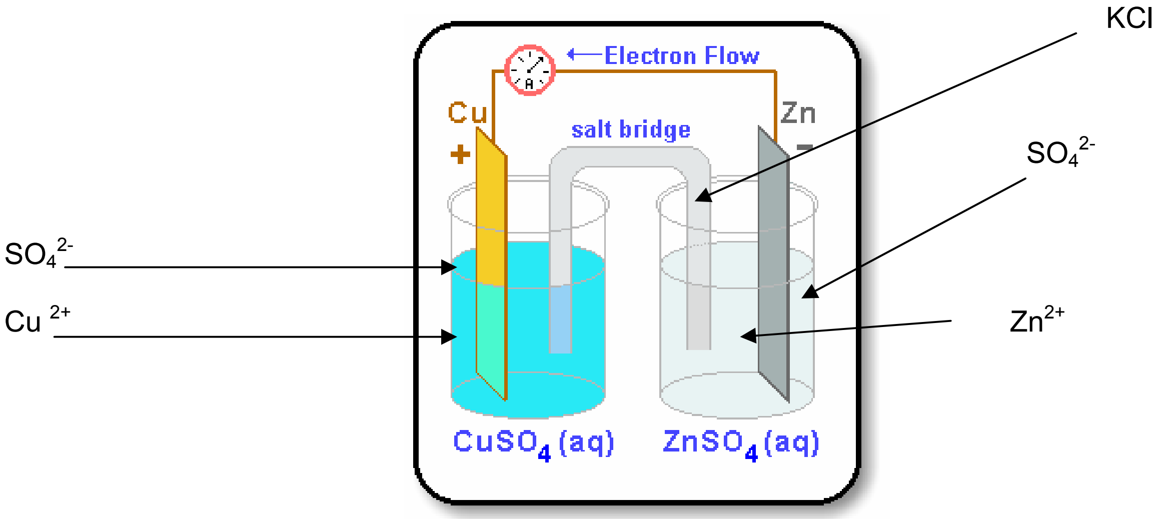
Examples: volumetric glassware, balance, thermometer…
GLO: C1, C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-A1 Demonstrate confidence in their ability to carry out investigations in chemistry.
GLO: C2, C5

The following diagram illustrates electrochemical cell for the following net reaction.

$$Cu^{2+}(aq) \quad + \quad Zn^{0}(s) \quad \rightarrow \quad Cu^{0}(s) \quad + \quad Zn^{2+}(aq) \quad + 1.10\ V$$



The above cell is a special case of an electrochemical cell. It was first successfully constructed by John Frederic Daniell (1790-1845). An Internet search will generate a significant amount of information if required. This particular electrochemical cell with Cu and Zn electrodes is now called a Daniell Cell.

In the diagram, the two half cell reactions are connected by a salt bridge. The salt bridge containing a soluble ionic salt like KCl is used as an internal circuit and allows the half cells to remain electrically balanced. In the case of this cell, as zinc ions are produced at the anode making the anodic compartment positive with an excess of positive ions, the Cl ions move from the salt bridge towards the anode to maintain electrical neutrality within that half cell. In the case of the cathodic copper cell, copper ions are being removed from the solution making it electrically negative. To counteract this, positive K ions from the salt bridge move towards the cathode to again maintain electrical neutrality within the cathodic cell. When the

Specific Learning Outcomes

C12-6-04: Explain the operation of a voltaic (galvanic) cell using at the visual, molecular and symbolic levels. Include: writing half-cell reactions, overall reaction and shorthand (line) notation. (1 hour)

C12-6-05: Construct a functioning voltaic (galvanic) cell and measure its potential. (1 hour)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-S4 Select and use scientific equipment appropriately and safely.
Examples: volumetric glassware, balance, thermometer…
GLO: C1, C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-A1 Demonstrate confidence in their ability to carry out investigations in chemistry.
GLO: C2, C5

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two half cells are joined with a wire path for the electrons and another path for the positive and negative ion movement, an electrochemical cell is made.

Each galvanic cell should consist of:

An anode (zinc) which oxidizes (loses e-).
A cathode (copper) which reduces (gains e-).

$Cu^{2+} + 2e^- \rightarrow Cu^0$ reduction reaction at the cathode (cations removed and limiting)
$Zn^0 \rightarrow Zn^{2+} + 2e^-$ oxidation at the anode (anions produced and excess)

Electrons flow from the anode to the cathode of an electrochemical cell.
Anions move toward the anode and cations move toward the cathode.

The migration of ions is essential to the operation of the cell since the accumulation of ionic charge in the solution around the electrodes would oppose the movement of electrons. The result is a voltage of +1.10V.

The same cell can be constructed with a porous cup acting as the salt bridge. Students should be given the opportunity to construct cells using either a salt bridge or a porous cup.

A short hand notation is often used to represent the voltaic cell diagram.

Reactant → Zn (s) | Product ↓ Zn^{2+} (1mol/L) || Reactant ↓ Cu^{2+} (1 mol/L) | Cu (s) ← Product

Zn (s) | Zn^{2+} (1mol/L) || Cu^{2+} (1 mol/L) | Cu (s) (many texts use M for mol/L)

Oxidation Half-cell — Reduction Half-cell

The single vertical line represents a phase boundary between the metal and the ion in solution.
The double vertical line represents the salt bridge. By convention, the anode is written first, to the left of the double lines and the cathode reaction is written second, to the right of the double lines.

Specific Learning Outcomes

C12-6-04: Explain the operation of a voltaic (galvanic) cell using at the visual, molecular and symbolic levels. Include: writing half-cell reactions, overall reaction and shorthand (line) notation. (1 hour)

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Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-A1 Demonstrate confidence in their ability to carry out investigations in chemistry.
GLO: C2, C5

Animations / Simulations

Department of Chemistry, Iowa State University
Electrochemical Cell Experiment (simulation)
This simulation helps the student create an electrochemical cell. The student has to select the electrodes and the ionic solutions needed to create a functioning electrochemical cell.
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/electroChem/volticCell.html

NCSSM Distance Learning Technologies
Electrochemistry
A set of six Flash animations **with narration** explaining how a voltaic cell works.
http://www.dlt.ncssm.edu/TIGER/chem6.htm#electro

Suggestions for Assessment

Paper and Pencil Tasks
Students must be able draw a diagram of a voltaic cell on which they identify the positive and negative electrodes, anode, cathode, half-reactions, direction of electron flow, direction of ion flow, solutions used, which electrode erodes, which electrode plates, the net cell reaction, and the voltage produced. Emphasis should be made to the particulate nature of matter when explaining electrode reactions, the movement of ions, and electrons through the circuit, and the maintenance of electrical neutrality in all parts of the cell.

Laboratory Skills
Students should be able to build and test simple voltaic cells. Lab skills should be assessed as necessary using the assessment rubrics found in the Appendix. Have students compare the results of their cells and explain differences in voltage. Try to have several groups of students using the same electrodes to ensure comparison of results.

Specific Learning Outcomes

C12-6-04: Explain the operation of a voltaic (galvanic) cell using at the visual, molecular and symbolic levels. Include: writing half-cell reactions, overall reaction and shorthand (line) notation. (1 hour)

C12-6-05: Construct a functioning voltaic (galvanic) cell and measure its potential. (1 hour)

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C12-0-A1 Demonstrate confidence in their ability to carry out investigations in chemistry.
GLO: C2, C5

Journal Writing
After an Internet research, students could describe the research done by any of the scientists responsible for the development of electrochemical cells.

Net Research
The following URL shows some of the history of the electrochemical cell together with images of some of the original voltaic cells.
http://physics.kenyon.edu/EarlyApparatus/Electricity/Electrochemical_Cell/Electrochemical_Cell.html

Check the following URL for a very clear explanation of various electrochemical cells.
http://www.funsci.com/fun3_en/electro/electro.htm

In this URL there is a mouse rollover diagram that shows very the various parts of an electrochemical cell.
http://chimge.unil.ch/En/redox/1red13.htm

Learning Resources Links
Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005
Ch.21.1 Voltaic Cells (663)

Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005
Ch.21.1 Voltaic Cells (665)

Small-Scale Chemistry Laboratory Manual, Prentice Hall Chemistry, Waterman and Thompson, Pearson Education / Prentice-Hall, 2005
36 Small-Scale Voltaic Cells (257)

Specific Learning Outcome

C12-6-06: Define standard electrode potential.
Include: hydrogen electrode as a reference. (0.5 hour)

C12-6-07: Calculate standard cell potentials. (1 hour)

C12-6-08: Predict the spontaneity of reactions using standard electrode potentials.

Skills and Attitudes Outcome

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3 (0.5 hour)

Entry-Level Knowledge

In the previous section treating specific learning outcomes C12-6-04 and C12-6-05, it was indicated that students in Grade 9 science worked with the principles of electricity at some depth, and to complement this prior knowledge, students have been discussing electron transfer for much of this year. However, each time a new layer of related knowledge is added to existing student knowledge, a review and assessment of student evolving student understandings is recommended. This is related to the notion of *learning transfer.*

Teacher Notes

When scientists first constructed voltaic (galvanic) electrochemical cells, they recorded net cell potentials that resulted from the reactions but they did not know how much each half cell contributed to the total net cell voltage. Many experiments were done in an attempt to determine the absolute E^0 for any half-cell reaction. Many ‘reference’ electrodes were tried before the hydrogen half-cell was chosen.

An excellent discussion of how and why chemists choose a standard electrode can be found in: *Chemistry: Experimental Foundations*, Published by Prentice-Hall Inc., Englewood Cliffs, New Jersey, Second Edition, 1975.

During their experiments, chemists found that not only did temperature affect the net cell potential, but so did the concentration of ions in solution and the pressure if a gas was used. Teachers should note that there is another term that is often used synonymously with cell potential, electromotive force, abbreviated to ***emf***.

Chemists chose the hydrogen electrode as the standard to which all other electrodes would be measured. Students will readily see that this choice was reasonable, if only for the reason that it appears in the middle of the table of standard electrode potentials.

In the hydrogen electrode shown below, hydrogen gas is bubbled into hydrochloric acid solution at 25˚C. The platinum electrode provided a surface on which the dissociation of hydrogen molecules can occur as well as serving as an electrical conductor to the external circuit. The diagram that follows it demonstrates the manner in which the hydrogen cell can then be used as a standard by which other metals’ electrode potential can be measured.

Specific Learning Outcome

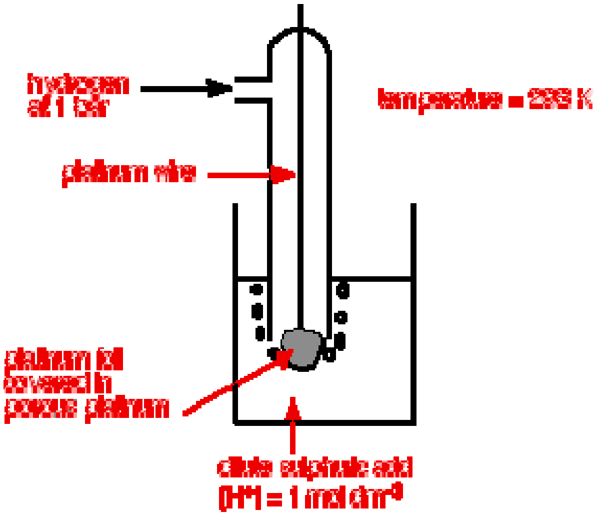
C12-6-06: Define standard electrode potential.
Include: hydrogen electrode as a reference. (0.5 hour)

C12-6-07: Calculate standard cell potentials. (1 hour)

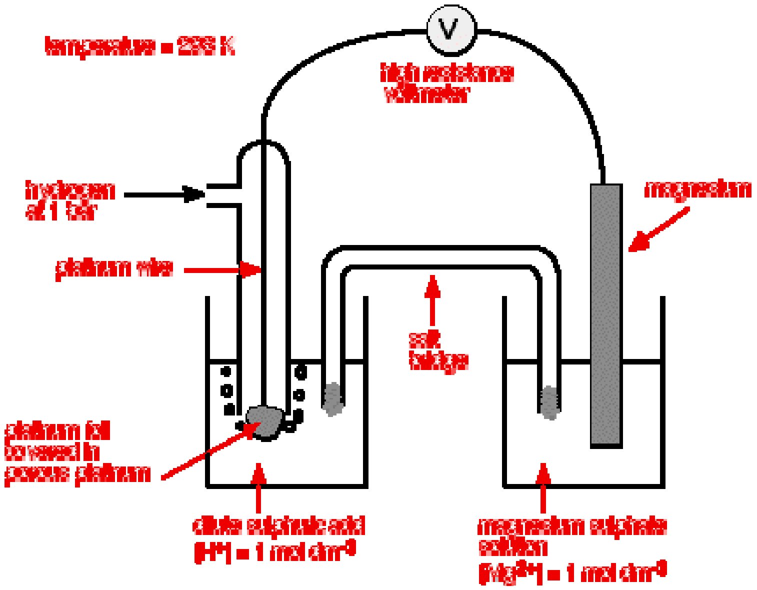
C12-6-08: Predict the spontaneity of reactions using standard electrode potentials.

Skills and Attitudes Outcome

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3 (0.5 hour)



Hydrogen Standard Cell
Used for Determining Electrode Potential for Magnesium



Source: http://www.moleclues.org/index

Specific Learning Outcome

C12-6-06: Define standard electrode potential.
Include: hydrogen electrode as a reference. (0.5 hour)

C12-6-07: Calculate standard cell potentials. (1 hour)

C12-6-08: Predict the spontaneity of reactions using standard electrode potentials.

Skills and Attitudes Outcome

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3 (0.5 hour)

Under standard conditions of 1 atm for hydrogen gas and 1 mol/L HCl, the potential for the reduction of H^+ at 25˚C is taken to be exactly zero.

$$2H^+\ (1\ mol/L)\ +\ 2e^- \rightarrow H_2\ (1\ atm) \qquad E^0 = 0\ v$$

The standard hydrogen electrode is often given the abbreviation SHE. Once the standard half-cell had been chosen, scientists were able to use this cell to determine the emf for all the other half-cell reactions on the electromotive series. These value were placed on a table with the half-cell reaction to produce a more useful table containing Standard Reduction Potentials.

e.g. A galvanic cell with a zinc electrode and a SHE. During the reaction, the zinc electrode looses mass that indicates that the zinc electrode half-cell reaction must be:

$$Zn\ (s) \rightarrow Zn^{2+}\ (aq) + 2e^-$$

The shorthand notation for this cell would be:

$$Zn\ (s)\ |\ Zn^{2+}\ (1\ M)\ ||\ H^+\ (1\ M)\ |\ H_2\ (1\ atm)\ |\ Pt\ (s)$$

The half-cell reactions:

anode (oxidation) $Zn\ (s) \rightarrow Zn^{2+}\ (1\ M) + 2e^-$
cathode (reduction) $2\ H^+\ (1\ M) + 2e^- \rightarrow H_2\ (1\ atm)$

net reaction $Zn\ (s) + 2\ H^+\ (1\ M) \rightarrow Zn^{2+}\ (1\ M) + H_2\ (1\ atm)$

By convention, the standard emf of the cell, E^0_{cell} that is composed of a contribution from the cathode and anode is given by:

$$E^0_{cell} = E^0_{cathode} - E^0_{anode}$$

$E^0_{cell} = E^0\,(H^+/H_2) - E^0\,(Zn^{2+}/Zn)$ (the voltage was measured for the cell at 0.76 V)

$0.76V = 0 - E^0\,(Zn^{2+}/Zn)$ solving for $E^0\,(Zn^{2+}/Zn)$

$E^0\,(Zn^{2+}/Zn) = -0.76\ V$

In a similar way, all electrode potentials were determined and placed together with their half–cell reactions on a table that chemists call the Standard Electrode Potentials.

Students should now be shown how to determine the net cell emf using half-cell reactions from the redox table of standard potentials.

Specific Learning Outcome

C12-6-06: Define standard electrode potential.
Include: hydrogen electrode as a reference. (0.5 hour)

C12-6-07: Calculate standard cell potentials. (1 hour)

C12-6-08: Predict the spontaneity of reactions using standard electrode potentials.

Skills and Attitudes Outcome

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3 (0.5 hour)

The table is organized according to a substances tendency to gain electrons. This tendency of a substance to gain electrons is its reduction potential. For every redox reaction, the half-reaction that is more positive will proceed as a reduction reaction and the half-reaction that is more negative will proceed as an oxidation reaction.

The Standard Reduction Potential Table is used to determine spontaneity and electrical potential of a given cell. Any positive cell potential value determined by finding the difference between the cathode and anode half-reaction potentials will result in a spontaneous redox reaction. Any negative cell potential value will indicate a non-spontaneous redox reaction.

Example
Calculate the cell potential for a silver-copper cell.

Solution
1. Find the half reactions for silver and copper from the reduction potentials table

$Cu^{2+}_{(aq)} + 2e^- \rightarrow Cu_{(s)}$ $E^o = +0.34$ V
$Ag^{+}_{(aq)} + 1e^- \rightarrow Ag_{(s)}$ $E^o = +0.80$ V

Since Ag^+ ions are more easily reduced than Cu^{2+} ions, the $Ag^{+}_{(aq)} + 1e^- \rightarrow Ag_{(s)}$ half reaction is the reduction half reaction and $Cu^{2+}_{(aq)} + 2e^- \rightarrow Cu_{(s)}$ needs to be reversed to become the oxidation half reaction. Another way of saying this is that the Ag^+ has a greater affinity for electrons than the Cu^{2+} ion and as a result the reaction with the lower + emf will become the oxidation reaction. When reversing any half reaction, the sign of the reduction potential is also reversed.

Therefore, the oxidation half reaction will be $Cu_{(s)} \rightarrow Cu^{2+}_{(aq)} + 2e^-$ $E^o = -0.34$ V

$Cu_{(s)} \rightarrow Cu^{2+}_{(aq)} + 2e^-$ $E^o = -0.34$ V oxidation
$Ag^{+}_{(aq)} + 1e^- \rightarrow Ag_{(s)}$ $E^o = +0.80$ V reduction

2. Substitute the half-cell potentials into the equation.

$$E^o_{cell} = E^o_{ox} + E^o_{red} = (-0.34\text{ V}) + (+0.80\text{ V}) = +0.46\text{ V}$$

This cell has a potential of + 0.46 V and confirms its spontaneity.

NOTE
Texts will often show two methods for the calculation of $E^0_{\ cell}$

$$E^o_{cell} = E^o_{ox} + E^o_{red}$$

Specific Learning Outcome

C12-6-06: Define standard electrode potential.
Include: hydrogen electrode as a reference. (0.5 hour)

C12-6-07: Calculate standard cell potentials. (1 hour)

C12-6-08: Predict the spontaneity of reactions using standard electrode potentials.

Skills and Attitudes Outcome

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3 (0.5 hour)

$E^o_{cell} = E^o_{cathode} - E^o_{anode}$

Either relationship will of course produce the correct result.

Students may also use the formula $E^o_{cell} = E^o_{red} - E^o_{ox}$ to obtain cell potential. Then they don't have to flip positive and negative signs before calculating values.

The latest edition of *Chemistry:* Chang, Raymond, Published by McGraw Hill Higher Education, Boston, Ninth Edition,2007,p 827 provides an excellent summary of information regarding the Standard Reduction Potential table.

Suggestions for Assessment

Paper and Pencil Tasks

A. Students should be able to answer questions about SHE

1. What was the necessity of finding the SHE?
   Answer: Any given pair of electrodes will give a specific cell emf but to compare the relative strengths and effects on cell dynamics, scientists needed to find a cell to which all others could be compared. Many reference cells were initially uses but the hydrogen cell conveniently fell in the middle of the table of potentials.

2. What would the table have looked like if another standard electrode were chosen other than SHE?
   Answer: If another cell were used instead of hydrogen, the reactions would still be in the same order of electron affinity, however, the new reference cell would be given the value of zero and all the others would be then compared to that cell. On either side of the new reference would be positive and negative numbers becoming larger moving away from the reference cell.

B. Students should be able to find the net cell potential of a given reaction or electrochemical cell and predict if the reaction is spontaneous and explain why.

Complete the following reactions based on a Standard Reduction Potential table. Calculate the net cell potential and indicate the reason why the reaction proceeds spontaneously as written. (Answers will vary depending on the tables used)

Specific Learning Outcome

C12-6-06: Define standard electrode potential.
Include: hydrogen electrode as a reference. (0.5 hour)

C12-6-07: Calculate standard cell potentials. (1 hour)

C12-6-08: Predict the spontaneity of reactions using standard electrode potentials.

Skills and Attitudes Outcome

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3 (0.5 hour)

1. Zn^0 (s) + Hg^{2+} (aq) → (Zn^{2+} + Hg^0(l)) E_{cell} = + 1.54 V
   This cell would run spontaneously. The net cell voltage is positive.

2. Cu^0 (s) + $2Ag^+$ (aq) → (Cu^{2+} + $2Ag^0$) E_{cell} = + 0.46 V
   This cell would run spontaneously. The net cell voltage is positive.

3. Mn^0(s) + 2 Cs^+ (aq) → No reaction E_{cell} = - 1.74 V
   This cell would not function. The net cell voltage is negative.

C. For each of the following situations, write balanced net ionic reactions, indicate the oxidation and reduction reactions, the cell emf, predict if the reaction is spontaneous and briefly explain why or why not.

1. In the middle ages, iron was used to make pots and pans. Could a solution of copper (II) acetate be stored in such an iron container? Explain your answer with reactions and a discussion of emf.

Answer: The acetate ion does not occur in the Standard Electrode Potential table and is therefore a spectator ion. The expected reaction will be:
Fe^0 + $2Cu^+$ → Fe^{2+} + Cu^0 E $_{cell}$ = + 0.96 V
As the net cell potential is positive, a reaction would occur spontaneously. It would not be a good idea to store the solution in an iron container.
The iron metal is oxidized to Fe^{2+}, the Cu^+ is reduced to elemental copper.

2. A solution of lead (II) nitrate solution is poured into a container in which a piece of zinc metal has been placed.

Answer: The nitrate ion only reacts when it is placed in an acidic solution, so in this example it will be a spectator ion. The expected reaction will be:
Zn^0 + Pb^{2+} → Zn^{2+} + Pb^0 E_{cell} = + 0.63 V
As the net cell potential is positive, a reaction will occur between the zinc metal and the lead solution.
The zinc metal is oxidized to Zn^{2+}, and the Pb^{2+} ion is reduced to metallic lead.

3. What metal container(s) could be used to safely hold a 0.20 mol/L solution of copper (1) acetate? Explain your answer.

Answer: The acetate ion does not appear in the Standard Electrode Potential table and so it will be a spectator ion.

Specific Learning Outcome

C12-6-06: Define standard electrode potential.
Include: hydrogen electrode as a reference. (0.5 hour)

C12-6-07: Calculate standard cell potentials. (1 hour)

C12-6-08: Predict the spontaneity of reactions using standard electrode potentials.

Skills and Attitudes Outcome

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3 (0.5 hour)

Cu^{+} appears in the following reduction reaction.
$Cu^{2+} + e^{-} \rightarrow Cu^{1+}$ $E^{0} = +0.15$
For a reaction to occur, the species must be on the non SI table above Cu^{+} and to the left for the net cell potential to be positive. So we must be looking for a metal below Cu^{+}. Possible containers in which a 0.20 mol/L solution of copper (1) acetate could therefore be: Pb^{0}, Sn^{0}, Ni^{0} , Co^{0}, Fe^{0}, Cr^{0}, etc.

Extension / Enrichment

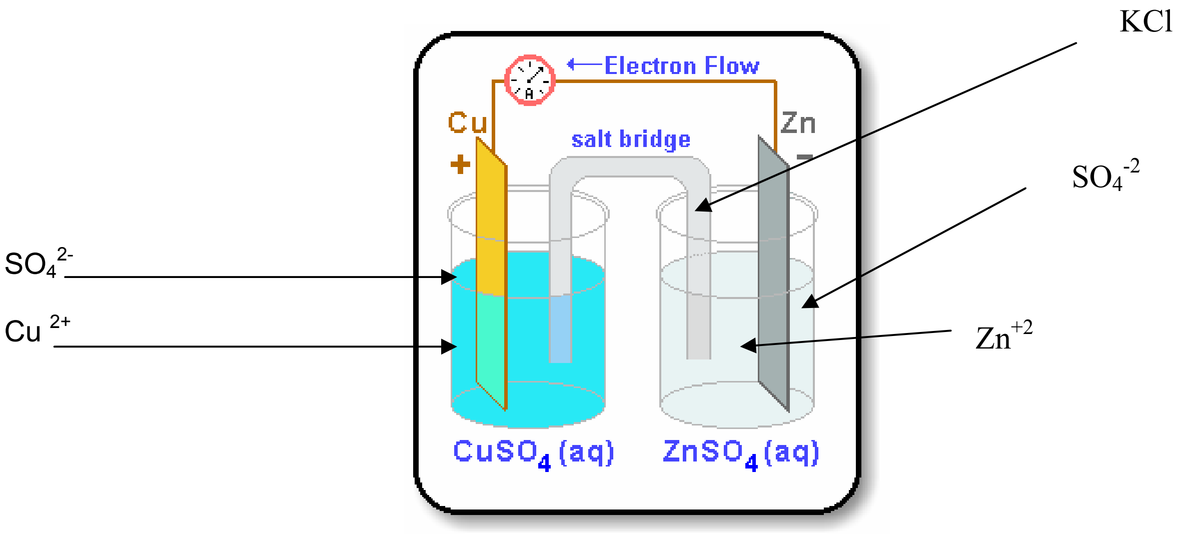
Students have used Le Chatelier’s Principle in their discussion of chemical equilibria in acid base chemistry, and solubility. Le Chatelier’s Principle applies equally to electrochemical cells.

Students already know that when a stress is placed on a system at equilibrium, the reaction shifts so as to off set or ameliorate the stress applied. After studying chemistry from grade 11 and grade 12, students know that as a reaction proceeds, the reactants decrease and the products increase. Have students consider what could be done to an electrochemical cell to prolong the voltage given that the initial emf will decrease over time.

The following example uses a Daniel cell to explore the effects of adding or removing substances from a system.

Recall that a Daniel Cell is a special case of a voltaic (galvanic) cell having the net reaction of:

$$Cu^{2+}(aq) + Zn^{0}(s) \rightarrow Cu^{0}(s) + Zn^{2+}(aq) + 1.10\ v$$



Specific Learning Outcome

C12-6-06: Define standard electrode potential.
Include: hydrogen electrode as a reference. (0.5 hour)

C12-6-07: Calculate standard cell potentials. (1 hour)

C12-6-08: Predict the spontaneity of reactions using standard electrode potentials.

Skills and Attitudes Outcome

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3 (0.5 hour)

Facts

- Immediately after the circuit is connected the voltage will begin to decrease from an emf of 1.10V
- The blue colour in the cathodic (reduction) cell due to the Cu^{2+} (aq) ion will become less dark as the ions are reduced to solid copper atoms that are deposited on the copper cathode.
- The concentration of Zn^{2+} (aq) ions will increase around the zinc anode

As a result, the concentration of reactants will continue to decrease and the concentration of products increase.

Effects to consider using Le Chatelier's Principle

- The addition of Cu^{2+} (aq) ions in any form using a soluble salt of Cu^{2+} (aq) will have tendency to more the equilibrium in the forward direction.
- The removal of Zn^{2+} (aq) ions by the addition of a precipitating anion will effectively remove soluble Zn^{2+} (aq) to a solid form that will precipitate e. g. sulphide ion S^-, forming solid ZnS, e.g. hydroxide OH^- ion forming solid $Zn(OH)_2$, etc.

Journal Writing/Process Notes

- Students could provide reasons for the great attention 'currently' being given to electrochemistry.
- Students could write the steps for the process of predicting whether any proposed redox reaction will occur spontaneously. (Notebook, Glencoe, p.287)
- Students could explain the difference between E_{cell} that are positive and E_{cell} that are negative. (Notebook, Glencoe, p.286)

Learning Resources Links

Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005
Table 21-1 Standard Reduction Potentials Table (667)

Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005
Table 21.2 Reduction Potentials Table (674)

Specific Learning Outcomes

C12-6-09: Compare and contrast voltaic (galvanic) and electrolytic cells. (0.5 hour)

C12-6-10: Explain the operation of an electrolytic cell at the visual, particulate, and symbolic levels. Include: a molten ionic compound; an aqueous ionic compound (1.5 hour)

C12-6-11: Describe practical uses of electrolytic cells.
Examples: electrolysis of water, electrolysis of brine, electroplating, production and purification of metals. (1 hour)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-U2 Demonstrate an understanding of chemical concepts.
Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…
GLO: D3

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

Entry-Level Knowledge

The following study of electrolytic cells complements the previous discussion of electrochemical cells. However, a review and assessment is always necessary to secure prior knowledge before a new layer of related information is added.

Teacher Notes

Demonstration

The electrolysis of water is always a good demonstration to begin the discussion of electrolytic cells even though it is generally a slow reaction.

The simplified schematic diagram below shows how a simple apparatus can be used for the decomposition of water. Many teachers will be familiar with the equipment on the right that is often found in chemistry labs. It is called the Hoffmann Apparatus and has been specially designed for the electrolytic decomposition of water. As water is a relatively poor conductor of water, the use of a 0.1 mol/L solution of either hydrochloric or sulphuric acids will speed up the reaction.

The addition of universal indicator to the acidic solution will cause a colour change when the reaction begins. The color will also make the difference in the volumes of gas produced more obvious to the observer.

The volume of gas is related to the empirical formula of water and therefore twice as much hydrogen gas is produced than oxygen gas. A glowing splint can be used to identify whether each gas is oxygen or hydrogen. If the splint glows brighter it is oxygen gas and if there is a "popping" sound then that gas tested is hydrogen.

Specific Learning Outcomes

C12-6-09: Compare and contrast voltaic (galvanic) and electrolytic cells. (0.5 hour)

C12-6-10: Explain the operation of an electrolytic cell at the visual, particulate, and symbolic levels.
Include: a molten ionic compound; an aqueous ionic compound (1.5 hour)

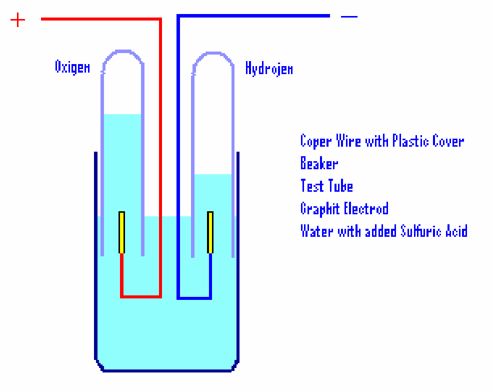
C12-6-11: Describe practical uses of electrolytic cells.
Examples: electrolysis of water, electrolysis of brine, electroplating, production and purification of metals. (1 hour)

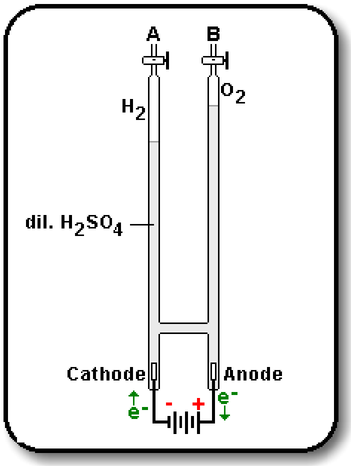
Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-U2 Demonstrate an understanding of chemical concepts.
Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…
GLO: D3

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2





Electrolysis is the process by which electrical energy is used to cause a non-spontaneous reaction to occur.

Specific Learning Outcomes

C12-6-09: Compare and contrast voltaic (galvanic) and electrolytic cells. (0.5 hour)

C12-6-10: Explain the operation of an electrolytic cell at the visual, particulate, and symbolic levels.
Include: a molten ionic compound; an aqueous ionic compound (1.5 hour)

C12-6-11: Describe practical uses of electrolytic cells.
Examples: electrolysis of water, electrolysis of brine, electroplating, production and purification of metals. (1 hour)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-U2 Demonstrate an understanding of chemical concepts.
Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…
GLO: D3

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

The following table compares electrolytic and electrochemical cells.

	Electrochemical Cell	**Electrolytic Cell**
Reaction Spontaneity	Spontaneous	Non-spontaneous
Cell Potential	Positive	Negative
Electricity	Produces	Consumes
Electrode Charge*	Cathode + Anode -	Cathode – Anode +
Cathode **Anode**	Reduction Oxidation	Reduction Oxidation
Change in Energy	Converts chemical energy to electrical energy	Converts electrical energy to chemical energy

*The discussion of electrode charge can be confusing to students. This should be a lower priority than the chemical processes that occur at each electrode.

Students should be required to describe the processes involved in these cells in terms of the various modes of representation just as they were for electrochemical cells. The particulate nature of matter is just as relevant and important with electrolytic cells. Students should be required to explain the complete operation of a working electrolytic cell in terms of the 3 modes of representation.

A labeled diagram of an electrolytic cell has been provided on the next page. Note the similarities to an electrochemical cell. One of the differences in the set up the apparatus is that in an electrolytic cell, both reactions occur in the same container, and a source of electricity is required to push the usually non-spontaneous to reaction to react.

Specific Learning Outcomes

C12-6-09: Compare and contrast voltaic (galvanic) and electrolytic cells. (0.5 hour)

C12-6-10: Explain the operation of an electrolytic cell at the visual, particulate, and symbolic levels.
Include: a molten ionic compound; an aqueous ionic compound (1.5 hour)

C12-6-11: Describe practical uses of electrolytic cells.
Examples: electrolysis of water, electrolysis of brine, electroplating, production and purification of metals. (1 hour)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-U2 Demonstrate an understanding of chemical concepts.
Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…
GLO: D3

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

The following items should be included in a diagram of an electrolytic cell: a container, an electrolytic solution (acid, base or salt), the two electrodes, an external electron "pump" (battery), positive electrode of battery connected to anode, negative electrode of battery connected to cathode. Half-cell reactions are still necessary as is the net reaction.

There are two different types of electrolytic cells. The more straightforward cell occurs when electricity is applied to a molten solution. The industrial applications of this particular cell will be discussed later. The second type of cell that is discussed here is when electricity is applied to an aqueous solution. This cell is complicated by the fact that there are many more species that can be oxidized and reduced.

A Electrolysis of Molten Solutions

Molten solutions are melted forms of the pure substance. Obviously, the cell container would be made of material that would withstand the high temperatures required to maintain the solution in the molten state. An industrial cell can be seen on the next page.

The negative side of the battery is connected to the cathode. As in an electrochemical cell, the cations move to wards the cathode and the anions to the anode according to the following reactions.

Anode (oxidation) $2Cl^- (l) \rightarrow Cl_2^0 (g) + 2e^-$

Cathode (reduction) $2Na^+ (l) + 2e^- \rightarrow 2Na^0 (l)$

Net reaction $2Na^+ (l) + 2Cl^- (l) \rightarrow 2Na^0 (l) + Cl_2^0 (g)$

Specific Learning Outcomes

C12-6-09: Compare and contrast voltaic (galvanic) and electrolytic cells. (0.5 hour)

C12-6-10: Explain the operation of an electrolytic cell at the visual, particulate, and symbolic levels.
Include: a molten ionic compound; an aqueous ionic compound (1.5 hour)

C12-6-11: Describe practical uses of electrolytic cells.
Examples: electrolysis of water, electrolysis of brine, electroplating, production and purification of metals. (1 hour)

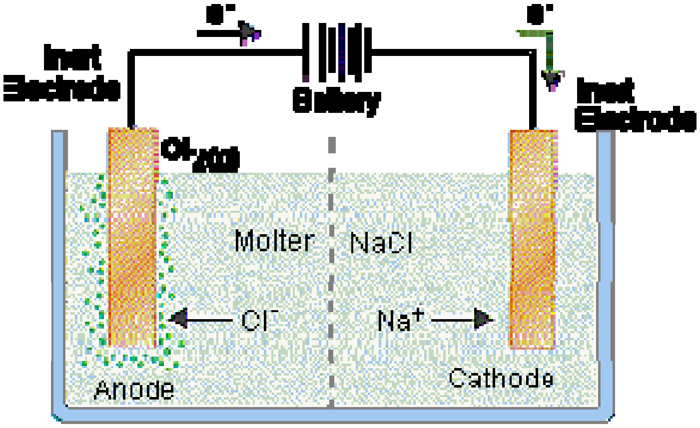
Skills and Attitudes Outcomes:

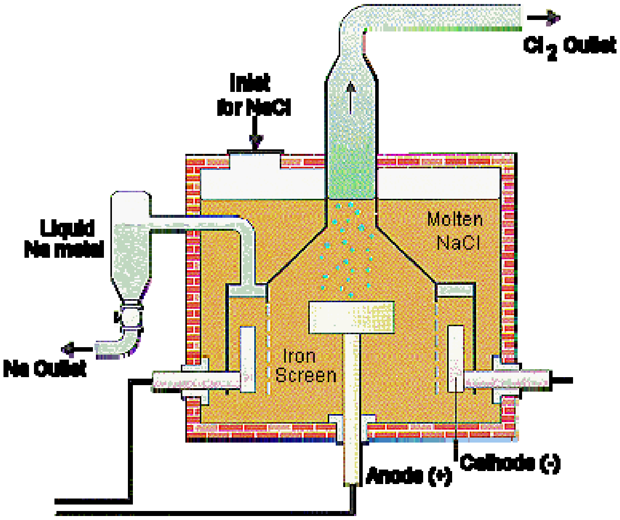
C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-U2 Demonstrate an understanding of chemical concepts.
Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…
GLO: D3

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

This reaction is used to produce pure supplies of sodium and chlorine gas. An industrial electrolytic cell can be seen in the right diagram.





Source: Manitoba Education, Citizenship and Youth, WebCT Chemistry 12

Specific Learning Outcomes

C12-6-09: Compare and contrast voltaic (galvanic) and electrolytic cells. (0.5 hour)

**C12-6-10: Explain the operation of an electrolytic cell at the visual, particulate, and symbolic levels.
Include: a molten ionic compound; an aqueous ionic compound (1.5 hour)**

**C12-6-11: Describe practical uses of electrolytic cells.
Examples: electrolysis of water, electrolysis of brine, electroplating, production and purification of metals. (1 hour)**

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-U2 Demonstrate an understanding of chemical concepts.
Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…
GLO: D3

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

B. Electrolysis of Aqueous Brine Solution

The explanation presented here is not for the faint of heart. Teachers should carefully review their own knowledge before teaching it to students. The presence of water adds additional species that could either oxidize or be reduced. An examination of the Standard Reduction Potential table shows that the following oxidation reactions could occur at the anode.

*1. $2Cl^- (aq) \rightarrow Cl_2^0 (g) + 2e^-$
2. $2H_2O (l) \rightarrow O_2 (g) + 4H^+ (aq) + 4e^-$

From the table we can see that both reactions have been reversed and so must be written as:

3. $Cl_2^0 (g) + 2e^- \rightarrow 2Cl^- (l)$ $E^0 = + 1.36$ V
4. $O_2 (g) + 4H^+ (aq) + 4e^- \rightarrow 2H_2O (l)$ $E^0 = + 1.23$ V

The half-cell emf values are close, but still indicate that for the reverse oxidation reaction, the $H_2O_{(l)}$ should be the first to be oxidized. However, it has been found experimentally that a much higher potential is required to oxidize water, and in fact $Cl_2^0{}_{(g)}$ is produced and NOT O_2 (g). The voltage required for the oxidation reaction in excess of the expected value is called the overvoltage. The causes of 'overvoltage' are very complex and beyond the consideration of even teacher background notes. In simplistic terms without any detail, a greater voltage is caused by difficulties encountered by the various species transferring electrons to atoms on the electrode/solution interface. As a result of this anomaly, E^0 values must be used cautiously in predicting the actual order of the oxidation or reduction of species in aqueous solutions.

Similarly, the following reduction reactions could occur at the cathode:

5. $2H^+ (aq) + 2e^- \rightarrow H_2^0 (g)$ $E^0 = 0.00$ V
*6. $2H_2O (l) + 2e^- \rightarrow H_2^0 (g) + 2OH^- (aq)$ $E^0 = - 0.83$ V
7. $Na^+ (aq) + 1e^- \rightarrow Na^0 (s)$ $E^0 = - 2.71$ V

Specific Learning Outcomes

C12-6-09: Compare and contrast voltaic (galvanic) and electrolytic cells. (0.5 hour)

C12-6-10: Explain the operation of an electrolytic cell at the visual, particulate, and symbolic levels. Include: a molten ionic compound; an aqueous ionic compound (1.5 hour)

C12-6-11: Describe practical uses of electrolytic cells.
Examples: electrolysis of water, electrolysis of brine, electroplating, production and purification of metals. (1 hour)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-U2 Demonstrate an understanding of chemical concepts.
Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…
GLO: D3

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

According to our redox table, the species that is most readily reduced is #5, however, in an aqueous salt solution at a pH of 7, the concentration of H^+ (aq) would be too low to consider at 1 x 10^{-7} mol/L. Consequently, the preferred reaction at the cathode would be #6
The reactions for the electrolysis of aqueous brine solution would be:

*Anode (oxidation) $2Cl^- (aq) \rightarrow Cl_2^0 (g) + 2e^-$
*Cathode (reduction) $2H_2O (l) + 2e^- \rightarrow H_2^0 (g) + 2OH^- (aq)$

Net reaction: $2H_2O (l) + 2Cl^- (aq) \rightarrow H_2^0 (g) + 2OH^- (aq) + Cl_2^0$ (g

Many useful reactions centre around the use of electricity to produce chemical changes. If time permits, students should be encouraged to research the application of electrolytic cells. According to the media fuel cells appear to be the energy of the future. The approved texts and each of the recommended reference text provide topical discussions of these cells.

1) Electrolysis of brine (a saturated solution of sodium chloride) for the purification of water and collection of sodium hydroxide, hydrogen and chlorine (Also known as the Chloro-Alkali Process).

2) Electrolysis of molten sodium chloride within a Down's cell to obtain elemental sodium and chlorine gas.

3) Aluminum metal is obtained by the electrolysis of aluminum oxide, which is refined from bauxite ore.

4) Extraction is the process by which a metal is obtained from an ore. Reactive metals, including lithium, beryllium, magnesium, calcium, and radium, are extracted industrially by the electrolysis of their molten chlorides.

5) Refining/purification occurs following extraction. During this process impurities are removed electrolytically to produce pure metals such copper or nickel. The result: 99.99% pure metals.

6) Electroplating coats an object with a thin layer of protective/decorative metal such as copper or silver.

Specific Learning Outcomes

C12-6-09: Compare and contrast voltaic (galvanic) and electrolytic cells. (0.5 hour)

C12-6-10: Explain the operation of an electrolytic cell at the visual, particulate, and symbolic levels.
Include: a molten ionic compound; an aqueous ionic compound (1.5 hour)

C12-6-11: Describe practical uses of electrolytic cells.
Examples: electrolysis of water, electrolysis of brine, electroplating, production and purification of metals. (1 hour)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-U2 Demonstrate an understanding of chemical concepts.
Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…
GLO: D3

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

7) Galvanizing is a process in which iron is covered with a protective layer of zinc.

8) Cathodic protection is a method of preventing rusting in which a more reactive metal (sacrificial anode) is attached to an object. This is used to protect ship hulls, oil and gas pipelines, boat motors, underground iron pipes and gasoline storage tanks.

Online demonstration showing the refining of several metals by electrolysis
http://www.physchem.co.za/Redox/Electrolysis.htm#Water

Activity / Demonstration

Students construct an electrolytic cell using a solution of copper (II) sulfate, copper metal strip, nickel or quarter, and 6V battery. The copper from the solution plates onto the nickel. Reversing the current removes the plated copper from the nickel.

Animation / Simulation

Department of Chemistry, Iowa State University

Electrolysis Electrochemical Cell Experiment (simulation)
This simulation allows the student to create an electrolytic cell using different types of metals and various ionic solutions. Voltage and current can be adjusted as can the mass of the electrode.

http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/electroChem/electrolysis10.html

Specific Learning Outcomes

C12-6-09: Compare and contrast voltaic (galvanic) and electrolytic cells. (0.5 hour)

C12-6-10: Explain the operation of an electrolytic cell at the visual, particulate, and symbolic levels.
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Examples: analogies, concept frames, concepts maps, manipulatives, molecular representations, role-plays, simulations, sort-and-predict frames, word cycles …
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GLO: D3

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

Suggestions for Assessment

Paper and Pencil Tasks
Students should be able to calculate the cell potential of electrolytic cells.
Students should be able draw a diagram of an electrolytic cell on which they identify the positive and negative electrodes, anode, cathode, half-reactions, direction of electron flow, direction of ion flow, solutions used, the cell reaction, which electrode erodes and which electrode plates.
Students should be required to explain the complete operation of a working electrolytic cell in terms of the 3 modes of representation: visual, particulate, and symbolic levels.

Compare and Contrast
Students can complete a compare and contrast think sheet for electrolytic and electrochemical cells.

Research Project
Students can research electrolytic processes by conducting an article review or creating a poster. Emphasis should be placed on local applications where relevant.

Learning Resources Links

Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005

Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005

Laboratory Manual Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005
21.2 Electroplating (165)

Laboratory Manual Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005
Lab 48 Electrochemistry (construct electrolytic cells) (287)

Specific Learning Outcomes

C12-6-09: Compare and contrast voltaic (galvanic) and electrolytic cells. (0.5 hour)

C12-6-10: Explain the operation of an electrolytic cell at the visual, particulate, and symbolic levels.
Include: a molten ionic compound; an aqueous ionic compound (1.5 hour)

C12-6-11: Describe practical uses of electrolytic cells.
Examples: electrolysis of water, electrolysis of brine, electroplating, production and purification of metals. (1 hour)

Skills and Attitudes Outcomes:

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
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Examples: use accurate scientific vocabulary, explain concepts to others, compare and contrast concepts, apply knowledge to new situations and/or contexts, create analogies, use manipulatives…
GLO: D3

C12-0-T3 Provide examples of how chemical principles are applied in products and processes, in scientific studies, and in daily life.
GLO: A5, B2

Specific Learning Outcome

C12-6-12: Using Faraday's law, solve problems related to electrolytic cells. (2 hours)

Entry-Level Knowledge

As was mentioned in an earlier in this topic in electrochemistry, students in Grade 9 Science 10F treated electricity at some detail. In the activities of the Grade 9 experience, students learned that the quantity of electric charge is equal of the product of the current and time. It can be useful for teachers to bring forth that prior knowledge in order to then set the stage for new understandings before proceeding with new learning experiences.

Teacher Notes

Michael Faraday (1791-1867) experimented extensively to determine the stoichiometric relationship between electric charge and chemical energy. He determined that the amount of substance produced or consumed in an electrolysis reaction is directly proportional to the quantity of electricity that flows through the circuit.

An ampere is defined as 1 coulomb flowing through a conductor in 1 second

Amperage = coulombs / second or rearranged as:

$Q = I\Delta t$

Q = charge (coulombs)
I = current (amperes)
Δt = change in time (seconds)

Faraday defined his constant as the quantity of electricity carried by a mole of electrons.

1 Faraday = Avogadro's Number x the charge on an electron
= $6.02 \times 10^{23} \cdot \text{mol}^{-1} \times 1.602192 \times 10^{-19}$ coulombs • electron^{-1}
= 96,484 coulombs • mole of electrons $^{-1}$ (usually rounded off for chemistry)

$$= \frac{96{,}500 \text{ coulombs}}{\text{mole of electrons}}$$

Combining these two relationships provides the chemist with a simplified way to calculate how much electricity is required to produce a mole of product at a given electrode. It is usually the cathode that interests us the most where a solid is deposited.

$$\text{Moles of electrons} = \frac{\text{amp x sec}}{96{,}500}$$

if we use the correct units for 96,500 as $96{,}500 \, \frac{\text{amp} \cdot \text{sec}}{\text{mole of electrons}}$

OR $96{,}500 \, \frac{\text{coulombs}}{\text{Mole of electrons}}$

We can use unit analysis to confirm our calculations and correct unit

The proportionality of ion charge to the grams liberated (deposited) from a solution (molten or aqueous salt) during the passage of 1 mole of electrons should be stressed to students.

Specific Learning Outcome

C12-6-12: Using Faraday’s law, solve problems related to electrolytic cells. (2 hours)

The following table illustrates the relationship between moles of electrons and the half-cell reactions.

Notice that with Mg^{2+} it requires twice as many moles of electrons (electricity) to discharge one mole of Mg than 1 mol of Na. Since there is 1 mole of electrons in a Faraday, only half a mole, or 12.2 g, of Mg metal is deposited. It requires 1 Faraday (96 500 coulombs) to discharge 1 mole of Na^+ ions, 2 Faradays of electricity to discharge 1 mole of Mg^{2+} ions and 3 Faradays to discharge 1 mole of Al^{3+} ions.

Solution or molten salt	**Ion**	**Oxidation number**	**Grams of element produced** **(gram equivalent weight)**
NaCl	Na^+	+1	23 g Na/Faraday
HCl	Cl^-	-1	35.5 g Cl/Faraday
$MgCl_2$	Mg^{2+}	+2	12.2 g Mg/Faraday (24.3 / 2)
A $l_2(SO_4)_3$	Al^{3+}	+3	9 g Al/Faraday (27 / 3)

Example 1

How many coulombs of current would be produced if 12.0 amp flow for 15.0 minutes?

$$\begin{aligned} Q &= I\Delta t \\ &= \text{amp x seconds} \\ &= 12.0 \text{ amp x } 15.0 \text{ min x } \frac{60 \text{ sec}}{\text{min}} \\ &= 10{,}800 \text{ coulombs} \end{aligned}$$

Example 2

If 7.85 amp flows through a molten solution of copper (I) chloride for 45.0 minutes, how many moles of electrons flow though the cell?

Half reaction $Cu^+ + 1e^- \rightarrow Cu^0$

$$\text{Moles of electrons} = \frac{\text{amp x sec}}{96{,}500}$$

$$\text{Moles of electrons} = \frac{7.85\ \cancel{\text{amp}} \text{ x } 45\ \cancel{\text{min}} \text{ x } 60\ \cancel{\text{sec}}}{96{,}500\ \cancel{\text{amp}} \bullet \cancel{\text{sec}} \bullet \text{mole of electrons}^{-1} \bullet \cancel{\text{min}}}$$

$$= 0.220 \text{ moles of electrons}$$

Specific Learning Outcome

C12-6-12: Using Faraday's law, solve problems related to electrolytic cells. (2 hours)

Example 3

Calculate the grams of zinc deposited if 5.00 moles of electrons pass through a zinc sulfate solution.

Solution

1. Write the reduction half reaction.

$$Zn^{2+} + 2\ e^{-} \rightarrow Zn$$

2. use the mole ratio from the reaction 2moles of electrons → 1 mole of Zinc metal

5 mol → x mol

$$x = 2.50\ \cancel{\text{mol}} \text{ x } 65.38\ \text{g} \cdot \cancel{\text{mol}}^{-1} \quad \text{or } 163.45 \text{ g or } 164 \text{ g to 3 sig figs}$$

Example 4

If 9.00 amp flows for 10.0 min through a molten silver fluoride solution, what mass of silver metal would be deposited at the cathode?

The cathode reaction: $Ag^{+}(aq) + 1e^{-1} = Ag^{0}(s)$

Therefore according to the stoichiometry of the reaction. 1 mol of electrons produces 1 mol Ag metal

$$\text{Mole of electrons} = \frac{\text{amp x sec}}{96{,}500}$$

$$= \frac{9.00\ \cancel{\text{amp}} \text{ x } 10.0\ \cancel{\text{min}} \text{ x }}{96{,}500\ \cancel{\text{amp}} \cdot \cancel{\text{sec}} \cdot \text{mol of electrons}^{-1} \cdot} \frac{60\ \cancel{\text{sec}}}{\cancel{\text{min}}}$$

$$= 0.0560 \text{ moles of electrons} \rightarrow 0.0560\ \cancel{\text{mol}} \text{ of Ag x } \frac{107.9\ \text{g}}{\cancel{\text{mol}}}$$

$$= 6.04 \text{ g of Ag to 3 sig figs}$$

Laboratory Activity

Students can perform a lab in which a potassium iodide solution is electrolyzed using carbon electrodes.

NOTE: Don't forget to have your students present the redox projects that they began preparing in Topic 1, Aqueous Reactions.

Suggestions for Assessment

Paper and Pencil Tasks

- Students should be able to calculate any one of the variables given all the other variables.
  e.g. Find mass given the cathode reaction, amperage, and time,
  e.g. Find the time required to deposit a given mass of metal at the cathode given, amperage and the cation.
  e.g. Find the amperage required to deposit a given mass of metal at the cathode for a given time period.
  e.g. Find the volume of gas generated at the anode given the amperage, time , gas produced and the temperature and pressure of the gas liberated.

Specific Learning Outcome

C12-6-12: Using Faraday's law, solve problems related to electrolytic cells. (2 hours)

Journal Writing

- Have students write an account of the various industrial uses of electrolytic cells
- Have students discuss the environmental effects of an electrochemical cell to manufacture pure elements.

Learning Resources Links

Chemistry, Raymond Chang (8th edition), McGraw-Hill Higher Education, 2005

Chemistry, Zumdahl *et al*, Houghton-Mifflin, 2005

Essential Experiments for Chemistry, Morrison & Scodellaro, SMG Lab Books, 2005
Experiment 14E Electrolytic Cells (256)