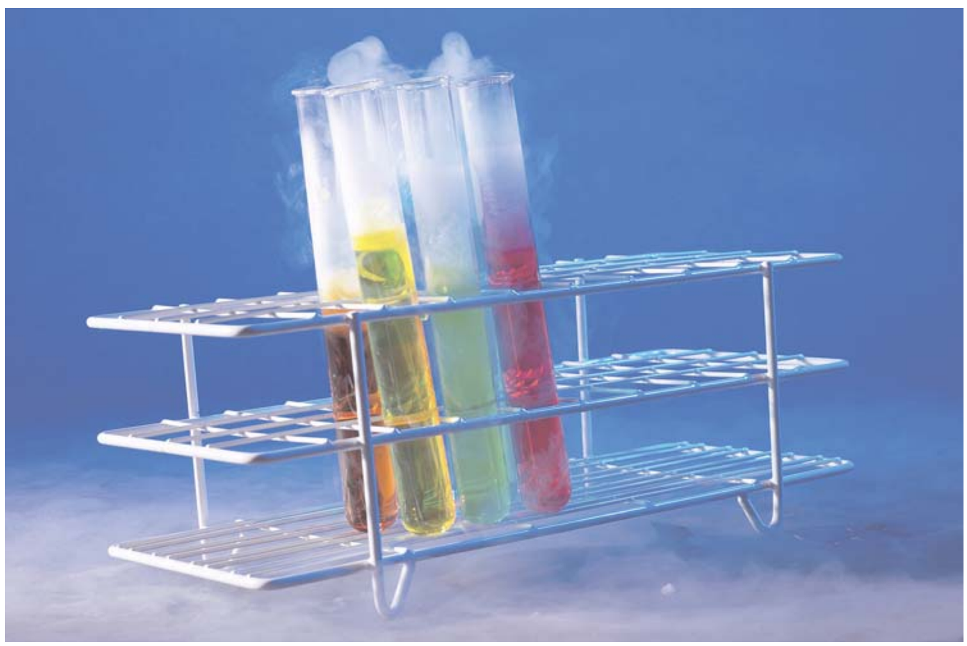
TOPIC 3:
CHEMICAL REACTIONS



Topic 3: Chemical Reactions

C11-3-01 Determine average atomic mass using isotopes and their relative abundance.
Include: atomic mass unit (amu)

C11-3-02 Research the importance and applications of isotopes.
Examples: nuclear medicine, stable isotopes in climatology, dating techniques…

C11-3-03 Write formulas and names for polyatomic compounds using International Union of Pure and Applied Chemistry (IUPAC) nomenclature.

C11-3-04 Calculate the mass of compounds in atomic mass units.

C11-3-05 Write and classify balanced chemical equations from written descriptions of reactions.
Include: polyatomic ions

C11-3-06 Predict the products of chemical reactions, given the reactants and type of reaction.
Include: polyatomic ions

C11-3-07 Describe the concept of the mole and its importance to measurement in chemistry.

C11-3-08 Calculate the molar mass of various substances.

C11-3-09 Calculate the volume of a given mass of a gaseous substance from its density at a given temperature and pressure.
Include: molar volume calculation

C11-3-10 Solve problems requiring interconversions between moles, mass, volume, and number of particles.

C11-3-11 Determine empirical and molecular formulas from percent composition or mass data.

C11-3-12 Interpret a balanced equation in terms of moles, mass, and volumes of gases.

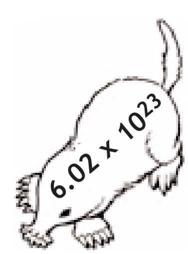
C11-3-13 Solve stoichiometric problems involving moles, mass, and volume, given the reactants and products in a balanced chemical reaction.
Include: heat of reaction problems

C11-3-14 Identify the limiting reactant and calculate the mass of a product, given the reaction equation and reactant data.

C11-3-15 Perform a lab involving mass-mass or mass-volume relations, identifying the limiting reactant and calculating the mole ratio.
Include: theoretical yield, experimental yield

C11-3-16 Discuss the importance of stoichiometry in industry and describe specific applications.
Examples: analytical chemistry, chemical engineering, industrial chemistry…

Suggested Time: 25.5 hours



SPECIFIC LEARNING OUTCOME

C11-3-01: Determine average atomic mass using isotopes and their relative abundance.

Include: atomic mass unit (amu)

(2.0 hours)

SLO: C11-3-01

SUGGESTIONS FOR INSTRUCTION

General Note to Teachers

As Topic 3 is a long unit, teachers are strongly encouraged to divide it into two parts.

Entry-Level Knowledge

In Grade 9 Science (learning outcome S1-2-04), students learned about the basic atomic structure (protons, neutrons, and electrons), atomic number, and average atomic mass of elements. They should be able to use this information to draw Bohr models of various atoms. See *Senior 1 Science: A Foundation for Implementation (*Manitoba Education and Training, A28, A34-37).

TEACHER NOTES

Different variations of atoms of the same element occur in nature. These variations are called *isotopes*. The average mass of the isotopes for each element is a characteristic of that element.

Isotopes are atoms of the same element (same number of protons) with different numbers of neutrons. They have identical atomic numbers (number of protons) but different mass numbers (number of protons plus number of neutrons).

$^{A}_{Z}X$

A = mass number

X = symbol

Z = atomic number

General Learning Outcome Connections

GLO A4: Identify and appreciate contributions made by women and men from many societies and cultural backgrounds that have increased our understanding of the world and brought about technological innovations.

GLO B1: Describe scientific and technological developments—past and present—and appreciate their impact on individuals, societies, and the environment, both locally and globally.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

GLO D5: Understand the composition of the Earth’s atmosphere, hydrosphere, and lithosphere, as well as the processes involved within and among them.

GLO E3: Recognize that characteristics of materials and systems can remain constant or change over time, and describe the conditions and processes involved.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Isotopes are usually represented in several ways.

Example:

Sodium-24 or ^{24}Na

The atomic mass unit (often designated as u, μ, or amu) is defined as 1/12th the mass of a carbon-12 (C-12) atom. The magnitude of the atomic mass unit is arbitrary. In fact, 1/24th the mass of a carbon atom or 1/10th the mass of the iron atom could have been selected just as easily. Three reasons for using 1/12th the mass of a C-12 isotope are:

- Carbon is a very common element.
- It results in nearly whole-number atomic masses for most other elements.
- The lightest element, hydrogen (H), has a mass of approximately 1 amu.

When the amu was first developed, the mass in grams of 1 amu was unknown; however, it has since been experimentally determined. The atomic mass unit is an extremely small unit of mass.

Activity: Average Atomic Mass

Illustrate how the average atomic masses of atoms are determined by their relative mass compared to C-12.

Students should use relative abundance data to calculate the average atomic mass of elements. Most elements have naturally occurring isotopes. The *CRC Handbook of Chemistry and Physics* will provide the relative abundance for each of them.

Note: When using data from the handbook, make sure that the percent abundance calculates to the actual atomic mass.

Examples:

One of the dietary sources of potassium is the banana: 93.1% of the potassium atoms are potassium-39 (20 neutrons), 6.88% are potassium-41, and only a trace are potassium-40.

Elemental boron is a combination of two naturally occurring isotopes: boron-10 has a relative abundance of 19.78% and boron-11 has a relative abundance of 80.22%.

SPECIFIC LEARNING OUTCOME

C11-3-01: Determine average atomic mass using isotopes and their relative abundance.

Include: atomic mass unit (amu)

(continued)

Sample:

Relative Abundance of Stable Magnesium (Mg) Isotopes		
Isotope	**Relative Abundance (%)**	**Atomic Mass (μ)**
Mg-24	78.70	23.98504
Mg-25	10.13	24.98584
Mg-26	11.17	25.98259

For additional questions, see Appendix 3.1: Calculating Average Atomic Mass.

Laboratory Activity

Students could develop their understanding of relative abundances by completing a simulation lab activity in which the average mass of Canadian pennies is used to mirror how the average atomic mass is determined. For this activity, students would require archival data from the Royal Canadian Mint outlining the percent composition of iron, steel, zinc, copper, and other metals (such as Sn) found in alloys used to mint pennies. About every five years, these alloys change, due to fluctuations in world commodity prices for the native metals.

For a history of the composition of the penny, see the following website:

Northern Blue Publishing. Canadian History Business News. The Small Canadian Penny: <http://northernblue.ca/cbushist/index.php?/archives/165-The-Small-Canadian-Penny.html>

Another activity related to percent composition in Canadian currency can be downloaded from:

Magma Communications. Doug De La Matter. Experiments with Coins: <http://www.magma.ca/~dougdela/ideas/coindemo.pdf>

Analogy

The use of weighted averages to determine a student's mark involves the same process as determining the average atomic mass.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Laboratory Activity

The lab activity that models the relative abundances of isotopes using the historical composition of Canadian pennies could be assessed either as a formal lab report using the Laboratory Report Format (see *SYSTH* 14.12) or by using questions and answers from the data collected from the activity.

Visual Display

Introduce students to isotopes by having them draw the isotopes of hydrogen (H).

$^{1}_{1}H$	$^{2}_{1}H$	$^{3}_{1}H$
Hydrogen	Deuterium	Tritium

Students could present what they have learned using

- posters
- pamphlets
- bulletin board displays
- models

Each of these presentation styles could be assessed using an appropriate rubric created with students prior to the assignment. A sample presentation rubric is provided in Appendix 10 of this document.

Paper-and-Pencil Tasks

Students should calculate the average atomic mass of various elements based on relative abundance data. When using data from the *CRC Handbook of Chemistry and Physics*, make sure that the percent abundance calculates to the actual atomic mass.

SPECIFIC LEARNING OUTCOME

C11-3-01: Determine average atomic mass using isotopes and their relative abundance.

Include: atomic mass unit (amu)

(continued)

LEARNING RESOURCES LINKS

Chemistry (Chang 49)

Chemistry: The Central Science (Brown, *et al.* 44)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 67)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 52)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 102)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 43)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 163)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 27)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 80)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 107)

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

NOTES

SPECIFIC LEARNING OUTCOME

C11-3-02: Research the importance and applications of isotopes.

Examples: nuclear medicine, stable isotopes in climatology, dating techniques…

(1.0 hour)

SLO: C11-3-02

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students were introduced to isotopes in the treatment of learning outcome C11-3-01. As yet, they have little knowledge about the uses of isotopes.

TEACHER NOTES

In addressing this learning outcome, teachers may want to include a discussion of half-life, but should avoid a detailed treatment of radioactive decay equations.

Introduce students to the importance and applications of isotopes by relating the uses of various isotopes. Some examples are provided below. (**Note:** Students will find an abundance of isotopes with minimal information on each. Therefore, research assignments should reflect the variety of isotopes rather than detailed information on one isotope.)

Additional information can be found in the following appendices:

- Appendix 3.2: Don't Be an Isodope: Get the Facts on Isotopes
- Appendix 3.3: Isotopes Used in Medicine and Climatology
- Appendix 3.4: The Importance and Applications of Isotopes

Isotope Applications

1. **Radioactive Tracers in Medical Diagnosis**
   - ^{131}I can be used to image the thyroid, heart, lungs, and liver, and to measure iodine levels in blood.
   - ^{24}Na (a beta emitter with a half-life of 14.8 h) injected into the bloodstream as a salt solution can be monitored to trace the flow of blood and detect possible constrictions or obstructions in the circulatory system.
   - PET (positron emission tomography) scans use ^{15}O in $H_2{}^{15}O$ and ^{18}F bonded to glucose to measure energy metabolism in the brain.

General Learning Outcome Connections

GLO A3: Distinguish critically between science and technology in terms of their respective contexts, goals, methods, products, and values.

GLO B4: Demonstrate knowledge of and personal consideration for a range of possible science- and technology-related interests, hobbies, and careers.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

C11-0-R2: Evaluate information obtained to determine its usefulness for information needs.
Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…

C11-0-R5: Communicate information in a variety of forms appropriate to the audience, purpose, and context.

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2. Radioactive Isotopes in Medical Treatment

- Implants of ^{198}Au or mixtures of ^{90}Sr and ^{90}Y have been used to destroy pituitary and breast cancer tumours.
- Gamma rays from ^{60}Co are used to destroy brain tumours.

3. Oxygen Isotopes in Climatology and Geology

Stable isotopes such as ^{16}O and ^{18}O were used to indicate global temperatures in the distant past. This can be done by determining the ratio of ^{18}O to ^{16}O in ice cores extracted from Earth's polar caps or from sediment cores exhumed from the ocean floor. There is a correlation between an excess of the light isotope, ^{16}O, in precipitation and global temperatures.

When ice sheets grow in the polar regions during glacial periods, they incorporate water that has been evaporated in the low latitudes and carried to the poles in the form of water vapour, which is then precipitated as snow.

Evaporation favours the light isotope of oxygen, ^{16}O, for reasons of simple kinetics, and so polar ice has proportionally more ^{16}O than the seawater left behind when evaporation rates are high (warmer periods). This means that newly deposited ocean sediments will have a greater abundance of the *heavier isotope*, ^{18}O, when world temperatures are higher than average. Therefore:

- When world ice volume increases during a glacial stage, the heavier isotope, ^{18}O, *decreases* in polar ice and snow.
- When ice volume shrinks during warming (interglacial) periods, such as we have right now, the abundance of ^{18}O *increases* in the world's oceans. This shows up in decreased ^{18}O content in polar ice.

This *isotopic signature* can be preserved in certain shelled animals such as marine Foraminifera. These tiny bottom-dwellers secrete a silicate shell that carries the ratio of $^{18}O/^{16}O$ consistent with what that ratio was in the seawater around it. "Heavy shell" = more ice on the planet. This makes for a very effective *paleothermometer* that can be used to correlate ocean temperatures, world climate, and sea-ice volumes. See Appendix 3.2 for a more detailed treatment.

SPECIFIC LEARNING OUTCOME

C11-3-02: Research the importance and applications of isotopes.

Examples: nuclear medicine, stable isotopes in climatology, dating techniques…

(continued)

4. Carbon and Hydrogen Isotopes in Atmospheric Nuclear Tests

Nuclear weapons tests put large and detectable amounts of certain radioactive isotopes into the atmosphere. After the near-elimination of nuclear bomb testing due to the Limited Test Ban Treaty in 1963, the carbon-14 (^{14}C) concentration in the atmosphere began decreasing immediately. Anybody born *before* 1965 or so possesses a significantly higher concentration of ^{14}C than someone born after atmospheric nuclear testing ended. Thus, we can tell how old many living organisms are (including humans) based on the recent history of ^{14}C content in the atmosphere. Such sources of radiogenic isotopes are often described as coming from *anthropogenic* (human-generated) activities.

A detailed discussion of *tritium in the atmosphere* can be found at the following websites:

U.S. Environmental Protection Agency: Radiation Information:
<http://www.epa.gov/radiation/radionuclides/tritium.htm>

U.S. Geological Survey:
<http://wwwrcamnl.wr.usgs.gov/isoig/period/h_iig.html>
The U.S. Geological Survey also provides information related to periods of atmospheric nuclear testing.

5. Isotopes in Dating Techniques

- Carbon-14, with a half-life of 5730 y, is used to determine the age of bones discovered at archeological sites because the ^{14}C continues to decay over the years, whereas the amount present in the atmosphere is constant. The maximum age of an object for dating purposes using ^{14}C is about 24 000 years, whereas a long-lived isotope such as ^{238}U can be used to date materials up to 4.5×10^9 years.
- Uranium-238 and lead-206 are commonly used to date very ancient objects such as minerals contained within rock samples.

Research/Reports

Students research and report on applications of isotopes in medicine, paleoclimatology (e.g., ice-core research), other dating techniques, and so on. WebQuests could be used to research the required information. Having students complete the search process on their own time would save some class time. The research reports could be presented in a variety of ways. See Appendix 3.4: The Importance and Application of Isotopes.

SKILLS AND ATTITUDES OUTCOMES

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

C11-0-R2: Evaluate information obtained to determine its usefulness for information needs.
Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…

C11-0-R5: Communicate information in a variety of forms appropriate to the audience, purpose, and context.

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Research Reports

Have students conduct and report their research either individually or in small groups. The information collected could be presented as

- written reports
- oral presentations
- bulletin board displays
- multimedia presentations

Visual Displays

Students could present what they have learned using

- posters
- pamphlets
- bulletin board displays
- models

Each of these presentation styles could be assessed using an appropriate rubric created with students prior to the assignment. Samples of presentation rubrics are provided in Appendix 10 of this document.

SPECIFIC LEARNING OUTCOME

C11-3-02: Research the importance and applications of isotopes.

Examples: nuclear medicine, stable isotopes in climatology, dating techniques…

(continued)

LEARNING RESOURCES LINKS

Chemistry (Chang 50, 564, 875, 934, 966)

Chemistry (Zumdahl and Zumdahl 54, 56, 83, 84, 88, 878)

Chemistry: The Central Science (Brown, *et al.* 43, 839)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 62, 756)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 52, 56, 1042)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 100)

Introductory Chemistry: A Foundation (Zumdahl 95, 97, 113, 117, 551)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 43)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 37, 162, 170)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 27, 165)

Nelson Chemistry 12, Ontario Edition (van Kessel, *et al.* 165)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 15, 80)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 107)

Teachers interested in collecting data, along with their students, for the analysis of isotopes in Manitoba precipitation can contact:

Department of Geography
Manitoba Network for Isotopes in Precipitation (MNIP)
The University of Winnipeg

SKILLS AND ATTITUDES OUTCOMES

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

C11-0-R2: Evaluate information obtained to determine its usefulness for information needs.
Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…

C11-0-R5: Communicate information in a variety of forms appropriate to the audience, purpose, and context.

NOTES

SPECIFIC LEARNING OUTCOME

C11-3-03: Write formulas and names for polyatomic compounds using International Union of Pure and Applied Chemistry (IUPAC) nomenclature.

(2.0 hours)

SLO: C11-3-03

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

The following learning outcomes were addressed in Grade 10 Science:

- S2-2-01: Relate an element's position on the periodic table to its combining capacity (valence).
- S2-2-02: Explain, using the periodic table, how and why elements combine in specific ratios to form compounds.
  Include: ionic bonds, covalent bonds
- S2-2-03: Write formulas and names of binary ionic compounds.
  Include: IUPAC guidelines and rationale for their use
- S2-2-04: Write formulas and names of molecular compounds using prefixes.
  Include: mono, di, tri, tetra

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share, Word Cycle, Three-Point Approach, Compare and Contrast) found in Chapters 9 and 10 of *SYSTH*. These strategies can be used to review the following terms: anion, cation, valence (combining capacity), ionic bond, covalent bond, metal, non-metal, electron sharing, formula unit, and binary.

TEACHER NOTES

Indicate that IUPAC is an acronym for the International Union of Pure and Applied Chemistry. This worldwide organization is the governing body that oversees—among many tasks—the formal naming of chemical compounds (nomenclature).

When introducing polyatomic ions, begin with simple examples (e.g., hydroxide). Indicate that *polyatomic ions* are sometimes referred to as *complex ions* or *radicals*. A list of polyatomic ions can be found in Appendix 3.5: Names, Formulas, and Charges of Some Common Ions.

General Learning Outcome Connections

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

Skills and Attitudes Outcomes

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Encourage students to determine formulas of compounds based on balancing ion charge, as opposed to the “criss-cross” method. Students may have seen the “criss-cross” method of determining the correct formula of a compound in a previous grade, but they should now be informed *why* this method works. Students may benefit from particulate representation activities to assist in formula determination. Paper shapes can be used to represent various cations and anions. The objective is to make a rectangular figure, which shows the correct ratio of ions.

Activation Activity

Students can play an Ionic Name Game in which they roll a pair of dice—one with representations of monoatomic cations and the other with monoatomic anions. Students will attempt to predict the correct formula and name of the binary ionic compound based on the ions. (See Appendix 3.6: Ionic Name Game.)

Laboratory Activities

1. In a lab activity found in *Microscale Chemistry Laboratory Manual* (Slater and Rayner-Canham, Experiment 14), students experimentally determine the relationship between positive metal ions and negative non-metal ions in a given formula. Various chloride solutions are titrated with silver nitrate using an eye dropper. The indicator, *dichlorofluorescein*, changes from white to pink when all the chloride ions in solution have reacted. By putting the data in a table form, students can see the relationship between positive and negative ions within a formula.
2. Another lab activity can be found in Appendix 3.7: Stoichiometry: The Formula of a Precipitate. Students can determine the formula of a precipitate, cobalt hydroxide, $Co(OH)_2$. Although precipitate solutions are not formally addressed in Grade 11 Chemistry, students will find this lab interesting and beneficial.

SPECIFIC LEARNING OUTCOME

C11-3-03: Write formulas and names for polyatomic compounds using International Union of Pure and Applied Chemistry (IUPAC) nomenclature.

(continued)

SUGGESTIONS FOR ASSESSMENT

Laboratory Reports

The lab activities suggested for this learning outcome could be assessed as formal lab reports using the Laboratory Report Outline or the Laboratory Report Format (see *SYSTH* 11.38, 14.12) or by using questions and answers from the data collected from the activities.

Paper-and-Pencil Tasks

- Students should be able to write the names and formulas for both binary and tertiary compounds. Multivalent ions such as Cu^{+} and Cu^{2+} should be included. Students could create questions and test their classmates.
- Students should be able to write out an explanation of why a given formula is correct based on the ions and their total charge in the molecule.

LEARNING RESOURCES LINKS

Chemistry (Chang 59)

Chemistry (Zumdahl and Zumdahl 66)

Chemistry: The Central Science (Brown, *et al.* 49)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 161)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 63)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 221)

Glencoe Chemistry: Matter and Change: Laboratory Manual – Teacher Edition (85—Investigation)

Introductory Chemistry: A Foundation (Zumdahl 134)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 25)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 97)

Microscale Chemistry Laboratory Manual (Slater and Rayner-Canham 39)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 90)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* Appendix C5)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 231)

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

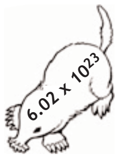
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

NOTES



SPECIFIC LEARNING OUTCOME

C11-3-04: Calculate the mass of compounds in atomic mass units.

(1.0 hour)

SLO: C11-3-04

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

The following learning outcomes were addressed in Grade 9 and Grade 10 Science, as well as in Grade 11 Chemistry:

- S1-2-04: Explain the atomic structure of an element in terms of the number of protons, electrons, and neutrons and explain how these numbers define atomic number and atomic mass.
- S2-2-02: Explain, using the periodic table, how and why elements combine in specific ratios to form compounds.

  Include: ionic bonds, covalent bonds
- S2-2-05: Investigate the Law of Conservation of Mass and recognize that mass is conserved in chemical reactions.
- C11-3-01: Determine average atomic mass using isotopes and their relative abundance.

  Include: atomic mass unit (amu)

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

Activation Activity

Use an Admit Slip to activate students' prior knowledge (see *SYSTH* 13.9-13.10).

General Learning Outcome Connections

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

TEACHER NOTES

Review with students how subscripts indicate the number(s) of atoms in a molecule or formula unit. Differentiate between molecular mass and formula mass.

- *Molecular compounds*, also known as *molecules*, contain atoms linked together in discrete, electrically neutral particles. Two examples are O_2 and CO_2. The mass of a molecule is called the *molecular mass*.
- *Ionic compounds* are composed of ions. Two examples are NaCl and $CuSO_4$. The mass of an ionic compound is called the *formula mass*.

Students should calculate the molecular mass and formula mass of various compounds. The sum of the average atomic masses of the atoms in a chemical formula is the molecular mass or formula mass of the compound. Begin with binary compounds and progress toward polyatomic compounds. The molecular mass of Aspirin or acetylsalicylic acid, $C_9H_8O_4$, can be calculated as follows:

$$
\begin{aligned}
C_9H_8O_4 &= 9C + 8H + 4O \\
&= (9 \times 12.01 \text{ amu}) + (8 \times 1.01 \text{ amu}) + (4 \times 16.00 \text{ amu}) \\
&= 180 \text{ amu}
\end{aligned}
$$

A Venn diagram would be an effective way to show similarities and differences between molecular mass and formula mass.

Laboratory Activity

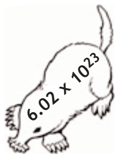
A number of investigations can be done related to this learning outcome:

- Find the formula of a hydrate.
- Find the percentage of water in a hydrated salt.
- **Extension:** Calculate the percent composition by mass.

SUGGESTIONS FOR ASSESSMENT

Paper-and Pencil Tasks: Written Test/Quiz

Students could calculate the mass of various compounds, in amu, given the names and/or formulas of the compounds.



SPECIFIC LEARNING OUTCOME

C11-3-04: Calculate the mass of compounds in atomic mass units.

(continued)

LEARNING RESOURCES LINKS

Chemistry (Chang 76)

Chemistry (Zumdahl and Zumdahl 81)

Chemistry: The Central Science (Brown, *et al.* 41)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 67)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 88)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 102)

Introductory Chemistry: A Foundation (Zumdahl 214)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 55)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 35)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 164)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 80)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 104, 110)

Skills and Attitudes Outcomes

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Notes

SPECIFIC LEARNING OUTCOMES

C11-3-05: Write and classify balanced chemical equations from written descriptions of reactions.
Include: polyatomic ions

(1.0 hour)

C11-3-06: Predict the products of chemical reactions, given the reactants and type of reaction.
Include: polyatomic ions

(1.0 hour)

SLO: C11-3-05
SLO: C11-3-06

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

The following learning outcomes were addressed in Grade 10 Science:

- S2-2-06: Balance chemical equations.
  Include: translation of word equations to balanced chemical reactions, and balanced chemical equations to word equations.
- S2-2-07: Investigate and classify chemical reactions as synthesis, decomposition, single displacement, double displacement, or combustion.

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

Discrepant Events/Demonstrations

The following discrepant events may be used to review reaction types.

1. Place an unlit candle on a balance. Have students predict what will happen to the mass of the candle when the candle is burned. Allow the candle to burn and observe the mass decrease. Students should explain that the mass decrease is a result of the gaseous products of the combustion reaction.
2. Place some steel wool (Fe) on the balance and note the mass. Again, ask students to predict what will happen if the wool is burned. Burn the wool and note the mass increase. Students should explain that the mass increase is due to the synthesis reaction.

$$4Fe_{(s)} + 3O_{2(g)} \rightarrow 2Fe_2O_{3(s)}$$

General Learning Outcome Connections

GLO C4: Demonstrate appropriate critical thinking and decision-making skills when choosing a course of action based on scientific and technological information.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

GLO E4: Recognize that energy, whether transmitted or transformed, is the driving force of both movement and change, and is inherent within materials and in the interactions among them.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

Laboratory Activity

Student knowledge of the characteristics of a chemical reaction can be reinforced through a lab activity. See Appendix 3.8: Indications of Chemical Reactions.

TEACHER NOTES

Students should have a solid understanding of balancing equations from Grade 10 Science. To review the different reaction types, teachers may wish to include lab activities and or demonstrations. When balancing equations, present students with more complex reactions that include polyatomic ions.

Students should be able to:

- Change word equations into balanced equations by inspection. Reactions should not be limited to one-to-one ratios. The following general rule works for most chemical reactions: Balance metals first, then ions, non-metals, and hydrogen, and finally oxygen. If there are no metals or ions, as in the case of an organic combustion reaction, carbon would be balanced first, then hydrogen, and finally oxygen.
- Include the states of the reactants and products (g, l, s, aq) when given the appropriate information in a question.
- Predict the products of a reaction when given the reactants and type of reaction. Begin with addition and decomposition reactions and progress toward single replacement, double replacement, and combustion reactions.

Collaborative Teamwork

Use the Jigsaw strategy in which each student becomes an "expert" on one type of reaction. Students meet as a larger group, with each student teaching classmates. Each expert devises questions for the other group members. (See *SYSTH* 3.19-3.20.)

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

SPECIFIC LEARNING OUTCOMES

C11-3-05: Write and classify balanced chemical equations from written descriptions of reactions.
Include: polyatomic ions

C11-3-06: Predict the products of chemical reactions, given the reactants and type of reaction.
Include: polyatomic ions

(continued)

SYSTH Activity

Have students complete a Three-Point Approach for each reaction type (see *SYSTH* 10.9-10.10, 10.22).

Laboratory Report

The lab activities could be assessed as formal lab reports using the Laboratory Report Outline or the Laboratory Report Format (see *SYSTH* 11.38, 14.12) or by using questions and answers from the data collected from the activities.

Journal Writing

Students could write journal entries about interesting demonstrations and lab activities.

Paper-and-Pencil Tasks

1. Given the written description of a chemical reaction, students write balanced chemical equations and identify the type of reaction.

   Example:

   When magnesium metal is burned in air, a white solid forms. Write the balanced chemical equation for the reaction, including the states, and indicate the type of reaction.

   $2Mg_{(s)} + O_{2(g)} \rightarrow 2MgO_{(s)}$

2. Given the reactants and type of chemical reaction, students predict the products and write a balanced chemical equation.

   Example:

   When zinc is treated with hydrochloric acid, a gas is produced. Write the balanced chemical equation for the reaction and indicate the type of reaction.

   $Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$

Student Activity: Written Test/Quiz

Students develop their own questions and share them with their classmates for additional practice. The student-developed questions may be included in a quiz or test.

Skills and Attitudes Outcomes

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

Learning Resources Links

Chemistry (Chang 92)

Chemistry (Zumdahl and Zumdahl 102)

Chemistry: The Central Science (Brown, *et al.* 76)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 198)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 102)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 353)

Introductory Chemistry: A Foundation (Zumdahl 155)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 29)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 114)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 210)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 282)

SPECIFIC LEARNING OUTCOMES

C11-3-07: Describe the concept of the mole and its importance to measurement in chemistry.

(0.75 hour)

C11-3-08: Calculate the molar mass of various substances.

(0.25 hour)

SLO: C11-3-07
SLO: C11-3-08

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students have not previously studied the concepts addressed in learning outcomes C11-3-07 and C11-3-08. A light treatment of significant figures was given in *Senior 2 Science: A Foundation for Implementation* (Appendix 7).

TEACHER NOTES

Lorenzo Romano Amedeo Carlo Avogadro (1776–1856) did not actually determine the number known as *Avogadro's number*. Avogadro worked principally with gases, attempting to demonstrate that equal volumes of gas under the same conditions contain the same number of particles. His work with particles on the molecular level laid the groundwork for further investigations by other scientists, such as Jean Baptiste Perrin (1870–1942). Perrin measured the displacement of colloidal particles that exhibited *Brownian* movement. He then used the results from these experiments to calculate the first value of what we call *Avogadro's constant*.

Discuss with students how Avogadro's hypothesis revolutionized thinking in chemistry and share how "N" was found in the past, compared to how it might be determined today.

The following article explains four definitions of a mole:

Barton, L. "The Definition of a Mole." *CHEM 13 NEWS* 327 (Feb. 2005): 10–11.

General Learning Outcome Connections

GLO A1: Recognize both the power and limitations of science as a way of answering questions about the world and explaining natural phenomena.

GLO A4: Identify and appreciate contributions made by women and men from many societies and cultural backgrounds that have increased our understanding of the world and brought about technological innovations.

GLO B1: Describe scientific and technological developments—past and present—and appreciate their impact on individuals, societies, and the environment, both locally and globally.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

Laboratory Activities

1. Have students do a small-scale investigation to determine the value of Avogadro's number. The procedure involves generating a monolayer of stearic acid. See *Microscale Chemistry Laboratory Manual* (Slater and Rayner-Canham 29).

2. Other student activities can be done to determine the size and mass of an oleic acid molecule or a molecular film layer.

   A number of websites outline procedures related to student activities with oleic acid, including the following:

   Georgia Perimeter College. Determination of the Length of an Oleic Acid Molecule and Avogadro's Number: <http://www.gpc.edu/~ddonald/chemlab/oleicavagno.html>

   Science Teachers' Resource Center. Oleic Acid Lab: <http://chem.lapeer.org/chem1docs/OleicAcidLab.html>

   Summer Research Program for Science Teachers. How Big Is a Molecule? <http://www.scienceteacherprogram.org/chemistry/Flomberg00.html>

   The following websites offer a key application to how antibiotics penetrate membrane layers in the body by virtue of molecular size.

   The Chemical Heritage Foundation. Molecular Size: Oleic Acid Monolayers: <http://www.chemheritage.org/educationalservices/pharm/antibiot/activity/size.htm>

   ---. Antibiotics in Action: Teacher's Guide: <http://www.chemheritage.org/educationalservices/pharm/tg/antibiot/activity/size.htm>

3. In another small-scale investigation, students estimate the size of a mole by comparing the average mass of split peas to the volume of a mole of peas. See *Microscale Chemistry Laboratory Manual* (Slater and Rayner-Canham 81).

TEACHER NOTES

Carefully explain to students the relationships among moles, the number of particles, and mass in grams. Emphasize that the *mole* is the central unit in most calculations. Encourage students to use dimensional analysis during problem solving. The intent of Grade 11 Chemistry is to limit calculations with Avogadro's number and focus more on practical calculations with mass, volume, and moles.

Advise students that in some chemistry texts and reference materials, *molar mass* is referred to as *molecular weight*.

SPECIFIC LEARNING OUTCOMES

C11-3-07: Describe the concept of the mole and its importance to measurement in chemistry.

C11-3-08: Calculate the molar mass of various substances.

(continued)

The following calculation would be considered an extension of these learning outcomes: What is the mass of 6 atoms of ammonium phosphate?

Over the years, chemistry teachers have tried many ways to assist students in mastering these sorts of calculations. One of these methods is provided below for information. When converting from one unit to another, always place the unknown on top, as shown in the example. Then solve for "X" (unknown) either by cross-multiplying or simply by dividing.

Sample Problems

1. How many moles are in 2.3 g of sodium atoms?

$$\frac{X}{1 \text{ mole}} = \frac{2.3 \ \cancel{g}}{23.0 \ \cancel{g}}$$

By dividing, the gram units cancel, leaving mole units for the answer. The units are still cross-multiplied.

X = 0.10 mole (2 sig. figures)

2. The same method works for finding how many moles are in 2.41×10^{23} atoms of copper.

$$\frac{X}{1 \text{ mole}} = \frac{2.41 \times 10^{23} \ \cancel{\text{atoms}}}{6.02 \times 10^{23} \ \cancel{\text{atoms}}}$$

The atom units cancel, leaving the answer in moles.

X = 0.400 mole (3 sig. figures)

3. When the conversion is done in the other direction, then cross-multiplying solves the ratio.

What is the mass of 0.25 mole of NaOH?

$$\frac{X}{40.0 \text{ g}} = \frac{0.250 \ \cancel{\text{mole}}}{1 \ \cancel{\text{mole}}}$$

$$X = 10.0 \text{ g } (3 \text{ sig. figures})$$

Have students check whether their answers are reasonable. By writing the ratios in this way, students are more likely to see the relationship between what is given and what is to be found. Unit (dimensional) analysis should be continued as a process in students' solutions in order to reinforce results obtained from the mole ratios.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

Laboratory Activity

Appendix 3.9: Determining the Molar Mass of a Gas describes a lab activity in which students can determine the molar mass of butane with accuracy.

Many other activities can be done with moles and mass. For example, have students pre-calculate the amounts required for the lab they will conduct for learning outcome C11-3-14.

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Laboratory Reports

The activities outlined for these learning outcomes could be assessed either as formal lab reports using the Laboratory Report Format (see *SYSTH* 14.12) or by using questions and answers from the data collected from the activities.

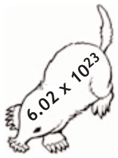
Visual Displays

Students could create a visual diagram or a concept map to illustrate how to convert from one unit to another.

Journal Writing

Students could create a poem, letter, greeting card, or poster inviting parents to a "Mole Day" celebration on October 23 from 6.02 a.m. to 6.02 p.m. The reference comes from linking Avogadro's number (6.02×10^{23} particles) to a specific date and time on October 23 (i.e., 10/23 at 6:02). For the second semester, the "Molar Equinox" occurs on April 23. We use this date for convenience, as it is six months from October 23 (hence, we get our 6×10^{23} again).

Each of these presentation forms could be assessed using an appropriate rubric created with students prior to the assignment. Samples of presentation rubrics are provided in Appendix 10 of this document.



Specific Learning Outcomes

C11-3-07: Describe the concept of the mole and its importance to measurement in chemistry.

C11-3-08: Calculate the molar mass of various substances.

(continued)

Learning Resources Links

Chemistry (Chang 77)

Chemistry (Zumdahl and Zumdahl 86)

Chemistry: The Central Science (Brown, *et al.* 86)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 405)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 87)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 310)

Introductory Chemistry: A Foundation (Zumdahl 216)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 42)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 172)

Microscale Chemistry Laboratory Manual (Slater and Rayner-Canham 29, 81, Experiment 10: Molar Mass of a Gas)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 168)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 83)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 310)

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

NOTES

SPECIFIC LEARNING OUTCOME

C11-3-09: Calculate the volume of a given mass of a gaseous substance from its density at a given temperature and pressure.

Include: molar volume calculation

(1.5 hours)

SLO: C11-3-09

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students have previously examined the property of density in solids, liquids, and gases. The following specific learning outcome was addressed in Grade 8 Science:

- 8-3-06: Measure, calculate, and compare densities of solids, liquids, and gases.

Students have also solved problems with the *density* = *mass/unit volume* (*d* = *m/v*) relationship using the appropriate units. Teachers may, however, need to review and assess student knowledge of this concept. The units commonly used previously related to solution concentration (e.g., grams/100 mL solvent).

Students have been introduced to the phases of matter, and have received an explanation for the properties of gases using the Kinetic Molecular Theory.

TEACHER NOTES

Teachers will remember that, for a gas to behave as an *ideal gas*, the intermolecular forces must be as low in value as possible. To accomplish this, the pressure of a gas must be much less than 1 atmosphere and the temperature must be relatively high. In addition, compliance with ideal gas properties varies significantly from one gas to another (Silberberg 207). Due to the complexity of this issue, assume that all gases are *ideal* for Grade 11 Chemistry.

Most high school chemistry texts define the ideal molar volume of *any* gas at STP to be 22.414 L. Students should be given all the units for STP 0°C and one of the following: 101.3 kPa, 760 mmHg, or 1.00 atm.

General Learning Outcome Connections

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

In fact, most gases vary from 22.414 L even at STP. A list of molar volumes at STP follows (Silberberg 207):

- Ammonia gas (NH_3) 22.079 L
- Chlorine gas (Cl_2) 22.184 L
- Carbon dioxide gas (CO_2) 22.260 L
- Oxygen gas (O_2) 22.390 L
- Argon (Ar) 22.397 L
- **Ideal gas 22.414 L**
- Neon gas (Ne) 22.422 L
- Hydrogen gas (H_2) 22.432 L
- Helium gas (He) 22.435 L

If students use three significant figures, calculations will closely approximate the value 22.4 L. A number of sample calculations follow.

Class Activities

Using a gas density table (see Appendix 3.10: Gas Density Table), have students calculate the molar volume of common gases and the volume of a given mass of a gaseous substance at a given temperature and pressure. Have students solve problems requiring conversions between mass and volume. Encourage them to use logic and reasoning, rather than relying on algorithms and ratios.

Sample Problems

Simple problems using the molar volume would include the following.

Examples (with notes):

1. Determine the volume of 8.00 g of oxygen gas at STP.
2. How many moles would be in 8.96 L of gas at STP?

If students are informed that the molar volume at 25°C and 1.00 atm is 24.5 L/mole, then the following types of problems can also be done.

3. Find the volume of 29.9 g of argon gas at 25.0°C and 1.00 atm.

Students can confirm the value for the molar volume of a gas by using the density of the gas.

SPECIFIC LEARNING OUTCOME

C11-3-09: Calculate the volume of a given mass of a gaseous substance from its density at a given temperature and pressure.

Include: molar volume calculation

(continued)

4. Calculate the molar volume of hydrogen gas if its density is 0.08999 g/L at 0°C and 760 mm of mercury.

   Density is defined as mass per unit volume.

$$D = \frac{M}{V} \text{ or } V = \frac{M}{D}$$

$$V = \frac{2.02\ \cancel{g} \cdot \text{mole}^{-1}}{0.08999\ \cancel{g} \cdot L^{-1}} = 22.4\ \text{L/mole}$$

Conversely, students could calculate the density of a gas at STP using the molar volume and the molar mass of the gas.

Laboratory Activity/Demonstration

The following activity not only gives good results, but also provides students with an opportunity to learn and practise safe lab skills.

A butane lighter is massed before and after the fuel has been released as a gas into a collecting chamber. This measurement is the mass of the gas released into the water. The accuracy of this lab depends to a great extent on the accuracy of the collecting chamber. An inverted funnel could be inserted into a eudiometer tube to collect more effectively any gas evolved. By knowing the accurate volume at a measured temperature and pressure, we can convert the volume of gas to what it would occupy at STP. Then, using 22.4 L/mole, we can calculate the moles of gas released. By dividing the mass of the gas released by the number moles of gas, we can calculate the molar mass of the gas. The gas should be butane, C_4H_{10}. Make a comparison with the correct molar mass. See *McGraw-Hill Ryerson Chemistry 11* (Mustoe, *et al.* 496).

Sample Problems

1. Calculate the molar mass of a gas if its density at 27.0°C and 1.5 atm is 1.95 g/L. What is the gas?

$$D = \frac{M}{V}$$

We know neither M nor V at these conditions, but we can change 22.414 L to these conditions using the combined gas laws.

22.414 L at 273 K and 1.0 atm

_____ L at 300 K and 1.5 atm

$$\frac{22.414\ \text{L} \times 300\ \cancel{\text{K}} \times 1.0\ \cancel{\text{atm}}}{273\ \cancel{\text{K}} \times 1.5\ \cancel{\text{atm}}} = 16.4\ \text{L}$$

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

$$\begin{aligned} M &= D \times V \\ &= \frac{1.95\ \text{g}}{\cancel{\text{L}}} \times \frac{16.4\ \cancel{\text{L}}}{\text{mole}} \\ &= 32.0\ \text{g/mole (3 sig. figures)} \end{aligned}$$

The gas could be O_2.

2. Calculate the density of ethene gas, C_2H_4, at –73°C and 0.445 atm.

   To use $D = \frac{M}{V}$ we must find the molar volume at the given conditions.

   22.414 L at 273 K and 1.0 atm
   _____ L at 200 K and 0.445 atm

$$\frac{22.414\ \text{L} \times 200\ \cancel{\text{K}} \times 1.0\ \cancel{\text{atm}}}{273\ \cancel{\text{K}} \times 0.445\ \cancel{\text{atm}}} = 36.9\ \text{L}$$

$$\begin{aligned} \text{Then } D &= \frac{M}{V} \\ &= \frac{28.04\ \text{g} \cdot \cancel{\text{mole}^{-1}}}{36.9\ \text{L} \cdot \cancel{\text{mole}^{-1}}} \\ &= 0.760\ \text{g/L} \end{aligned}$$

   Problems can also be connected to grams and moles.

3. Calculate the volume of 11.0 g of carbon dioxide gas at 173°C and 55.6 kPa.

$$\begin{aligned} \text{Moles} &= \frac{11.0\ \cancel{\text{g}}}{44.0\ \cancel{\text{g}} \cdot \text{mol}^{-1}} \\ &= 0.250\ \text{mol} \end{aligned}$$

   Volume at STP = 0.25 mol × 22.4 L
   = 5.60 L

   5.60 L at 273 K and 101.3 kPa
   ____ L at 446 K and 55.6 kPa

SPECIFIC LEARNING OUTCOME

C11-3-09: Calculate the volume of a given mass of a gaseous substance from its density at a given temperature and pressure.

Include: molar volume calculation

(continued)

$$\frac{5.60\ \text{L} \times 446\ \cancel{\text{K}} \times 101.3\ \cancel{\text{kPa}}}{273\ \cancel{\text{K}} \times 55.6\ \cancel{\text{kPa}}}$$

Answer = 16.8 L of gas.

Extension

Other problems are possible in combination with the gas laws once students have completely understood the concept of molar volume.

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks

Students solve problems using the molar volume and the definition of density. Most chemistry texts provide a reasonable selection of simple and advanced problems.

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Journal Writing

Students may want to reflect, in their journals, on the results of the classroom activities related to specific learning outcome C11-3-09.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

LEARNING RESOURCES LINKS

Chemistry (Chang 180)

Chemistry (Zumdahl and Zumdahl 205)

Chemistry: The Central Science (Brown, *et al*. 279)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 189, 207)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 66)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 490, 496)

Microscale Chemistry Laboratory Manual (Slater and Rayner-Canham, Experiment 9)

Note: Many of the resources use the Ideal Gas Equation (PV = nRT) or modifications to this relationship to calculate density and molar volume. However, the calculations can be done by changing conditions to STP and then using 22.414 $L \cdot mole^{-1}$.

SPECIFIC LEARNING OUTCOME

C11-3-10: Solve problems requiring interconversions between moles, mass, volume, and number of particles.

(3.0 hours)

SLO: C11-3-10

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students have not previously studied the concepts addressed in learning outcome C11-3-10.

TEACHER NOTES

Historical Connection

Since 1865 there have been over 80 determinations of what we now call Avogadro's number or constant. The name Avogradro's number is an honorary name given as a result of the distinguished work done by Lorenzo Romano Amedeo Carlo Avogadro. He worked with gases, attempting to prove that equal volumes of gas under the same conditions contain the same number of particles.

Avogadro's work with particles on the molecular level laid the groundwork for further investigations by other scientists, such as Jean Baptiste Perrin and Josef Loschmidt. Perrin measured the displacement of colloidal particles that exhibit Brownian motion, and he used the results from these experiments to calculate the first value of Avogadro's constant. Loschmidt's research was based on the Kinetic Molecular Theory.

For a summary of the research done on Avogadro's number, see the following website:

Furtsch, T.A. "Some Notes on Avogadro's Number, 6.022×10^{23}." Tennessee Technological University: <http://iweb.tntech.edu/chem281-tf/avogadro.htm>.

Scroll down to the link "Loschmidt's Number" near the bottom of the page. The summary describes both the original methods that were used and the more modern methods using X-ray diffraction and radioactivity.

Search for other websites containing information on Avogadro. Use your favourite search engine for this.

The official value listed by the National Institute of Standards and Technology (NIST) for Avogadro's constant is 6.0221415×10^{23} mol^{-1}.

General Learning Outcome Connections

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

GLO E1: Describe and appreciate the similarity and diversity of forms, functions, and patterns within the natural and constructed world.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Discuss with students how Avogadro's hypothesis revolutionized thinking in chemistry, and share how "N" was originally found, compared to the modern methods used today.

Students usually have a difficult time relating to such a large number. It is helpful to provide examples.

Sample Problems

1. If we had Avogadro's number of pennies to divide among all the people in the world, how much would each person get?

   As of January 15, 2005, the world population was estimated to be 6,412,930,900.

   $$\frac{6.02 \times 10^{23} \text{ pennies}}{6,412,930,900 \text{ people}} = 9.3873 \times 10^{13} \text{ pennies or approximately \$939,000,000,000}$$

2. If Avogadro's number of sheets of paper were stacked one on top of one another, the pile would reach past our solar system.

3. Avogadro's number of grains of rice would cover the surface of the Earth to a depth of 75 m. See *Prentice Hall Chemistry: Connections to Our Changing World* (LeMay, *et al*. 319).

Engage students further with practical problems relating to the conversion of mass, moles of substance, and volume units. Less emphasis should be placed on the conversion of numbers of particles to these other units.

In the following examples, devote particular attention to the use of correct units. Recall that students used unit analysis with the problems in Topic 2, which addressed the gas laws.

Sample Problems

1. Determine the mass of 0.250 mol of NH_4OH.

   $$0.250 \cancel{\text{mol}} \times \frac{35.0 \text{ g}}{\cancel{\text{mol}}} = 8.75 \text{ g}$$

SPECIFIC LEARNING OUTCOME

C11-3-10: Solve problems requiring interconversions between moles, mass, volume, and number of particles.

(continued)

2. How many particles are in 2.0 mol of C atoms?

   If 1.0 mol = 6.02×10^{23}, then 2.0 mol should be twice as much.

$$2.0\ \cancel{\text{mol}} \times \frac{6.02 \times 10^{23}\ \text{particles}}{\cancel{\text{mol}}} = 12.04 \times 10^{23}\ \text{particles}$$

   or 1.2×10^{24} particles (2 sig. figures)

3. What would be the volume of 1.70 g of ammonia gas, NH_3, at STP?

$$\frac{1.70\ \text{g}}{17.0\ \text{g} \cdot \cancel{\text{mol}^{-1}}} \times 22.4\ \text{L} \cdot \cancel{\text{mol}^{-1}}$$

   Answer = 2.24 L (3 sig. figures)

4. How many moles in 4.82×10^{24} particles?

$$\frac{4.82 \times 10^{24}\ \cancel{\text{particles}}}{6.02 \times 10^{23}\ \cancel{\text{particles}} \cdot \text{mol}^{-1}} = 8.01\ \text{mol}$$

5. Calculate the number of molecules of carbon dioxide gas, CO_2, in 1.68 L of gas at STP?

$$\frac{1.68\ \cancel{\text{L}}}{22.4\ \cancel{\text{L}} \cdot \cancel{\text{mol}^{-1}}} \times 6.02 \times 10^{23}\ \text{particles} \cdot \cancel{\text{mol}^{-1}}$$

   Answer = 4.52×10^{22} particles

SUGGESTIONS FOR ASSESSMENT

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment.

Research Reports

Have students, individually or in small groups, conduct research on Avogadro's number and report their findings. The information collected could be presented as

- written reports
- oral presentations
- bulletin board displays
- multimedia presentations

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Visual Displays

Students could present examples that might illustrate better the size of Avogadro's number. The examples could be displayed as

- posters
- pamphlets
- bulletin board exhibits

Journal Writing

Students may want to write a journal entry about Avogadro's number or examine the reasons why his name has been attached to this quantity even though he was not responsible for suggesting the number. An interesting twist to the history would be to have Avogadro "as himself" write the letter in the first person.

Creative Writing Activity

For a distinctively different focus on the mole, see Appendix 3.11: Creative Mole: Writing Activity.

LEARNING RESOURCES LINKS

Chemistry (Chang 77)

Chemistry (Zumdahl and Zumdahl 87)

Chemistry: The Central Science (Brown, *et al.* 89)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 406)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 91)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 320)

Introductory Chemistry: A Foundation (Zumdahl 216)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 50)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 172)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 171)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 82)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 319, 323)

SPECIFIC LEARNING OUTCOME

C11-3-11: Determine empirical and molecular formulas from percent composition or mass data.

(0.5 hour)

SLO: C11-3-11

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students have previously written formulas in Grade 10 Science and in Topic 3 of Grade 11 Chemistry:

- S2-2-04: Write formulas and names of molecular compounds using prefixes.
  Include: mono, di, tri, tetra
- C11-3-03: Write formulas and names for polyatomic compounds using International Union of Pure and Applied Chemistry (IUPAC) nomenclature.

However, students have not yet been informed that there are many types of formulas.

TEACHER NOTES

Most Learning Resources Links listed for this outcome provide a detailed explanation of the various types of formulas, together with activities and labs designed to allow students to determine formulas experimentally.

General information about various types of formulas follows:

- In a *chemical* formula, the elements are represented by symbols, and a subscript number represents the number of each element.
  Example: The chemical formula for ethane is C_2H_6.
- An *empirical (simplest)* formula represents the relative number of atoms of each element in the compound.
  Example: The empirical formula for ethane is CH_3.
- A *molecular* formula represents the actual number of atoms of each element rather than a ratio of atoms.
  Example: The molecular formula for ethane is C_2H_6.

General Learning Outcome Connections

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

GLO E1: Describe and appreciate the similarity and diversity of forms, functions, and patterns within the natural and constructed world.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Another way of representing this is:

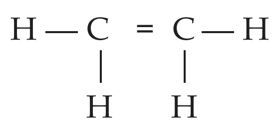
Molecular formula = $(\text{empirical formula})_n$, where “n” is a whole number such as n = 1, etc.

In this example, n = 2

$C_2H_6 = (CH_3)_2$

- A *structural* formula shows the bonds that connect each atom and provides information about the number of atoms.

  Example: The structural formula for ethane is



Since students will be determining formulas from percent composition and mass, remind them that there is a distinction between molecular and ionic compounds. In the strictest sense, it is not correct to say that 58.5 g/mol is the molar mass of non-molecular NaCl. It is more correct to call it the *formula mass*.

The percent composition of a compound is the mass of each element divided by the total mass of the compound x 100%. The percent composition can be determined from the formulas of the compound or experimentally by a decomposition reaction of the compound. In the activities suggested for this learning outcome, students are given either the percent composition or mass data and are required to determine the appropriate formula.

The problems that students are expected to solve with respect to the determination of formula from percent composition and mass data should be kept as simple as possible. Several examples follow.

SPECIFIC LEARNING OUTCOME

C11-3-11: Determine empirical and molecular formulas from percent composition or mass data.

(continued)

Sample Problems

1. If a compound has a composition of 40.0% carbon (C), 6.714% hydrogen (H), and 53.29% oxygen (O), determine the *empirical* formula of the compound.

   Assume that there is a 100.0 g sample of the compound, in which case:

   $$\text{C} \quad \frac{40.0\ \text{g}}{12.0\ \text{g/mol}} = 3.3\ \text{mol}$$

   $$\text{H} \quad \frac{6.71\ \text{g}}{1.01\ \text{g/mol}} = 6.7\ \text{mol}$$

   $$\text{O} \quad \frac{53.29\ \text{g}}{16.0\ \text{g/mol}} = 3.3\ \text{mol}$$

   By dividing by the smallest number of moles, the ratio between the elements in the formula is $C_1H_2O_1$.

2. If a compound contains 71.65% chlorine (Cl), 24.27% carbon (C), and 4.07% hydrogen (H), determine the *molecular* formula if the molar mass is 98.96 g/mol.

   Assume that there is a 100.0 g sample of the compound, in which case:

   $$\text{Cl} \quad \frac{71.65\ \text{g}}{35.5\ \text{g/mol}} = 2.02\ \text{mol}$$

   $$\text{C} \quad \frac{24.27\ \text{g}}{12.01\ \text{g/mol}} = 2.02\ \text{mol}$$

   $$\text{H} \quad \frac{4.07\ \text{g}}{1.01\ \text{g/mol}} = 4.01\ \text{mol}$$

   By dividing by the smallest number of moles, the ratio between the elements is $C_1H_2Cl_1$, and the formula mass would then be 49.5 g/mol.

   If the molar mass is 98.96 g/mol, the molecular formula would be a multiple of the simplest formula, or

   $$\frac{98.96\ \text{g/mol}}{49.5\ \text{g/mol}} = 2$$

   The molecular formula is therefore $C_2H_4Cl_2$.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

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3. Experimental analysis determined that a compound contained 7.30 g of sodium (Na), 5.08 g of sulphur (S), and 7.62 g of oxygen (O). What is the *simplest* formula of this compound?

$$\text{Na} \quad \frac{7.30\ \cancel{\text{g}}}{23.0\ \cancel{\text{g}}/\text{mol}} = 0.317\ \text{mol}$$

$$\text{S} \quad \frac{5.08\ \cancel{\text{g}}}{32.1\ \cancel{\text{g}}/\text{mol}} = 0.158\ \text{mol}$$

$$\text{O} \quad \frac{7.62\ \cancel{\text{g}}}{16.90\ \cancel{\text{g}}/\text{mol}} = 0.476\ \text{mol}$$

By dividing by the smallest number of moles, the simplest formula becomes:

$Na_2S_1O_3$

SUGGESTIONS FOR ASSESSMENT

Laboratory Reports

If students participate in lab activities, their work could be assessed as formal lab reports using the Laboratory Report Outline or the Laboratory Report Format (see *SYSTH* 11.38, 14.12) or by using questions and answers from the data collected from the activities.

Paper-and-Pencil Tasks

Students could be assessed on solving various problems that relate to formulas and either percent composition or mass data.

Specific Learning Outcome

C11-3-11: Determine empirical and molecular formulas from percent composition or mass data.

(continued)

Learning Resources Links

Chemistry (Chang 89)

Chemistry (Zumdahl and Zumdahl 93)

Chemistry: The Central Science (Brown, *et al.* 84)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 426)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 328)

Introductory Chemistry: A Foundation (Zumdahl 226)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 78)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 207)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 111)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 332)

Investigations

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 329—percent composition of sweeteners)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 92—determining the empirical formula of magnesium oxide, MgO)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 212—determining the empirical formula of MgO)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 195—determining the formula of a hydrate)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 121—percent composition by mass of MgO)

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

NOTES

SPECIFIC LEARNING OUTCOMES

C11-3-12: Interpret a balanced equation in terms of moles, mass, and volumes of gases.

(0.5 hour)

C11-3-13: Solve stoichiometric problems involving moles, mass, and volume, given the reactants and products in a balanced chemical reaction.

Include: heat of reaction problems

(3.5 hours)

SLO: C11-3-12
SLO: C11-3-13

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

A detailed discussion of the molar coefficients has not previously taken place. However, in Grade 10 Science, students wrote chemical reactions from word equations and balanced them for conservation of atoms (learning outcome S2-2-06). In Grade 11 Chemistry, students will likely have balanced reactions that contained polyatomic ions in the treatment of learning outcome C11-3-05.

Assessing Prior Knowledge

Check for student understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share—see *SYSTH*, Chapter 9).

TEACHER NOTES

Show students the various ways in which a balanced chemical equation or reaction can be interpreted. Emphasize that the *mole* is the central unit in understanding the relationship between reactants and products in a chemical reaction—that is, the balanced reaction coefficients can represent moles, molecules, conservation of mass in grams, or amu, or volumes of gas. See *Chemistry: The Molecular Nature of Matter and Change* (Silberberg 105).

General Learning Outcome Connections

GLO A1: Recognize both the power and limitations of science as a way of answering questions about the world and explaining natural phenomena.

GLO A2: Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop.

GLO A4: Identify and appreciate contributions made by women and men from many societies and cultural backgrounds that have increased our understanding of the world and brought about technological innovations.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

GLO E1: Describe and appreciate the similarity and diversity of forms, functions, and patterns within the natural and constructed world.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

Since students have previously written and balanced chemical reaction equations involving polyatomic ions (learning outcome C11-3-05), teachers could now introduce an extension to stoichiometry using polyatomic species.

Historical Connection

Jeremias Benjamin Richter (1762–1807) introduced *stoichiometry* in 1792. He is credited with stating, “stoichiometry is the science of measuring the quantitative proportions or mass ratios in which chemical elements stand to one another.”

Sample Problems

1. At first, provide students with very simple questions regarding the use of coefficients, and then have them work through a series of more complex examples. A suggested progression follows:

   Example: $3H_{2(g)} + 1N_{2(g)} = 2NH_{3(g)}$

   Sample Questions (with notes):

   a) First, work though multiples of molar coefficients.

      How many moles of ammonia would be produced from the reaction of 6 mol of $H_{2(g)}$ and 2 mol of $N_{2(g)}$?

   b) Then:

      How many moles of $N_{2(g)}$ would be required to react exactly with 9 mol of $H_{2(g)}$?

   c) Followed by:

      How many moles of hydrogen and nitrogen gases would be required to produce 0.4 mol of ammonia?

   Through this progression, students have an opportunity to work with coefficients before working with mass and volume. (However, the molar coefficients also represent volumes of gas.)

SPECIFIC LEARNING OUTCOMES

C11-3-12: Interpret a balanced equation in terms of moles, mass, and volumes of gases.

C11-3-13: Solve stoichiometric problems involving moles, mass, and volume, given the reactants and products in a balanced chemical reaction.

Include: heat of reaction problems

(continued)

2. Once students can manipulate the coefficients to solve mole problems, start with one reactant that is given as mass.

   Example: $3H_{2(g)} + 1N_{2(g)} = 2NH_{3(g)}$

   Question: Calculate the number of moles of ammonia produced with 12.0 g of hydrogen gas and an unlimited amount of nitrogen.

   Solution: Since 12.0 g is 6.0 mol, which means the mole ratio is doubled, there must be 4.0 mol of ammonia produced.

3. There are almost as many ways of solving *mass-to-mass stoichiometry problems* as there are chemistry teachers.

   One such progression is provided here as an example. Standard chemistry texts also provide additional methods. Most texts provide their own "unique" method of setting up these calculations. Teachers should fit the solution format to the learning style and ability of their students.

   A recommendation is to use mass amounts that give moles that can be solved visually with the mole ratio of the balanced reaction.

   Example: $3H_{2(g)} + 1N_{2(g)} = 2NH_{3(g)}$

   Question: Calculate the mass of ammonia produced from 1.2 g of hydrogen reacting with an excess of nitrogen.

   Solution: 1.2 g of hydrogen = 0.60 mol

   Have students place the moles of hydrogen over the molar coefficient for hydrogen. As the amount of nitrogen is unlimited, the amount of product is dependent on the amount of hydrogen, and so we can ignore nitrogen from the mole ratio.

   $$\frac{0.60}{3H_{2(g)}} + \frac{\text{unlimited}}{1N_{2(g)}} = \frac{X}{2NH_{3(g)}}$$

   The mole ratio is

   $$\frac{0.60}{3} = \frac{X}{2}$$

   X = 0.40 mol of NH_3 or 6.8 g of product

Skills and Attitudes Outcomes

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

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4. Once students have mastered mass-to-mass problems, introduce the *heat of reaction*.

   Question: What quantity of heat is produced in the complete combustion of 60.16 g of ethane, C_2H_6, if the heat of combustion is 1560 kJ/mol of ethane?

   $$2C_2H_{6(g)} + 7O_{2(g)} \rightarrow 4CO_{2(g)} + 6H_2O_{(g)}$$

   Solution:

   $$60.16\ \cancel{g\ C_2H_6} \times \frac{1\ \cancel{mol\ C_2H_6}}{30.08\ \cancel{g\ C_2H_6}} \times \frac{1560\ kJ}{1\ \cancel{mol\ C_2H_6}} = 3120\ kJ$$

Laboratory Activities

The following lab activities could be used to reinforce the concept of stoichiometry.

1. **Stoichiometry of a Reaction Producing a Precipitate:** This microscale experiment requires students to react solid iron with copper(II) sulphate. The full lab procedure can be found in Experiment 14 in *Microscale Chemistry Laboratory Manual* (Slater and Rayner-Canham 39).

2. **Stoichiometry: Concept Extension:** This lab involves reacting solutions of varying concentrations in order to develop the stoichiometric proportions between sodium hypochlorite, NaOCl, and sodium thiosulphate, $Na_2S_2O_3$.

   This lab activity could also be used when addressing specific learning outcomes dealing with the notion of *limiting reagents*.

Suggestions for Assessment

Laboratory Reports

The activities suggested for these learning outcomes could be assessed as formal lab reports using the Laboratory Report Outline or the Laboratory Report Format (see *SYSTH* 11.38, 14.12) or by using questions and answers from the data collected from the activities.

Written Test/Quiz

Students could interpret various stoichiometric word problems in which they balance chemical equations and determine quantities of reactants and products.

SPECIFIC LEARNING OUTCOMES

C11-3-12: Interpret a balanced equation in terms of moles, mass, and volumes of gases.

C11-3-13: Solve stoichiometric problems involving moles, mass, and volume, given the reactants and products in a balanced chemical reaction.

Include: heat of reaction problems

(continued)

Internet Research

Based on their knowledge of stoichiometry and their research on gasoline and the size of gas tank and fuel economy of specified vehicles, students calculate the following:

- the cost of filling a tank of gas
- the number of moles of gasoline in a full tank of gas
- the mass of a full tank of gas
- the distance travelled on a full tank
- the amount of carbon dioxide, CO_2, emitted when a full tank is consumed

See Appendix 3.12: The Stoichiometry of Gasoline: Internet Research Activity.

Visual Displays

Use concept-mapping software to create a concept map indicating the various quantitative relationships among terms such as mole, mass, volume, reactants, products, and chemical equation.

Peer Assessment

Students construct stoichiometry problems that could be used for peer assessment.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

LEARNING RESOURCES LINKS

Chemistry (Chang 95)

Chemistry (Zumdahl and Zumdahl 108)

Chemistry: The Central Science (Brown, *et al.* 95)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 404)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 105)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 354)

Introductory Chemistry: A Foundation (Zumdahl 255)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 119)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 235)

Microscale Chemistry Laboratory Manual (Slater and Rayner-Canham 39)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 144)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 347)

SPECIFIC LEARNING OUTCOME

C11-3-14: Identify the limiting reactant and calculate the mass of a product, given the reaction equation and reactant data.

(3.0 hours)

SLO: C11-3-14

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Specific chemistry examples involving limiting factors (such as amounts of reagent) have not been addressed before Grade 11, although teachers have likely cited many examples in day-to-day living where the product has been limited by what was available.

TEACHER NOTES

In learning outcome C11-3-13, students were introduced to the idea that a reactant could be available in excess or even unlimited in amount. A class discussion could then lead students to conclude that, where more than one reactant is involved, the reactant that is *not in excess* would *limit* the amount of product and that some of the excess reactant would be left over and admixed with the product.

To reinforce this concept, students need to appreciate practical, real-life examples of limiting factors, such as the key ingredients required to bake a cake (e.g., sodium bicarbonate), or the parts required to manufacture a car that functions. If one of the ingredients (or parts) is *missing*, the final product cannot be produced. For instance, as the missing ingredient or part would determine whether the process could be completed at all, the concept of a *limiting factor* can become apparent to students.

Students should begin by solving *limiting reagent* type of problems that are confined to mole-mole calculations. Emphasize the need to balance the equation first so as to obtain the correct mole ratios. As students gain confidence, mass and volume calculations should be incorporated into the problems. By the time learning outcome C11-3-14 has been demonstrated, students should be able to calculate the quantity of excess reagent that does not react and account for its presence among the products of a reaction.

General Learning Outcome Connections

GLO C4: Demonstrate appropriate critical thinking and decision-making skills when choosing a course of action based on scientific and technological information.

GLO C6: Employ effective communication skills and use information technology to gather and share scientific and technological ideas and data.

GLO C7: Work cooperatively and value the ideas and contributions of others while carrying out scientific and technological activities.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-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

C11-0-S3: Design and implement an investigation to answer a specific scientific question.

Include: materials, independent and dependent variables, controls, methods, safety considerations

C11-0-S5: Collect, record, organize, and display data using an appropriate format.

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

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

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Emphasize that the limiting reactant is not necessarily the reactant with the smallest mass or volume. Explain to students that they must calculate the number of moles of product formed from the number of moles of each reactant in order to identify the limiting reactant. For a solution strategy, consult learning resources for typical problem-solving techniques involving limiting reagent situations. In doing these problems, students readily see the powerful use of the mole concept. (For a solution strategy, see Appendix 3.13: How to Solve a Limiting Reactant Problem.)

Demonstration

The burning of magnesium can be used to introduce students to limiting reactants.

$$Mg_{(s)} + O_{2(g)} \rightarrow MgO_{(s)}$$

When all the magnesium is burned, the reaction ceases. Therefore, magnesium is the limiting reactant because it dictates the quantity of product formed. Oxygen gas is the excess reactant because it is still present when the reaction ceases.

Laboratory Activities

Students could do simple labs to reinforce the *limiting factor* concept experimentally.

1. Cut four or five pieces of magnesium ribbon of different sizes. Do a pre-lab test to determine the correct amount of magnesium and concentration of hydrochloric acid required to inflate a balloon. The amount and concentration of the acid would be constant, whereas the amount of magnesium would vary. Have students place the pieces of magnesium into pre-stretched balloons that are similar in size. Attach the balloons to an Erlenmeyer flask to which an appropriate amount of acid has been added. Once the balloons are fitted, the balloon can be tipped to allow the magnesium strip to fall into the acid. As the magnesium is the limiting factor, the balloons will inflate to different amounts to

SPECIFIC LEARNING OUTCOME

C11-3-14: Identify the limiting reactant and calculate the mass of a product, given the reaction equation and reactant data.

(continued)

illustrate that the acid is excess and the magnesium is limiting. It is possible to calculate the stoichiometric volume of hydrogen gas expected using Boyle's Law and knowing the atmospheric pressure in the room. The gas volume could be collected by water displacement if the apparatus was modified with a delivery tube. See *Prentice Hall Chemistry: Connections to Our Changing World* (LeMay, *et al*. 366).

2. This activity could also be done by adding differing amounts of effervescent antacid tablets to water and collecting the gas that is produced.

References to more formal student experiments can be found in the Learning Resources Links.

STSE Issue

Automobiles use the energy produced during the combustion of gasoline. The combustion of gasoline usually produces water and carbon dioxide. Gasoline is a complex mixture of many organic compounds; however, the following reaction is considered to be representative of a general reaction.

$$2C_8H_{18(l)} + 25O_{2(g)} = 16CO_{2(g)} + 18H_2O_{(g)}$$

If the quantity of oxygen is limited in the reaction, however, the pollutant carbon monoxide is produced instead. Students could calculate the volume of $CO_{2(g)}$ emission from 1 L of gasoline as the limiting factor and oxygen as an unlimited reactant, assuming the conditions to be STP.

Have students then calculate the amount of $CO_{2(g)}$ for their own family automobile or other means of transport for a day, a week, and over the average life expectancy of the vehicle.

A discussion of the merits and shortcomings of the scientific community's research agenda into the anthropogenic CO_2 contribution to potential global warming could be conducted in relation to this topic. It should be noted that there is significantly polarized debate on the issue among scientists. Students should be justifiably cautious about accepting unsubstantiated claims about global warming. This issue provides an opportunity to engage students in the patterns of behaviour that occur within science during what can be termed a "crisis" situation. The word "crisis" in this context is that of philosopher and historian of science, Thomas S. Kuhn, and comes from his influential writing *The Structure of Scientific Revolutions*.

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-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

C11-0-S3: Design and implement an investigation to answer a specific scientific question.

Include: materials, independent and dependent variables, controls, methods, safety considerations

C11-0-S5: Collect, record, organize, and display data using an appropriate format.

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

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

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RAFT Activity

Students complete a RAFT activity in which they describe their role in a reaction on behalf of a limiting reactant or an excess reactant. (See *SYSTH* 13.23-13.28.)

SUGGESTIONS FOR ASSESSMENT

Paper-and-Pencil Tasks: Written Test/Quiz

Students solve problems involving a limiting reactant.

Journal Writing

1. Students create an analogy to represent a limiting reactant problem.

   Example: If a sundae requires 2 scoops of ice cream, 1 cherry, and 50 mL of chocolate syrup, how many sundaes can be made with 8 scoops of ice cream, 6 cherries, and 100 mL of chocolate syrup?

2. Students could also identify how limiting reactants influence their everyday lives.

   Example: The barbeque stops functioning when it runs out of propane.

3. Journal writing could be connected to an STSE issue.

Problem Construction

Students construct their own limiting reactant problems, including a solution.

SPECIFIC LEARNING OUTCOME

C11-3-14: Identify the limiting reactant and calculate the mass of a product, given the reaction equation and reactant data.

(continued)

Research Reports

Have students, individually or in small groups, present their examples for limiting factor situations. The information collected could be presented as

- written reports
- oral presentations
- bulletin board displays
- multimedia presentations

Each of these presentation styles could be assessed using an appropriate rubric created with students prior to the assignment. Samples of presentation rubrics are provided in Appendix 10 of this document.

Laboratory Reports

The activities suggested for this learning outcome could be assessed as formal lab reports using the Laboratory Report Format (see *SYSTH* 14.12) or by using questions and answers from the data collected from the activities.

LEARNING RESOURCES LINKS

Chemistry (Chang 99)

Chemistry (Zumdahl and Zumdahl 113)

Chemistry: The Central Science (Brown, *et al.* 99)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 220)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 111)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 364)

Glencoe Chemistry: Matter and Change: Laboratory Manual – Teacher Edition (89—limiting reactant investigation with magnesium metal and varying amounts of hyrochloric acid)

Introductory Chemistry: A Foundation (Zumdahl 197—treatment of the combustion of fuels, 259)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 112—limiting reactant investigation with sodium hydrogen carbonate and hydrochloric acid, 129)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 252, 255—limiting reactant investigation with aluminum metal and copper(II) chloride)

SKILLS AND ATTITUDES OUTCOMES

C11-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles…

C11-0-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…

C11-0-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

C11-0-S3: Design and implement an investigation to answer a specific scientific question.

Include: materials, independent and dependent variables, controls, methods, safety considerations

C11-0-S5: Collect, record, organize, and display data using an appropriate format.

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

C11-0-S7: Interpret patterns and trends in data, and infer and explain relationships.

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

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Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 230, 232—limiting reactant investigation with calcium nitrate and sodium phosphate)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 149)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 366)

Most learning resources provide simple activities or analogies that illustrate the concept of limiting reactants. Choosing which activity to complete as a class lab or as a teacher demonstration will ultimately be determined by what materials are available and how much time is on hand.

SPECIFIC LEARNING OUTCOME

C11-3-15: Perform a lab involving mass-mass or mass-volume relations, identifying the limiting reactant and calculating the mole ratio.

Include: theoretical yield, experimental yield

(2.0 hours)

SLO: C11-3-15

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students have previously studied gases, including the relationship between pressure and temperature.

TEACHER NOTES

Students will perform labs involving a limiting reactant. Provide students with the necessary background on the techniques that may be required to perform the labs, such as filtration and the use of gas-collecting tubes.

Laboratory Activities

Have students perform a lab to investigate the stoichiometric relationship between reactants and products. Many experiments can be done to illustrate this concept. A number of suggestions follow; however, the details for these experiments would have to be obtained from lab manuals. Additional references for student investigations are available in the Learning Resources Links listed for this learning outcome.

1. A classic lab example is the reaction of an excess of copper with a limiting solution of silver nitrate.

   $$Cu_{(s)} + 2AgNO_{3(soln)} = 2Ag_{(s)} + Cu(NO_3)_{2(soln)}$$

   This investigation gives excellent results and can be extended to include the conservation of mass by using additional procedures and reactions. (See Appendix 3.14: The Behaviour of Solid Copper Immersed in a Water Solution of the Compound Silver Nitrate.)

General Learning Outcome Connections

GLO C1: Recognize safety symbols and practices related to scientific and technological activities and to their daily lives, and apply this knowledge in appropriate situations.

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

GLO C3: Demonstrate appropriate problem-solving skills when seeking solutions to technological challenges.

GLO C4: Demonstrate appropriate critical thinking and decision-making skills when choosing a course of action based on scientific and technological information.

GLO C6: Employ effective communication skills and use information technology to gather and share scientific and technological ideas and data.

GLO C7: Work cooperatively and value the ideas and contributions of others while carrying out scientific and technological activities.

SKILLS AND ATTITUDES OUTCOMES

C11-0-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

C11-0-S3: Design and implement an investigation to answer a specific scientific question.

Include: materials, independent and dependent variables, controls, methods, safety considerations

C11-0-S5: Collect, record, organize, and display data using an appropriate format.

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

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

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2. Another example is the single replacement reactions of
   - copper(II) sulphate pentahydrate and steel wool

     $Fe_{(s)} + CuSO_4 \cdot 5H_2O_{(aq)} = Cu_{(s)} + FeSO_{4(soln)}$

   Or
   - aluminum and copper(II) chloride dehydrate

     $2Al_{(s)} + 3CuCl_{2(aq)} = 3Cu_{(s)} + 2AlCl_{3(soln)}$

3. A further example is the reaction of magnesium ribbon with an excess of hydrochloric acid.

   $Mg_{(s)} + 2HCl_{(aq)} = H_{2(g)} + MgCl_{2(soln)}$

   The hydrogen gas produced would be collected by the displacement of water in a eudiometer tube. In this lab, students convert the experimental volume of gas at room temperature to the volume occupied at STP conditions. (Dalton's Law of partial pressures was not discussed in the treatment of gas laws. So the partial pressure from water vapour would have to be neglected. Fortunately, the contribution from water vapour is not large.) Students calculate the theoretical yield from the mass of magnesium and the reaction and compare it to the experimental value. (See Appendix 3.15: A Quantitative Investigation of the Reaction of a Metal with Hydrochloric Acid.)

4. If teachers have access to probeware, they may choose to do a lab procedure using probes, electronic data collection, and a plotting software interface to represent the data. (See Appendix 3.16: Stoichiometry: Reactants, Products, and Enthalpy Changes.)

SPECIFIC LEARNING OUTCOME

C11-3-15: Perform a lab involving mass-mass or mass-volume relations, identifying the limiting reactant and calculating the mole ratio.

Include: theoretical yield, experimental yield

(continued)

SUGGESTIONS FOR ASSESSMENT

Laboratory Reports

The experiments suggested for this learning outcome could be assessed as formal lab reports using the Laboratory Report Format (see *SYSTH* 14.12) or by using questions and answers from the data collected from the activities.

For each of the experiments, students determine the predicted and experimental yields. They then use these values to calculate the percent yield. Encourage students to identify and explain sources of experimental error.

Student Activity

Have students design an experimental lab that could be used to illustrate quantitatively the concept of a *limiting reactant*. A sample student-designed experiment can be found in most standard chemistry resources for students.

Rubrics/Checklists

See Appendix 10 for a variety of rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment of lab skills and lab reports.

Paper-and-Pencil Tasks

Students could solve problems that involve one of the reactants being excess.

SKILLS AND ATTITUDES OUTCOMES

C11-0-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

C11-0-S3: Design and implement an investigation to answer a specific scientific question.

Include: materials, independent and dependent variables, controls, methods, safety considerations

C11-0-S5: Collect, record, organize, and display data using an appropriate format.

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

C11-0-S9: Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction

LEARNING RESOURCES LINKS

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 374—reaction of Fe with $CuSO_4 \cdot 5H_2O$)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 112—reaction of HCl and $NaHCO_3$)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 235—reaction of HCl and $NaHCO_3$)

Microscale Chemistry Laboratory Manual (Slater and Rayner-Canham, Experiment 14: reaction of Fe with $CuSO_4 \cdot 5H_2O$, Experiment 15: reaction of $NaHCO_3$ and H_2SO_4)

Nelson Chemistry 11, Ontario Edition (Jenkins, *et al.* 227—reaction of zinc and lead(II) nitrate)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 154—reaction of strontium chloride and copper(II) sulphate)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 374—reaction of Fe with $CuSO_4 \cdot 5H_2O$)

SPECIFIC LEARNING OUTCOME

C11-3-16: Discuss the importance of stoichiometry in industry and describe specific applications.

Examples: analytical chemistry, chemical engineering, industrial chemistry…

(2.5 hours)

SLO: C11-3-16

SUGGESTIONS FOR INSTRUCTION

Entry-Level Knowledge

Students have not previously studied the concepts in this learning outcome.

TEACHER NOTES

Students are not expected to study the examples identified in this learning outcome in great detail. The examples simply serve as an indicator of the importance of stoichiometry in our lives. Teachers are encouraged to use local examples of the application of stoichiometry, wherever possible. Examples could include: air bags, ammonia production, breath analysis, fertilizers, metallurgy, rocket fuels, and so on. Some information is provided below.

Teachers can have students collect background information from their own chemistry textbooks or do additional research using print and online resources. Some teacher resources referenced in the Learning Resources Links also provide related information.

Many online sources connect stoichiometry principles to applications. For example, see the links at the following website.

Chemistry Coach: <http://www.chemistrycoach.com/tutorial.htm#tutorials>

The online resources listed below can provide teachers with some initial guidance in identifying common industrial applications of classical stoichiometry. These examples are by no means exhaustive.

Applications of Stoichiometry: Examples

- **Air-Bag Technology (Gas Chemistry)**

  The following reaction illustrates the explosive production of nitrogen gas from sodium azide to inflate automobile air bags:

  $$2NaN_{3(s)} = 2Na_{(s)} + 3N_{2(g)}$$

General Learning Outcome Connections

GLO A5: Recognize that science and technology interact with and advance one another.

GLO B4: Demonstrate knowledge of and personal consideration for a range of possible science- and technology-related interests, hobbies, and careers.

SKILLS AND ATTITUDES OUTCOMES

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

C11-0-R2: Evaluate information obtained to determine its usefulness for information needs.
Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…

C11-0-R3: Quote from or refer to sources as required and reference information sources according to an accepted practice.

C11-0-R5: Communicate information in a variety of forms appropriate to the audience, purpose, and context.

- **Ammonia Production**

AUS-e-TUTE. Haber Process for the Production of Ammonia: <http://www.ausetute.com.au/haberpro.html>

This website describing the Fritz Haber process for manufacturing ammonia may be somewhat complex for students, but is a valuable resource for teachers.

Wikipedia: <http://en.wikipedia.org/wiki/Fritz_Haber>

This website provides a biography of Fritz Haber, along with further readings and external links. Do exercise caution with materials here, as Wikepedia relies upon its audience to referee the soundness of the content.

- **Fireworks**

Glencoe Online. An Internet WebQuest. The Chemistry of Fireworks: <http://www.glencoe.com/sec/science/webquest/content/fireworks.shtml>

- **Breath Analysis (Breathalyzers)**

Howstuffworks. How Breathalyzers Work: <http://science.howstuffworks.com/breathalyzer3.htm>

This website explains how breathalyzers work to detect alcohol in vapours and provides information about various kinds of breathalyzers marketed today.

The following reaction equation summarizes a colourful reaction involving a change in the oxidation state of chromium from the +6 state to the reduced state of +3 (initially as potassium chromate going to chromium sulphate):

$$2K_2Cr_2O_7 + C_2H_5OH + H_2SO_4 \rightarrow 2Cr_2(SO_4)_3 + K_2SO_4 + HC_2H_3O_2 + H_2O$$

(reddish-orange) (green)

An explanation is available in *Chemistry* (Chang 138).

SPECIFIC LEARNING OUTCOME

C11-3-16: Discuss the importance of stoichiometry in industry and describe specific applications.

Examples: analytical chemistry, chemical engineering, industrial chemistry…

(continued)

- **Industrial Use**

  Hydrogen sulphide gas is often used in the manufacture of cellophane.

  $2CH_{4(g)} + S_{8(s)} = 2CS_{2(l)} + 4H_2S_{(g)}$

  Wood pulp (cellulose fibre) is dissolved in sodium hydroxide and treated with H_2S gas to form viscose, an intermediate in the formation of rayon and cellophane.

  Potash and quicklime are used in the manufacture of soap.

  $K_2CO_{3(s)} + CaO_{(s)} + H_2O_{(l)} = 2KOH_{(soln)} + CaCO_{3(soln)}$

- **Metallurgical Use**

  Due to its light weight and strength, titanium is a transition metal used in the manufacture of many alloys.

  $TiO_{2(s)} + C_{(s)} + 2Cl_{2(g)} = TiCl_{4(s)} + CO_{2(g)}$

- **Chemical Engineering**

  Solid rocket fuel is a mixture of 12% aluminum powder and 74% ammonium perchlorate. Once ignited, the reaction *cannot* be stopped!

  $8Al_{(s)} + 3NH_4ClO_{3(s)} = 4Al_2O_{3(s)} + NH_4Cl_{(s)}$

SUGGESTIONS FOR ASSESSMENT

Class Discussion

To validate stoichiometry as a topic not only for the chemistry classroom, have students provide examples of industrial applications.

Research/Reports

Have students research and report on one or more applications of stoichiometry. Results could be shared in written, verbal, or electronic format. If students are to use the Internet for research, provide them with key search words to reduce search time. Many of the texts listed in the Learning Resources Links contain information on some examples identified in the learning outcome.

SKILLS AND ATTITUDES OUTCOMES

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

C11-0-R2: Evaluate information obtained to determine its usefulness for information needs.
Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…

C11-0-R3: Quote from or refer to sources as required and reference information sources according to an accepted practice.

C11-0-R5: Communicate information in a variety of forms appropriate to the audience, purpose, and context.

Research Report Presentations

Based on their research, students describe how stoichiometry is used in industry. Information may be shared with the entire class through Jigsaw activities (see *SYSTH* 3.19, 3.20) or through formal presentations to the entire class.

Visual Display

Students create a visual display, such as a poster, to demonstrate an application of stoichiometry (e.g., a poster that highlights an industrial application of stoichiometry).

Collaborative Teamwork

Instructional strategies, such as Jigsaw or Roundtable, could be used to have students share knowledge of specific applications of stoichiometry with classmates. (See *SYSTH* 3.19, 3.20.)

Community Connections

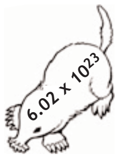
Conduct a field trip to a local industry that uses stoichiometry.

Journal Writing

Students reflect on an industrial application of stoichiometry. Their reflection could be based on how industrial stoichiometry influences their everyday lives or on careers that use stoichiometry.

Rubrics/Checklists

See Appendix 10 for rubrics and checklists that can be used for self-assessment, peer assessment, and teacher assessment for any of the research presentations, either visual or written.



SPECIFIC LEARNING OUTCOME

C11-3-16: Discuss the importance of stoichiometry in industry and describe specific applications.

Examples: analytical chemistry, chemical engineering, industrial chemistry…

(continued)

LEARNING RESOURCES LINKS

Chemistry (Chang 95)

Chemistry (Zumdahl and Zumdahl 108)

Chemistry: The Central Science (Brown, *et al.* 95)

Chemistry: Concepts and Applications (Phillips, Strozak, and Wistrom 404)

Chemistry: The Molecular Nature of Matter and Change (Silberberg 105)

Glencoe Chemistry: Matter and Change (Dingrando, *et al.* 354)

Introductory Chemistry: A Foundation (Zumdahl 255)

McGraw-Hill Ryerson Chemistry, Combined Atlantic Edition (Mustoe, *et al.* 110)

McGraw-Hill Ryerson Chemistry 11, Ontario Edition (Mustoe, *et al.* 235)

Microscale Chemistry Laboratory Manual (Slater and Rayner-Canham, Experiments 14 and 15)

Nelson Chemistry 12: College Preparation, Ontario Edition (Davies, *et al.* 144)

Prentice Hall Chemistry: Connections to Our Changing World (LeMay, *et al.* 347)

SKILLS AND ATTITUDES OUTCOMES

C11-0-R1: Synthesize information obtained from a variety of sources.
Include: print and electronic sources, specialists, other resource people

C11-0-R2: Evaluate information obtained to determine its usefulness for information needs.
Examples: scientific accuracy, reliability, currency, relevance, balance of perspectives, bias…

C11-0-R3: Quote from or refer to sources as required and reference information sources according to an accepted practice.

C11-0-R5: Communicate information in a variety of forms appropriate to the audience, purpose, and context.

NOTES