

Chemistry 3102C

Acid/Base Reactions & Electrochemistry

Curriculum Guide

Prerequisite: Chemistry 3102B

Credit Value: 1

Chemistry Concentration

Chemistry 1102
Chemistry 2102A
Chemistry 2102B
Chemistry 2102C
Chemistry 3102A
Chemistry 3102B
Chemistry 3102C

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To the Instructor

I. Introduction to Course 3102C

The first part of this course further develops student knowledge of acids and bases by studying how equilibrium concepts for K_c apply to weak acids and bases. Students will also study the process of neutralization and use it to develop analytical skills through the use of titrations.

The second part of the course covers electrochemistry and is generally of great interest to students as they all tend to know something about corrosion, batteries and electroplating. Most students enjoy the later part of the electrochemistry section, once they have passed through the theoretical material in the beginning.

Students taking this course need to know how to solve for unknowns and use a scientific calculator.

II. Curriculum Guides

Each new ABE Science course has a Curriculum Guide for the instructor and a Study Guide for the student. The Curriculum Guide includes the specific curriculum outcomes for the course. Suggestions for teaching, learning, and assessment are provided to support student achievement of the outcomes. Each course is divided into units. Each unit comprises a **two-page layout of four columns** as illustrated in the figure below. In some cases the four-column spread continues to the next two-page layout.

Curriculum Guide Organization: The Two-Page, Four-Column Spread

Unit Number - Unit Title		Unit Number - Unit Title	
Outcomes Specific curriculum outcomes for the unit.	Notes for Teaching and Learning Suggested activities, elaboration of outcomes, and background information.	Suggestions for Assessment Suggestions for assessing students' achievement of outcomes.	Resources Authorized and recommended resources that address outcomes.

To the Instructor

III. Study Guides

The Study Guide provides the student with the name of the text(s) required for the course and specifies the sections and pages that the student will need to refer to in order to complete the required work for the course. It guides the student through the course by assigning relevant reading and providing questions and/or assigning questions from the text or some other resource. Sometimes it also provides important points for students to note. (See the *To the Student* section of the Study Guide for a more detailed explanation of the use of the Study Guides.) The Study Guides are designed to give students some degree of independence in their work. Instructors should note, however, that there is much material in the Curriculum Guides in the *Notes for Teaching and Learning* and *Suggestions for Assessment* columns that is not included in the Study Guide and instructors will need to review this information and decide how to include it.

IV. Resources

Essential Resources

Chemistry: Mustoe, Jansen, et al; McGraw-Hill Ryerson, 2004.
McGraw-Hill Chemistry Teacher's Resource (including CD-ROM)

Recommended Resources

Chemistry 3202 Curriculum Guide:
http://www.ed.gov.nl.ca/edu/sp/chem_3202.htm

Other Resources

Center for Distance Learning and Innovation: <http://www.cdli.ca/>

Access Excellence Resource Center:
<http://www.accessexcellence.org/RC/chemistry.html>

Virtual Chemistry: <http://neon.chem.ox.ac.uk/vrchemistry/>

To the Instructor

V. Recommended Evaluation

Written Notes	10%
Labs/Assignments	20%
Test(s)	20%
Final Exam (<i>entire course</i>)	<u>50%</u>
	100%

The overall pass mark for the course is 50%.

Acid/Base Reactions & Electrochemistry

Unit 1 - Acid - Base Equilibria

Outcomes

- 1.1 Compare strong and weak acids and bases using the concept of equilibrium.
- 1.1.1 Explain the difference between monoprotic and polyprotic acids.
- 1.1.2 Define K_a and K_b qualitatively and write the equilibrium constant expression from the equation of reaction with water.
- 1.1.3 Understand that the strength of acid/base systems is described by percent ionization and K_a (or K_b).
- 1.1.4 Define a buffer according to both its components and its function.
- 1.1.5 Recognize that blood is a buffer and that without this natural buffering, homeostasis would not be maintained.

Notes for Teaching and Learning

Students should realize that K_a and K_b are simply equilibrium constants applied specifically to acids and bases respectively. Students should define K_a and K_b qualitatively and relate their values to their strength. Students should write appropriate K_a and K_b equilibrium constant expressions, knowing that water as a liquid is omitted in the equilibrium expression.

K_a and K_b are expressions using the same format as that used for the equilibrium constant, K_c . Point out to students that the same expression is used, but the subscript is changed.

Students are not expected to complete the problems in section 15.1.

A buffer solution is a combination of either a weak acid and its conjugate base or a weak base and its conjugate acid. The conjugate acid or base is usually supplied by dissolving an appropriate salt in solution. Buffer solutions react to a small amount of added acid or base in a way that minimizes the fluctuation in pH value. See the Teaching Strategies in the *Teacher's Resource* for description of an easy way to demonstrate buffer solutions.

Unit 1 - Acid - Base Equilibria

Suggestions for Assessment

Students could investigate how the pH of human blood remains extremely constant. (Hint: $[\text{HCO}_3^- (\text{aq})]$ ions are present.)

Instructors should check student answers to questions 1.1 - 1.7 in the Study Guide.

Resources

MGH Chemistry, pages 582 - 597.

Teacher's Resource for MGH Chemistry (including CD-ROM).

Website for the text:
<http://www.mcgrawhill.ca/school/booksites/chemistry/index.php>

Department of Education website:
http://www.ed.gov.nl.ca/edu/science_ref/chem3202.htm

The centre for distance learning and innovation website:
<http://www.cdli.ca/>

Unit 2 - Acid - Base Titrations

Outcomes

- 2.1 Explain how acid-base indicators function.
 - 2.1.1 Define neutralization reaction and salt.
 - 2.1.2 Define acid/base indicators operationally.
 - 2.1.3 Define acid/base indicators theoretically.
 - 2.1.4 Perform calculations involving neutralization reactions.
- 2.2 Demonstrate an understanding of the titration process.
 - 2.2.1 Define titration.
 - 2.2.2 Describe the process of a titration.
 - 2.2.3 Define primary standard and recognize its importance in a titration procedure.
 - 2.2.4 Differentiate between indicator end point and equivalence (stoichiometric) point.

Notes for Teaching and Learning

Students should know the terminology involved with titrations: pipette, burette, endpoint, equivalence point, primary standard, standard solution, standardization and indicator.

In evaluating the lab reports of titration experiments, instructors may consider allocating marks to precision in repeated trials and/or quality of endpoints obtained using observation and checklists.

Instructors should ensure that students understand that the accuracy of the titration process is dependent upon the accuracy of the primary standard, standard solution, and specialized glassware. Instructors could use the titration process as an excellent illustration of the difference between accuracy and precision. Students should understand the importance of obtaining titration data within a given volume range for several trials (textbooks may vary in their acceptable ranges).

Instructors should also stress that the best end point is one which has the slightest detectable permanent color change. For example, when using a phenolphthalein indicator which changes from colourless to pink with added base, a very slight pink, not a intense pink indicates the endpoint.

Students should compare the qualitative term, endpoint, with the quantitative term, equivalence point.

Unit 2 - Acid - Base Titrations

Suggestions for Assessment

Neutralization is a process that is controlled in lab experiments. Teachers could ask students: "How do you think this process works?" or "Does it work in other environments, such as a lake or your stomach?"

Students could examine diagrams of apparatus used in titrations and describe the use of each. Examples should include the burette and Erlenmeyer flask

Instructors could observe student use of the equipment in an acid-base titration and allow students to practice the safe and efficient use of the equipment.

Instructors could ask students: "Why is a burette, not a graduated cylinder, used in a titration?"

Instructors could ask students: "What is equivalence point? endpoint?" and "Why is it important that both occur at approximately the same pH in a titration?"

If a titration between a weak acid and a strong base has an equivalence point pH of 9.5, students could determine which indicators could be used to detect the equivalence point of the titration.

Students could determine which indicators would work best for a titration with

- an equivalence point at a pH of 4.0
- a weak base with a strong acid

They should use an indicator chart as a reference and justify their choice.

Resources

MGH Chemistry, pages 599 - 607.

MGH Chemistry, Appendix E, Table E-19, "End-Point Indicators", page 849.

MGM Teacher's Resource CD-ROM, Solutions Manual.

Unit 3 - Oxidation - Reduction

Outcomes

- 3.1 Define oxidation and reduction theoretically.
- 3.1.1 Define the terms: oxidation, reduction, oxidizing agent, reducing agent and half-reaction
- 3.1.2 Define oxidation and reduction in terms of the loss or gain of electrons.
- 3.1.3 Identify redox reactions.
- 3.1.4 Identify the species oxidized or reduced in a redox reaction.
- 3.1.5 Identify the oxidizing and reducing agents in a redox reaction.
- 3.1.6 Write half-reactions from balanced chemical reactions for oxidation reduction systems.
- 3.1.7 Investigate oxidation reduction reactions.
- 3.1.8 Determine the relative activities of metals from single displacement reactions.

Notes for Teaching and Learning

Students should understand from the beginning that electrochemistry involves the study of all reactions in which transfer of electrons takes place. Some of these reactions produce electricity for our use (e.g. batteries) while others need electrical energy to occur (e.g. electrolysis of water). However, many electrochemical reactions occur where no electricity is produced or used (e.g. $\text{Na} + \frac{1}{2} \text{Cl}_2 \rightarrow \text{NaCl}$).

The transfer of electrons may be illustrated using simple Bohr models to show formation of Na^+ from Na and Cl^- from Cl and the resulting electron loss and gain.

One way to begin this topic is to ask students to observe an electrochemical reaction. A simple one is to place a strip of zinc metal in a CuSO_4 solution. Copper metal forms on the surface of the zinc, zinc metal disappears, and the blue color of the Cu^{2+} ions fades. The two half-reactions represent electron loss and electron gain at the zinc surface. These can be determined, along with the overall reaction, by doing questions similar to the following:

e.g. What happened to the Cu^{2+} ions? They changed to Cu metal.

What is the equation for this? $\text{Cu}^{2+} + \text{Cu}$

How can this occur? Cu^{2+} gains two electrons.

Is the equation balanced? It is not balanced for charge but it can be balanced using the two electrons lost as follows:

$\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}$ This is one half reaction.

Where do the two electrons come from?

The Zn as it changes to Zn^{2+} in solution.

What is the second half reaction? $\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$

At this point the definitions of oxidation and reduction can be introduced using the two half-reactions above as examples. The mnemonics OIL (Oxidation Involves Loss) and RIG (Reduction Involves Gain) can be introduced to help students remember the meaning of both terms.

Unit 3 - Oxidation - Reduction

Suggestions for Assessment

Instructors could:

- Give the student an equation and ask if it is a redox reaction.
- Give balanced redox equations and ask the student to identify the element oxidized, and reduced as well as the oxidizing and reducing agent

e.g. $\text{Cl}_2 (\text{aq}) + 2 \text{KBr} (\text{aq}) \rightarrow \text{Br}_2 (\text{aq}) + 2 \text{KCl} (\text{aq})$
- Also, for equations like the one above, ask the student to break it into an oxidation half-reaction and a reduction half-reaction.
- Assign some extra problems found on the CDLI site.
- List examples of redox reactions that might occur in the home.

Students are to complete and submit Investigation 18-A, “Single Displacement Reactions” and submit a lab report. The report should be used as part of the evaluation for this course.

The Teacher’s Resource provides tips for the lab and all the answers to the lab questions.

Resources

MGH Chemistry: pages 712-719.

MGH Chemistry
Teacher’s Resource:
pages 273-283.

ww.cdli.ca
Chemistry 3202: Unit 04:
Section 01: lesson 01.

Core Lab:
Investigation 18-A,
“Single Displacement
Reactions”, pages 718-
719.

Unit 3 - Oxidation - Reduction

Outcomes

3.2 Students will understand and use the concept of oxidation number.

3.2.1 Define oxidation number.

3.2.2 Use rules to determine the oxidation number of an element.

3.2.3 Identify the species oxidized or reduced using oxidation numbers.

3.2.4 Identify if a reaction is a redox reaction using oxidation numbers.

Notes for Teaching and Learning

Thought Lab: Finding Rules for Oxidation Numbers can be used with students to help introduce them to the rules.

Remind students that elements do not actually possess the value of the oxidation number i.e. C is not +4 in CO_2 . Oxidation numbers are a tool to help in understanding electrochemistry.

Instructors should note that a common error by students is to assign oxidation, reduction, oxidizing agent and reducing agent with four different substances (reactants and products) involved in a redox reaction. It is important for students to remember that oxidation, reduction, oxidizing agent and reducing agent only involve the reactants.

Students should learn the oxidation number rules and be able to apply them to determine the oxidation number of all species in molecules or ions. By applying oxidation number rules to equations, students should be able to predict if the reaction is an oxidation-reduction reaction or not. Using the numbers assigned to individual species, they should be able to identify the species oxidized, species reduced, oxidizing agent and reducing agent.

Unit 3 - Oxidation - Reduction

Suggestions for Assessment

Instructors should check students' answers all questions from the Study Guide.

Instructors could assign extra problems from the Section Review, Chapter Review and/or Unit Review of the text or from the "Additional Practice Problems" on the Teacher's Resource CD-ROM.

Instructors will also find extra problems on the CDLI (Center for Distance Learning and Innovation) site.

Resources

MGH Chemistry: pages 721-729.

MGH Chemistry Teacher's Resource: pages 284-287.

MGH Teacher's Resource, CD-ROM.

www.cdli.ca
Chemistry 3202: Unit 04:
Section 01: lesson 02.

MGH Teacher's Resource, CD-ROM.

Unit 3 - Oxidation - Reduction

Outcomes

3.3 Write and balance redox reactions.

3.3.1 Balance half reaction for acidic solutions.

3.3.2 Use balanced half reactions to balance redox reactions in acidic solution.

Notes for Teaching and Learning

Many oxidation reduction processes require acids or bases. This course restricts itself to acidic media.

Students may need help understanding how the rules apply to an equation. They may need to work through several examples with their instructor before they are ready to solve these problems on their own.

Investigation 18-B could be completed to give students concrete examples of redox reaction involving acids.

Unit 3 - Oxidation - Reduction

Suggestions for Assessment

Extra problems are on the CDLI site.

Other textbooks and the web have many redox equations for balancing. (Careful the questions chosen are reasonable!)

Problems 1 to 21 on pages 751-753 of the text provide addition questions, (omit those in basic solution).

Students could be provided with a copy of BLM 18-1, “The Half-Reaction Method of Balancing Equations”, for practice.

BLM 18-3, “Chapter 18 Test”, also includes questions that could be used for practice.

Resources

MGH Chemistry: pages 730-741.

MGH Chemistry
Teacher’s Resource:
pages 287-291.

www.cdli.ca
Chemistry 3202: Unit 04:
Section 01: lesson 03.

BLM 18-1, “The Half-Reaction Method of Balancing Equations”,
BLM 18-3, “Chapter 18 Test”.

Unit 4 - Electrochemical and Electrolytic Cells

Outcomes

- 4.1 Understand how oxidation-reduction reactions can be a source of electricity.
- 4.1.1 Explain what is meant by a spontaneous redox reaction.
 - 4.1.2 Identify the components of a galvanic cell and describe how they work.
 - 4.1.3 Determine half-cell reaction, the direction of current flow, electrode polarity, cell potential, and ion movement in a galvanic cell.
 - 4.1.4 Build galvanic cells in the laboratory.
 - 4.1.5 Use electrochemical cell notation to represent an electrochemical cell.
 - 4.1.6 Describe the construction of primary and secondary batteries.

Notes for Teaching and Learning

Note that the positions of the anode and cathode are switched in Figure 19.5 on page 759 of the text. This is to avoid the misconception that a diagram must always show the anode on the left.

See the Teacher's Resource for suggested Teaching Strategies for Section 19-1, Galvanic Cells, and for tips for carrying out the lab.

Full solutions for all Practice Problems are in the solutions manual on the Teacher's Resource CD-ROM.

Unit 4 - Electrochemical and Electrolytic Cells

Suggestions for Assessment

Investigation 19-A should be completed and a lab report submitted. The report should be used as part of the evaluation for the course.

BLM 19-9, “Galvanic Cell Notation”, can be used to give students extra practice working with shorthand notation for galvanic cells.

Resources

MGH Chemistry: pages 756-764

MGH Chemistry
Teacher’s Resource:
pages 299-303.

Core Lab:

Investigation 19-A,
“Measuring Cell
Potentials of Galvanic
Cells”, pages 762-763.

BLM 19-1, “Galvanic
Cell Notation”.

Unit 4 - Electrochemical and Electrolytic Cells

Outcomes

- 4.2 Understand standard cell potentials.
- 4.2.1 Describe the use of the hydrogen half-cell as a reference.
 - 4.2.2 Predict cell voltage using a table of Standard Half-Cell Potentials.
- 4.3 Understand the process of electrolysis.
- 4.3.1 Determine if an oxidation-reduction reaction is spontaneous using a table of standard half-reaction
 - 4.3.2 Identify the components of an electrolytic cell and describe how they work.
 - 4.3.3 Explain the process of electrolysis and electroplating.
 - 4.3.4 Determine oxidation and reduction half-cell reactions, direction of current flow, electrode polarity, cell potential and ion movement for electrolysis of molten salts.

Notes for Teaching and Learning

Although the text presents two methods of calculating standard cell potentials, the subtraction method is preferred. It emphasizes that only the difference has meaning and it avoids the need to explain why you do not change the potential when you multiply the equation by a numerical coefficient.

Electrolytic cells are essentially the reverse of galvanic cells. An external source of current induces a non-spontaneous redox reaction. In an electrolytic cell, oxidation occurs at the anode and reduction occurs at the cathode. The anode has a positive charge, and the cathode has a negative charge.

Unit 4 - Electrochemical and Electrolytic Cells

Suggestions for Assessment

BLM 19-2, “Electrolytic Cells and Galvanic Cells”, can be copied and worked through with students to review the similarities and differences between electrolytic cells and galvanic cells.

Resources

MGH Chemistry: pages 768-775, 776-777; 794-795.

MGH Chemistry
Teacher’s Resource:
pages 303-305; 309-311.

BLM 19-2, “Electrolytic Cells and Galvanic Cells”.

Unit 4 - Electrochemical and Electrolytic Cells

Outcomes

4.4 Understand and use Faraday's Law.

4.4.1 Describe the relationship between time, current and the amount of substance produced or consumed in an electrolytic process.

4.4.2 Solve problems using Faraday's Law.

4.4.3 Investigate Faraday's Law by performing an electroplating process in the laboratory.

4.4.4 Define metallurgy, pyrometallurgy and hydrometallurgy.

4.4.5 Differentiate between mineral and ore.

4.4.6 Explain what is meant by the terms extraction and refining

4.4.7 Assess some environmental issues associated with the refining of metals.

Notes for Teaching and Learning

Using Faraday's Law and stoichiometry, the amount of products produced by an electrolytic cell can be determined. Faraday's Law determines the number of moles of electrons which pass through a cell when a particular current is applied over a period of time. Current (in amperes) multiplied by time (in seconds) gives the total charge, in coulombs, carried by the electrons. Faraday's Constant ($F = 96\,500$ coulombs/mole) gives the charge on 1 mole of electrons, therefore by dividing, the moles of electrons are obtained.

$$n = \text{moles } e^- = \frac{\text{current (amp)} \times \text{time (sec)}}{\text{Faraday's constant}} = \frac{I \times t}{F}$$

Using stoichiometry and the appropriate half reaction occurring, the amount of product produced can be determined. For example, calculate the moles of Mg produced when a current of 60.0 A is passed through a magnesium chloride solution for 4.00 hours.

Unit 4 - Electrochemical and Electrolytic Cells

Suggestions for Assessment

Investigation 19-C should be completed and a report submitted.

Assignment, “From Mineral to Metal: Metallurgy and Electrolytic Refining”, should be completed and submitted. Instructors may require completion of questions in addition to those mentioned in the Study Guide.

Both the Lab Report and the assignment should be used as part of the evaluation for the course.

BLM 19-3, “Chapter 19 Test”, can be used for selection of questions for review.

A final comprehensive exam should be given for the course.

Resources

MGH Chemistry: pages 790-797.

MGH Chemistry Teacher’s Resource: pages 309-311.

Assignment, “From Mineral to Metal: Metallurgy and Electrolytic Refining”, Appendix B.

Core Lab:

Investigation 19-C, “Electroplating”, pages 794-795.

BLM 19-3, “Chapter 19 Test”.

Appendix A

Acid Around Us

Introduction

What do the following have in common: a bee sting, burning coal to fuel factories, the winner of the Tour de France, diabetes, the colour of a hydrangea in full bloom, the taste of cola soft drinks, healthy blood, a soothing bath and sauerkraut? At first, we would all be hard pressed to find something in common between these phenomena. Yet one exists: acid-base chemistry. This module will go beyond Arrhenius, Bronsted and Lowry and investigate some aspects of acid-base chemistry that may be relevant to you.

1. Acids and Bases: Would you believe that...

... a bee's sting is acidic, whereas a wasp's sting is basic.

While both stings are painful, the chemical makeup of each sting and how we treat them are very different. Consider what you know of household acids and bases and neutralization: which household acids and bases would soothe each type of sting? Could you use the same substance to soothe both a bee's sting and a wasp's sting?



Figure 1. A honeybee about to leave its stinger

... if you don't like to exercise, blame it on an acid!

If you've ever exercised to the point where your legs have that "burning" sensation, lactic acid is to blame. Lactic acid is produced by our bodies as we burn glycogen (stored carbohydrates), and it only takes as much as a teaspoon of lactic acid in your legs to cause them to scream "stop!" during intense physical activity. It has been said that the best cyclists or marathon runners are not necessarily in the best physical condition, but can withstand the burning pain of lactic acid buildup and continue to perform. A major part of a professional sports therapist's job is to find methods to reduce the effects of lactic acid for their athlete clients. Many sports therapists currently believe that long, relatively easy workouts that build an aerobic base is the key to both minimizing and tolerating the lactic acid produced during exercise.

... many flowers have colours that are dependent upon soil pH. A commonly grown garden plant in Atlantic Canada is the hydrangea, as shown in Figure 2. In acidic soil, the flowers are blue in colour whereas in basic soil the same plant has pink flowers! This variation in colour is not unique to hydrangea. Some fruits and vegetables also have pH

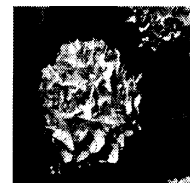


Figure 2. Hydrangea

dependent colour, including blackberries, blueberries, strawberries and red cabbage. If any of the above are crushed and boiled in a small amount of water, the resulting solution can be used as a natural acid-base indicator. Blackberry extract, for example, is pink-red in acid and is deep purple in base.

... some of your favourite foods owe their taste to acids.

The operational definition of acids states that acids generally taste sour while bases are bitter. A check of some of your favourite foods ingredients, you will reveal some surprising results. For example, there is both phosphoric acid and carbonic acid in Pepsi® and Coke®! Even if you drink "no-name" colas, you will find that phosphoric acid is used to give the cola its characteristic tangy cola taste. Table 1 gives a small sample of foods which contain acids.

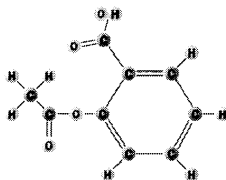
<i>Food</i>	<i>Acid Present</i>
vinegar	5% acetic acid v/v
tomato, spinach, rhubarb	oxalic acid
sour cream, sauerkraut, 'sour' cheeses	lactic acid
oranges, lemons, limes (citrus fruit)	citric acid

Table 1. Common Foods Containing Significant Amounts of Acid.

By the way, all of the above are digested by gastric juice - an enzyme of hydrochloric acid in your stomach. If you are a sufferer of 'heartburn', this affliction has nothing to do with your heart, but instead excess acid in your digestive system. One remedy: milk of magnesia - a base!

... if all of this chemistry is giving you a headache, take some acetylsalicylic acid!

Sound scary? Well, we're only talking about ASA, the common pain reliever in Aspirin®. If you would rather not run for the medicine cabinet but instead could just do with a nice soothing bath, why not increase your comfort by using a *bath fizzer*? If you've never seen a bath fizzer (also



known as a "bath bomb"), the name pretty much says it all. When added to a hot bath, a bath fizzer produces a huge volume of soothing bubbles and some bath oil. The bubble effect is caused by the neutralization of sodium hydrogen carbonate (base) with citric acid, and the recipe for making the fizzers is given in the *Activity* section of this module.

2. Acid Deposition

From Environment Canada's website:

"Acid deposition - commonly called acid rain - is caused by emissions of sulphur dioxide and nitrogen oxides. Although natural sources of sulphur oxides and nitrogen oxides do exist, more than 90% of the sulphur and 95% of the nitrogen emissions occurring in eastern North America are of human origin. These primary air pollutants arise from the use of coal in the production of electricity, from base-metal smelting, and from fuel combustion in vehicles. Once released into the atmosphere, they can be converted chemically into such secondary pollutants as nitric acid and sulfuric acid, both of which dissolve easily in water. The resulting acidic water droplets can be carried long distances by prevailing winds, returning to Earth as acid rain, snow, or fog." ⁷

According to Environment Canada, over 80% of Canadians live in areas with high acid rain levels, and the problem is not unique to the large cities of Canada and the US. In a long-term study conducted from 1980 to 1998 by Environment Canada, five sites in the Atlantic Provinces downwind from major North American polluters were equipped with Acid Precipitation Collectors (Figure 3). The results of the study indicate that acid deposition exceeds critical levels across most of New Brunswick and Nova Scotia. Lowering the pH of Atlantic Canada's waterways has a devastating impact on its biodiversity of aquatic ecosystems. The environment will remain at risk and more damage to forest health and productivity will occur unless further drastic cuts to sulfur dioxide and nitrogen dioxide emissions are implemented. ^{7, 8, 9}



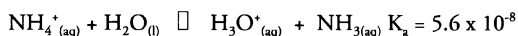
Figure 3. An Acid Precipitation Collector. ⁹

Since junior high, you may have encountered the issue of acid rain many times. Where do you stand in the acid rain debate? Are industries doing enough? Are governments doing enough? Are *you* doing enough?

3. Maintaining Blood pH - the Carbon Dioxide - Bicarbonate Buffer

A *buffer* is a solution, containing a weak acid and its conjugate or a weak base and its conjugate, which has the ability to maintain a relatively constant pH when limited amounts of strong acid or base are added to it. Consider: addition of 0.01 mol of HCl_(aq) to 1 L of pure water causes the pH to drop from 7.0 to 2.0 - a drop of 5 pH units. That is an increase in [H₃O⁺] of 100000. When the same amount of acid is added to 1 L of naturally buffered blood, the pH drops from 7.35 to approximately 7.25. - *a drop of only 0.1 in pH*. That is an increase in [H₃O⁺] of 1.3. The ability for our blood to withstand large pH changes is a necessity. The pH of normal blood is 7.35; a difference of 0.2 pH units will greatly decrease the ability of blood to uptake oxygen, while a difference of 0.4 pH units is usually fatal.

A buffer is commonly made up of *a weak acid and its conjugate base*, allowing the buffer solution to withstand addition of either acid or base. One buffer is the ammonium - ammonia buffer:



Remember *both* NH₄⁺_(aq) and NH₃_(aq) are initially present in this buffer system. This means that if strong base is added, the ammonium (weak acid) component of the buffer will react with the added base and neutralize it; meanwhile, if strong acid is added to the buffer, the ammonia (conjugate base) component will react and neutralize the added acid. This is just an application of Le Châtelier's Principle. The pH of the buffered solution therefore does not change drastically with the stress of strong acid or base added to the system.

One of the major buffers which regulates blood pH is the equilibrium between carbonic acid and the bicarbonate ion. This buffer is created when dissolved carbon dioxide (from cellular respiration) in the blood

plasma reacts with water to produce carbonic acid:
 $\text{CO}_{2(g)} + \text{H}_2\text{O}_{(l)} \rightleftharpoons \text{H}_2\text{CO}_{3(aq)}$

Carbonic acid then reacts with water to produce the buffer system:



When a base is added, it reacts with the carbonic acid in the buffer:



When an acid is added, it reacts with the bicarbonate ion:



Note that since we remove CO_{2(g)} from our bodies as we breathe, the rate at which we breathe will affect the amount of HCO₃⁻_(aq) in our blood, and therefore will affect blood's natural buffer. This is particularly important in activities held at high altitude, such as mountain climbing. Since there is a lessened amount of oxygen in air at high elevation compared to sea level, a mountain climber (without supplemental oxygen) would breathe in more frequently to intake more oxygen. At the same time, breathing out more frequently would remove more dissolved CO₂ (and thus HCO₃⁻) than usual from the climber's blood buffer system. The climber would be at risk for *alkalosis* - the condition of blood pH increasing to dangerously high levels. Can you use Le Châtelier's Principle and the equation for the carbon dioxide - bicarbonate buffer to explain alkalosis?

Another blood condition related to the blood's natural buffer is *acidosis* - the condition of blood pH decreasing to dangerously low levels. Acidosis may occur when blood's buffer is challenged with a sudden influx of acid. This may occur in diabetics or athletes undergoing prolonged, extensive exertion. Treating or preventing alkalosis and acidosis is an important part of a physical trainer's job. Accordingly, the careers of traditional medicine and sports medicine require a working knowledge of buffer systems.

So - What are your plans after graduation?

With the end of your high school career around the corner, hopefully you are starting to think about a potential profession. Note that several interesting careers have been introduced by this module, where a knowledge base of chemistry would be an asset. A horticulturist must have a working knowledge of pH and chemicals which could safely control water and soil pH; a nutritionist would need a knowledge of the chemical components within various foods; environmental chemists tackle the problem of acid deposition on a daily basis; sports physicians need to have a working knowledge of lactic acid formation and buffers. Is there a career in this module for you?

Understanding Concepts

- List three substances or products that are found around the house that are *acidic*.
 - List three substances or products that are found around the house that are *basic*.
 - Decide which substance from your lists above that you would use to treat (i) a bee's sting versus (ii) a wasp's sting.
 - A liquid pipe clog remover (such as Drano®) is basic. Why would this household item be inappropriate for treating either type of sting?
 - What do you think would be the effect of placing vinegar on a bee's sting?
- What colour would be expected for blackberry extract in:
 - soapy water?
 - lemon juice?
- Calculate the pH of a solution of vinegar, given that it is a 5% v/v solution of acetic (ethanoic) acid and that glacial (pure) acetic acid has a stock concentration of 17.4 mol/L. (Hint: think about what "% v/v" means in terms of how the solution is prepared from pure acetic acid.)
- Another acid that may cause bodily discomfort is uric acid. Gout, a form of arthritis, is caused by uric acid buildup in ankle and foot joints. An internet source¹⁰ states that taking 1/2 tsp. of baking soda will help reduce gout. Do you think this is a reasonable home remedy to treat gout? Why?
- In the recipe for bath fizzers given in the *Activity*, it states that "any non-water containing oil suitable for skin contact" will work in sticking the bath fizzer together. Use collision theory (from the previous unit) to explain why water cannot be present when the bath fizzer ingredients are mixed.
- Environment Canada states that sulfuric acid and nitric acid are the resulting products when sulfur dioxide and nitrogen dioxide react with moist air to form acid deposition. Write complete chemical equations for the production of (a) sulfuric acid and (b) nitric acid under these conditions.
- State your position on acid rain, and whether you believe: (i) industry (ii) government and (iii) individuals within society are doing their part in reducing acid rain.
 - Fully describe one suggestion for each of: (i) industry (ii) government and (iii) individual citizens to help out in acid rain reduction.
- For blood's buffer, the K_a for the buffer equation is 4.4×10^{-7} @ 37°C. In most studies, an equilibrium temperature of 25°C is quoted. Explain why 37°C is used here.
- What property of the bicarbonate ion is illustrated by the action of the buffer in the presence of excess acid or base?
- Use Le Châtelier's Principle and the equation for the carbon dioxide - bicarbonate buffer to explain alkalosis.
- After taking an overdose in a narcotic, a person begins to breathe in a slow and shallow manner. Is this person potentially at risk for alkalosis or acidosis? Explain.
- Which specific acid compound likely adds to the condition of acidosis in athletes? (Hint: think back to an earlier section in the module.)

Making Extensions

- Research the different colours of blueberry, strawberry and red cabbage extract in acids versus bases.
 - Obtain samples of the berries and / or red cabbage, and use them to test various household substances that are expected to be acidic or basic.
- Cola drinks have a phosphoric acid content that is described as "from 0.057 to 0.0684% of 75% phosphoric acid, by mass." Estimate the pH range of cola drinks corresponding to this range of H_3PO_4 (aq) content.
- Research and write the chemical structures for the acids found in food given in Table 1.
 - What do each of these acids have in common?
- In the bath fizzer activity, aqueous sodium citrate is given as the third product in the chemical equation and is quite safe for you to bathe in. In fact, citric acid and sodium citrate are the most widely used buffer systems in the food industry to control pH of foods and drugs. Using the internet or your local drug store, research some products that use the citric acid-sodium citrate buffer.
- In teams, research and debate the issues surrounding acid deposition, given that industry and society seem to be having problems in reducing the emissions that cause acid rain.
- Research the symptoms and effects of: (a) acidosis and (b) alkalosis.
- During a climb up Alpe d'Huez during a recent Tour de France, one of the cyclists had such a buildup of acid in his muscles that the ratio of bicarbonate to carbonate in his system was decreased to 10. Is this athlete in physical danger? Explain. (Hint: Start with the K_a constant expression for the buffer, and substitute known quantities.)

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Acids and Bases - "Kitchen and Bathtub" Activity

Making Bath Fizzers

What you need:

- 2 tablespoons citric acid (available at a home-brewing store)
- 2 tablespoons cornstarch
- 1/4 cup baking soda
- 1/4 tsp essential oil or fragrance oil (optional; available at some cosmetics stores)
- 3-6 drops food colour (various colours)
- 3 tablespoons baby oil, vegetable oil or other non-water containing oil suitable for skin contact
- 2 bowls
- waxed paper

Preparation:

1. Mix all dry ingredients: citric acid, baking soda and cornstarch in a bowl.
2. Mix the baby oil, fragrance or essential oils and colouring together in a separate bowl (or cup)
3. Slowly mix the liquid mixture into the dry ingredients.
4. Make small (2cm) balls of the mixture and place them on waxed paper to dry.
5. Allow 24 to 48 hours for the bath fizzer to dry completely. They should be completely dry before storage. Store bath balls in a tightly sealed container, away from moisture.

(For larger amounts of bath fizzers, expand the mixture, using the proportions above.)

Use:

1. Pour bath to desired warmth.
2. Toss in: 1) a bath fizzer and 2) yourself!
3. Enjoy!

Chemistry:

The chemical reaction employed by the bath fizzer is:



Internet References

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www.pvsoap.com/recipe_bath_bomb.htm

www.nexus.chemistry.duq.edu/snes/chemistry/faculty/isenhour/chem121f/Chap04.htm

Appendix B

From Mineral to Metal: Metallurgy and Electrolytic Refining

Introduction

The use of metals has provided a means for historians to mark the evolution of world civilizations. Metalworking and copper smelters in Egypt date back to 4500BC; by 2500 BC, metalworking had spread through Europe and Asia. These early civilizations used copper, silver and gold because these are found in *native* form, uncombined with other elements. The ancient Roman civilization added tin, iron, lead and mercury to the list of known metals, and being able to use these metals helped the Roman civilization to spread throughout Europe. By 700 AD, alchemists had the dream of finding the philosopher's stone: a magical substance which was believed to turn base metals (such as lead) into precious metals (such as gold). While this dream has never been fulfilled, the development of *metallurgy*, the science of extracting and refining metals from their ores and compounding alloys, continued to evolve through the ages.

We depend upon metals for so much in our daily lives that producing a complete list of their uses would be impossible. Remember: we use more than pure metals; we also use metals in the form of

alloys (mixtures of metals) and ionic compounds. The need for metals and alloys makes metal production a multi-billion dollar industry annually in Canada. Mineral shipments from Newfoundland and Labrador alone exceeded \$850 million in 2002, with 95% of the value of these shipments being the iron ore produced by the IOCC (Iron Ore Company of Canada) in Labrador City. Mining and metallurgy is considered a major growth industry in the province as the Voisey's Bay nickel-copper-cobalt project is added to an already vibrant mining and metallurgy sector. The purpose of this module is to introduce and explore the chemistry behind metallurgy - from mineral to metal.

Processing Ore: Pyrometallurgy vs. Hydrometallurgy

Most metals are not found in a native state. A *mineral* is a naturally occurring substance with a characteristic range of chemical composition. Table 1 lists the known native metals along with several examples of mineral types. The term *ore* is used to describe material with a sufficient amount of mineral deposit to allow for commercial recovery of the desired metal.

<i>Native Metal / Mineral Type</i>	<i>Metal / Mineral Formula (and Name)</i>
<i>Native metals</i>	<i>Ag, Au, Bi, Cu, Ir, Os, Pd, Pt</i>
Carbonate minerals	CaCO ₃ (calcite), CaCO ₃ · MgCO ₃ (dolomite), FeCO ₃ (siderite), BaCO ₃ (witherite)
Halide Minerals	CaF ₂ (fluorite), NaCl (halite)
Oxide Minerals	Al ₂ O ₃ · 2H ₂ O (bauxite), Cu ₂ O (cuprite), Fe ₂ O ₃ (haematite), Fe ₃ O ₄ (magnetite)
Sulfide Minerals	Cu ₂ S (chalcocite), CuFeS ₂ (chalcopyrite), NiS (millerite), Fe ₉ Ni ₉ S ₁₆ (pentlandite), FeS ₂ (pyrite)

Table 1. Native Metals and Minerals

In general, the three main steps in obtaining a pure metal from its ore are:

1. primary treatment,
2. extracting the metal,
3. refining the metal.

How these three are accomplished depends upon whether pyrometallurgy or hydrometallurgy is used.

Pyrometallurgy (or "pyromet" for short) uses extreme heat (in blast furnaces at temperatures of 1500°C and above) to roast the ore into a form where the metal can be more easily isolated.

Hydrometallurgy (or "hydromet", for short) uses chemicals to react and dissolve the metal from its ore, allowing the metal to be isolated at much more moderate temperatures.

One of the main debates around the Voisey's Bay project was whether a pyromet (i.e., classic smelter) or a hydromet facility should be used to process the ore. This module will compare pyrometallurgy versus hydrometallurgy for obtaining pure copper and nickel. Each process offers a wide range of impacts on our society, economy and the environment. Perhaps, after reading the module, you will decide which process you feel is best for the Voisey's Bay project.

Copper Pyromet Versus Hydromet

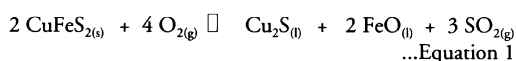
Pyrometallurgy of Copper

A common mineral of copper metal is chalcopyrite, CuFeS₂. The overall pyromet process is complex since the ore: 1) contains a equal amounts of iron to

the desired copper, and 2) is usually very impure with clay and sand.

The primary treatment of chalcopyrite is concentration of the ore by *floatation*. This involves grinding the ore into a fine powder which is then added to a mixture of water, oil and detergent. Upon beating or blowing the ore mixture into a foam, the oil preferentially sticks to the mineral particles and carries the mineral to the top; the water-insoluble *gangue* (non-mineral impurities of clay and sand in the ore) then settles to the bottom. The foam, containing the mineral, is skimmed off the surface.

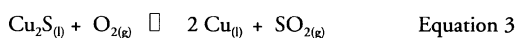
The second step is to heat the mineral in a blast furnace with the oxygen pressure and temperature carefully controlled. The copper and iron become separated from the chalcopyrite:



Sand (SiO₂) is then added to the blast furnace so that the iron(II) oxide produced is immediately converted into a dense liquid layer of iron(II) silicate, termed *slag*:



The slag is removed, and the copper(I) sulfide from Equation 1 is reduced to copper metal upon reaction with oxygen in air:



Zinc and iron (from other trace minerals in the ore) are common impurities in the molten copper that forms by Equation 3. The final step in obtaining highly pure copper metal involves using an electrolytic cell to refine the copper. In the electrochemical cell, *impure* copper acts as the anode and *pure* copper acts as the cathode in a sulfuric acid solution containing Cu^{2+} ions. The cell is shown in Figure 1.

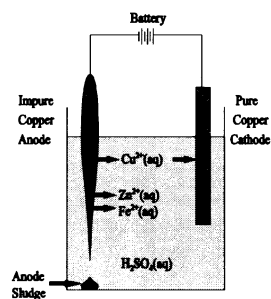


Figure 1. Electrolytic purification of copper.

The voltage applied to the electrodes is just high enough to oxidize the copper atoms at the anode to copper(II) ions. The copper(II) ions enter the solution and travel to the cathode (as indicated by the arrows) where they are reduced to *pure* copper metal.

The impurities which are more electrolytically active than copper dissolve from the anode, but are not reduced at the cathode (as shown by the single arrow from the anode). These ions remain in solution.

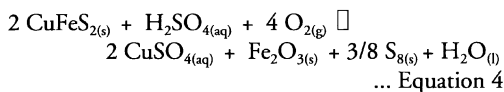
The anode sludge which forms as the impure anode disintegrates is definitely not garbage; it yields significant quantities of less active metals such as, gold, silver, platinum and palladium.

The copper which is purified by this process is usually at least 99.9% pure, as required for electrical wiring standards.

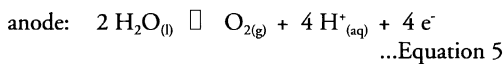
Hydrometallurgy of Copper

Once flotation is completed, the major difference with hydromet processes is *leaching* instead of roasting. Leaching refers to the dissolving of the

desired metal ions from the mineral into an aqueous solution. In the case of obtaining the copper from chalcopyrite, sulfuric acid is added to the ore in the presence of oxygen at room temperature:



Next, the iron (III) oxide and sulfur are filtered off. The solution is placed in an electrolytic cell to obtain pure metallic copper in a single step. The reactions at the anode and cathode are as follows:



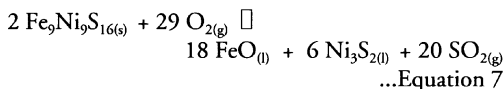
The hydromet process for obtaining pure copper is now complete. Looking back at the pyromet process for copper, do you see any advantages and/or disadvantages to using either method?

Pyrometallurgy Versus Hydrometallurgy for Nickel

Pyrometallurgy of Nickel

The two major nickel smelting methods currently used have been developed by the International Nickel Company of Canada (Inco) and Outokumpu Oy of Finland. The chemical reactions of the two processes are similar: after flotation, iron and sulfur are oxidized to produce impure liquid nickel.

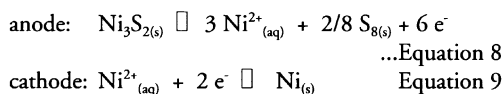
The nickel deposit at Voisey's Bay is in the form of pentlandite ($\text{Fe}_9\text{Ni}_9\text{S}_{16}$). After the flotation of pentlandite, the mineral is smelted in two steps. First, the pentlandite is roasted at extremely high temperatures in air to yield iron(II) oxide and nickel(II) subsulfide, Ni_3S_2 . (Note that the nickel(II) subsulfide contains a rather unusual oxidation state for sulfur.)



The FeO gets converted to FeSiO_3 slag (as in Equation 2 for copper pyromet). Upon pouring off

the FeSiO_3 , impure liquid nickel(II) subsulfide remains. The process may now take one of two routes: 1) conversion of the Ni_3S_2 to NiO , which is refined into pure nickel by a distillation known as the Mond process, or 2) placing the Ni_3S_2 in an electrolytic cell. We will only look at the electrolytic method here in detail.

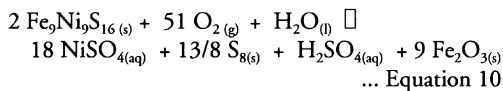
Obtaining pure nickel from the impure Ni_3S_2 is also known as *electrowinning*. At the anode of the electrolytic cell, the Ni_3S_2 reacts to produce Ni^{2+} ions and S_8 ; the Ni^{2+} is then reduced at the cathode to produce nickel metal:



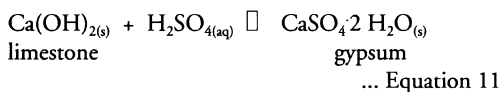
Again, the electrolytic process provides an excellent method for refining a metal, as the nickel produced by electrowinning is over 99.9% pure.

Hydrometallurgy of Nickel

Hydromet is currently not the common method used by companies worldwide for nickel production. However, in 1954, Sherritt Gordon Mines Ltd. dissolved Ni^{2+} ions from sulfide ores using air, ammonia and water under high pressure and 85°C . While this was a successful process, Inco intends to dissolve Ni^{2+} ions from pentlandite using pure oxygen and water. The oxygen oxidizes most of the sulfide ions in the ore to solid sulfur; any excess sulfide is oxidized to sulfate ions (in the form of sulfuric acid), which helps to dissolve the metals. At the resulting pH of 3, solid Fe_2O_3 is produced. The reaction for this initial leaching process is:



The byproduct $\text{H}_2\text{SO}_{4(aq)}$ which forms is later neutralized by adding limestone ($\text{Ca}(\text{OH})_2$) to form gypsum, which separates from solution:



Since all of the solid sulfur, gypsum and iron(III) oxide can be filtered off, the remaining solution contains only nickel(II) ions which may be reduced to pure nickel metal directly, without interference from all other ions and compounds originally in the ore.

Where do You Stand: Pyromet or Hydromet?

There are many considerations when choosing the type of processing plant for a mining project such as Voisey's Bay. There are environmental issues, factory cost, efficiency, employment and factory lifetime issues to consider. From the basic principles behind hydromet and pyromet technologies, which process would you endorse?

Understanding Concepts

1. Use your knowledge of chemistry to give a brief explanation of why *the philosopher's stone* does not nor can not exist.
2. Consider Equations 1 to 3 in the pyrometallurgy of chalcopyrite to yield copper. State two reasons why an environmentalist would be unimpressed with this means of copper extraction.
3. (a) For the purification of copper (Figure 1), write complete half-reactions for the reaction at: (i) anode, and (ii) cathode.
(b) Attempt to write the "overall reaction" for the process, by showing the result of combining the anode half-reaction and the cathode half reaction from part (a) above.
(c) Use the result from part (b) above to explain while simple *purification* of the copper metal occurs during the electrolytic purification of copper, *no other chemical processes* occur for the copper.
4. Using Equations 5 and 6 under the hydromet process for isolating copper, determine:
 - (a) the overall cell reaction for the electrolysis.
 - (b) using a table of standard electrode potentials, the minimum potential required to electrolyze the solution and obtain copper metal.

5. The nickel(II) subsulfide, Ni_3S_2 , obtained in the pyromet process for nickel has an unusual oxidation state for sulfur.
 - (a) What is the oxidation state of the sulfur?
 - (b) Why is this state considered "unusual"?
6. Given that the electrowinning process for refining nickel is an electrolytic process, what can be said about the sign and magnitude of the standard reduction potential of Ni_3S_2 in Equation 8?
7. For the hydromet process in isolating pure nickel electrolytically, propose the two reactions which occur at the anode and the cathode, the overall cell reaction, and the minimum voltage that would be necessary to carry out this process.
8. (a) Given the information provided in the module and any research you may care to follow up with, compare and contrast a pyromet processing plant versus a hydromet processing plant according to the following issues:
 - (i) environmental concerns
 - (ii) cost / efficiency of production
 - (iii) employment
 - (iv) factory lifetime / adaptability of the plant to be used with other ores / minerals.
 (b) Based upon your response to (a), decide whether you believe pyromet or hydromet is a better process, assuming each process is viable for the ore which must be processed.

gangue, and how this may be carried out on an industrial scale.

3. Research today's stock market closing values for copper, gold, silver and platinum. Use these results to explain why a small amount of anode sludge from electrolytic purification of copper can be as valuable as the pure copper produced by the process.
4. Research the Mond process used to obtain and refine pure nickel from nickel(II) oxide. Make special note of any novel reactions, procedures or safety precautions employed. (Note: the process is also known as the "nickel carbonyl process".)

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Making Extensions

1. There was once a major iron ore mine on Bell Island. Research the mine, including type of iron mineral which was mined and mining methods.
2. In iron ore production (such as in the IOCC mines in Labrador City), the mineral magnetite (Fe_3O_4) can be separated from the gangue using other physical properties instead of the property of solubility used in the floatation process. Brainstorm or research the physical property that may be used to separate Fe_3O_4 from its