Unit 1
Stoichiometry
Specific Curriculum Outcomes
Suggested Time: 55 Hours

Stoichiometry

Introduction

Chemistry is a qualitative and quantitative science. Students have generally been studying chemistry in a qualitative sense. In this introduction to the quantitative aspect of chemistry, students will examine stoichiometry. Stoichiometry is the mole to mole relationship in a balanced chemical equation.

This unit provides the opportunity to apply chemical principles to everyday life and industry. When studying reactions, students need opportunities to investigate the usefulness of the reactions. The corresponding calculations provide the tools to investigate and support the students' responses.

Focus and Context

This unit focuses on problem-solving and decision-making. One way to introduce this unit is to begin with a contextualized problem requiring students to learn the chemistry to solve the problem and make decisions. The unit begins with an introduction to the concept of moles, Avogadro's number, and molar mass.

Stoichiometry introduces the problem-solving aspect of this course, providing students with the opportunity to develop skills in single problem solving (finding molar mass) and multi-level problem solving (percent yield).

This unit should focus on both the laboratory exercises and mathematical calculations as well as research on commercial production of compounds used by society. Chemicals in commercial or industrial environments are a context used through stoichiometry.

Science Curriculum Links

In Science 1206, students learned how to name and write formulas for ionic, molecular compounds and acids. Entering Chemistry 2202 they should know how to balance equations, types of reactions, predict products, use a solubility table, significant digits (counting and rounding) and SI units. In Chemistry 3202, stoichiometry is used in solutions, acids and bases, and redox chemistry.

The stoichiometry unit provides the quantitative foundations for the remainder of high school chemistry.

Curriculum Outcomes

STSE	Skills	Knowledge
Students will be expected to **Nature of Science and Technology** **114-4** identify various constraints that result in tradeoffs during the development and improvement of technologies **114-7** compare processes used in science with those used in technology **115-3** explain how a major scientific milestone revolutionized thinking in the scientific communities **Social and Environmental Contexts of Science and Technology** **117-2** analyze society's influence on scientific and technological endeavours	*Students will be expected to* **Initiating and Planning** **212-3** design an experiment identifying and controlling major variables **212-4** state a prediction and a hypothesis based on available evidence and background information **Performing and Recording** **213-3** use instruments effectively and accurately for collecting data **213-4** estimate quantities **213-5** compile and organize data, using appropriate formats and data treatments to facilitate interpretation of the data **213-8** select and use apparatus and materials safely **Analysing and Interpreting** **214-10** identify and explain sources of error and uncertainty in measurement and express results in a form that acknowledges the degree of uncertainty **214-12** explain how data support or refute the hypothesis or prediction **214-13** identify and correct practical problems in the way a technological device or system functions **214-15** propose alternative solutions to a given practical problem, identify the potential strengths and weaknesses of each, and select one as the basis for a plan **Communication and Teamwork** **215-1** communicate questions, ideas, and intentions, and receive, interpret, understand, support, and respond to the ideas of others	*Students will be expected to* **323-1** define molar mass and perform mole-mass inter-conversions for pure substances **323-6** determine the molar solubility of a pure substance in water **323-10** identify mole ratios of reactants and products from balanced chemical equations **323-11** perform stoichiometric calculations related to chemical equations **323-12** identify various stoichiometric applications **323-13** predict how the yield of a particular chemical process can be maximized

The Mole and Molar Mass

Outcomes

Students will be expected to

- explain how a major scientific milestone, the mole, changed chemistry (115-3)
  - define an isotope and use isotopic notation (carbon-12 or ${}^{12}_{6}C$)
  - identify Avagadro's number (6.02×10^{23}), as the mole, the unit for counting atoms, ions, or molecules
  - recognize that moles are not a directly measurable quantity
  - define the mole as the number of atoms (Avagadro's number) in exactly 12 g of carbon-12

Elaborations—Strategies for Learning and Teaching

Throughout this stoichiometry unit, teachers might wish to look at chemicals and chemical reactions that are used in commercial or industrial environments.

Chemistry has changed from hit and miss calculations for a product to exact amounts being calculated for an industrial product. Students could discuss the mole and its influence on chemistry with reference to commercial or industrial production.

This topic should be covered briefly and for the purpose of explaining decimal values of atomic mass. Isotopes occur when two atoms of the same element have a different number of neutrons. Isotopes are indicated using symbols such as, ${}^{35}_{17}Cl$ or chlorine-35, where 35 is the sum of the number of neutrons and protons in the nucleus.

A useful question for students to examine is "If you know the mass of a dozen identical items, how could you find the mass of one of the items without measuring it directly?" After discussion, students might consider the question "How can chemists count atoms by using a balance?" An activity to visualize the relationships among counting units, such as dozens; counting individual items within a unit; and finding the mass of both, would help students consolidate their experiences with their new knowledge. The rice/peas lab or any handful of identical items that could be counted and the mass of which could be found works well.

The teacher could place one mole of sample elements and compounds in sealed bottles. Students could then see the volume associated with one mole of various elements and compounds at room temperature.

From the table below, students should see that 6.02×10^{23} is common in each case and is the quantity to represent the number of particles in a sample of a given substance. The new unit created is called the mole (mol) which is defined as the number of atoms in exactly 12 g of carbon-12.

Avogadro's Number, 6.02×10^{23}

	Element	Ionic Compound	Molecular Compound
name	carbon, C	sodium chloride, NaCl	water, H_2O
mass	12.01 g	58.44 g	18.02 g
number	6.02×10^{23} atoms	6.02×10^{23} formula units of NaCl 6.02×10^{23} Na^+ ions 6.02×10^{23} Cl^- ions	6.02×10^{23} molecules of H_2O 6.02×10^{23} O atoms $2(6.02 \times 10^{23})$ H atoms

The Mole and Molar Mass

Tasks for Instruction and/or Assessment

Journal

- What do all the following have in common: dozen, gross, seconds, and mole? What amount does each of these represent? (115-3, 323-1)
- Research the origin of the mole being based upon carbon -12. (115-3, 323-1)
- Research why the word "mole" was chosen to mean a given amount of substance. (115-3, 323-1)

Presentation

- Celebrate Mole Day. Develop a mole day activity. Present your activity to the class in a variety of formats, such as a scavenger hunt, games, puzzles, songs, artwork, or poems. (323-1, 115-3)
- Research some methods chemists initially used to arrive at Avogadro's number. Then compare these methods with modern methods. How have methods used in science changed or improved to help with information? (115-3)

Paper and Pencil

- Research some isotopes of common elements. (323-1)

Resources/Notes

www.gov.nl.ca/edu/science_ref/main.htm

MGH Chemistry, p. 14, 43

MGH Chemistry, pp. 47-50

MGH Chemistry, pp. 47-50

The Mole and Molar Mass *(continued)*

Outcomes

Students will be expected to

- explain how a major scientific milestone, the mole, changed chemistry (115-3) (**Cont'd**)
  - explain how it allowed chemists to write equations for chemical reactions
  - explain how it allowed chemists to make accurate predictions using balanced chemical reactions
- define molar mass and perform mole-mass inter-conversions for pure substances (323-1)
  - explain the relative nature of atomic mass
  - calculate the average atomic mass given isotope data
  - define molar mass
  - calculate the molar mass of compounds
  - define STP and the molar volume of a gas at STP

Elaborations—Strategies for Learning and Teaching

The impact of the mole, based on a standard, carbon-12, might be an interesting discussion for students because of its effect on production of chemicals for society.

Avogadro's number, 6.02 x 10^{23}, might be celebrated on the 10th month, 23rd day from 6:02 a.m. to 6:02 p.m. Students might develop problems or activities based on the mole, molar mass, and mole-mass inter-conversions for pure substances. For students' interest, the number is named after Avogadro but it was Perrin's work on Brownian movement that connects the number and the mole.

Students are expected to realize that the atomic molar mass for all other elements is based upon the atomic mass of carbon.

Students should understand how the average atomic masses given on the periodic table are established. Calculation of percent abundance from average atomic mass would be considered an extension. Sample calculations could include: Calculate the average atomic mass of oxygen. Oxygen has three naturally occurring isotopes: oxygen-16, with a mass of 15.99 amu; oxygen-17, with a mass of 17.00 amu; and oxygen-18, with a mass of 18.00 amu. The relative abundances are 99.76%, 0.038%, and 0.20%, respectively.

Molar mass is the mass of 1 mole of particles. The values on the periodic table are weighted averages based on natural abundance of isotopes. Students should calculate the average atomic mass of an element from data for each of its isotopes.

Teacher's could use the introduction of the molar gas volume as an opportunity to link with the work of Amedo Avogadro. Avagadro's hypothesis, that equal volumes of gases contain the same number of particles at the same conditions of temperature and pressure, was at first widely dismissed. Although the hypothesis resolved many problems that puzzled scientists at the time, it was decades later before the hypothesis gained acceptance.

The Mole and Molar Mass *(continued)*

Tasks for Instruction and/or Assessment

Paper and Pencil

- Calculate the molar mass of the element which has the mass of 0.950g when 0.0500mol is present. Identify the element. (323-1)
- Calculate the: a) number of moles; b) number of atoms, in 12.5 g of lithium. (323-1)
- How is a mole defined? How is molar mass defined? (323-1)
- Alisha has one mole of NaCl, one mole of $K_2Cr_2O_7$, and $6.02x10^{23}$ molecules or one mole of $C_6H_{12}O_6$. What aspect(s) of each sample is (are) not equal? (323-1)

Presentation

- Students could research the number of isotopes and natural abundances of the isotopes for a given element. The students could then calculate the weighted molar mass (as found in the periodic table) and present their results on bristol board.
- Create a display of one mole of representative substances, such as water, sucrose, copper, gas at STP.
- Research an element, noting its industrial uses and present a time-line of the information. Silicon and semiconductors might be a good example to show how scientific thinking has helped society. (115-3)
- Write a newspaper article about a famous chemist and his or her times. Chemists who were key players in the development of the mole concept (Dalton, Gay-Lusiac, Avagadro) could be used. (115-3)

Performance

- Conduct a lab to count rice particles and find the mass of one. Other particles that might be used are peas or beans. (323-1)

Informal Observation

- Students could compare solutions of assigned problems to see if the following are included: proper use of symbols, inclusion of all units in each step, logical sequence of steps, and completed answer. (323-1)

Resources/Notes

MGH Chemistry, pp. 68-69

MGH Chemistry, p. 44

MGH Chemistry, pp. 44-45

MGH Chemistry, p. 55

MGH Chemistry, pp. 56-57

MGH Chemistry, pp. 67-70

The Mole and Molar Mass *(continued)*

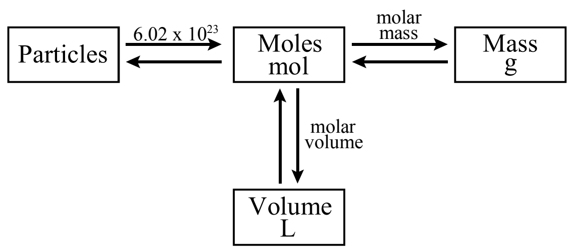
Outcomes

Students will be expected to

- define molar mass and perform mole-mass inter-conversions for pure substances (323-1) (**Cont'd**)
  - – perform calculations converting between the number of particles, moles, volume of gas at STP and mass of various substances

Elaborations—Strategies for Learning and Teaching

Teachers might use learning centre activities for students to learn/review information on naming and writing chemical formulas. Students could associate the formula with its molar mass. Students could use various problem-solving techniques that involve mole-mass, mole-volume and mole-particle conversions. Particles are atoms in monatomic elements, formula units in ionic compounds, or molecules in polyatomic elements and molecular compounds. Two methods are the conversion factor method and the direct formula method. The conversion factor method uses either Avagadro's number, molar mass or molar volume (as required) with cancelling units emphasized to set up the conversion factor correctly.



The direct formula method uses the simple formulae shown below, and rearrangment of the formulae may be required. Either method is acceptable.

$$n = \frac{m}{M} \qquad n = \frac{\#\text{ particles}}{6.02 \times 10^{23}} \qquad n = \frac{v}{V_{STP}}$$

These calculations could be one of the steps to converting mass of a compound to number of particles or number of particles of a gas to volume

Teachers might look at calculations for the correct use of units and organization/planning of responses. Significant figures are addressed and expected to be mastered in level I mathematics and Science 1206. Correct significant figure use is important, but time should be spent on understanding problem solving as opposed to time on significant figure rules.

Students could convert a quantity of a substance (such as; vinegar, glucose, and vitamins) from moles to mass and then trade their answer with that of another student who will convert from mass to moles. This co-operative learning will help students communicate the process of conversions using moles and masses of elements and compounds.

The Mole and Molar Mass *(continued)*

Tasks for Instruction and/or Assessment

Paper and Pencil

- Calculate the mass of two moles of hydrogen gas. (Hint: Diatomic molecules [H_2, O_2, F_2, I_2, N_2, Cl_2]can be remembered by various mnemonics such as: 7Up {start at nitrogen [atomic number7] go right across the periodic table to the halogens to make a "7" from the blocks on the table. Then look "up" to H at the beginning of the table and this mnemonic then gives the diatomic elements}, HOBrFINCl, HOFBrINCl, HONourable Hal {"HON" and the "Hal"ogens are diatomic gas elements.}) (323-1)
- Calculate how many moles are in 80.0 g of ammonium nitrate. (323-1)
- Calculate how many molecules are in 5.0 mol of water. (323-1)
- Calculate how many grams are in 1.2×10^{24} molecules of CH_3COOH. (323-1)

Presentation

- Design a flashcard game which interconverts between mass, molar volume of gas, and representative particles for various substances. (323-1)

Resources/Notes

MGH Chemistry, pp. 50-53, 57-64, 70-73

The Mole and Molar Mass *(continued)*

Outcomes

Students will be expected to

- define molar mass and perform mole-mass inter-conversions for pure substances (323-1) (**Cont'd**)
  - calculate the percent composition from a compound's formula
  - determine the empirical formula from percent composition data
  - determine the molecular formula from percent composition and molar mass data
- use instruments effectively and accurately for collecting data (213-3)
- estimate quantities (213-4)
- select and use apparatus and materials safely (213-8)
- identify and explain sources of error and uncertainty in measurement and express results in a form that acknowledges the degree of uncertainty (214-10)
- identify and correct practical problems in the way a technological device or system functions (214-13)

Elaborations—Strategies for Learning and Teaching

It is expected that students would be able to perform calculations involving percent composition and empirical formula for compounds containing **four** different elements. Teachers could enrich the class by using more complex substances such as everyday substances whose formulae they have looked up in the Handbook of Chemistry and Physics or the Merck Index. Such examples as household chemicals, vitamins, drugs, nitrogen in fertilizers, and steroids might be interesting. One student could choose a formula and find the percent composition. This could be given to another student to find the empirical formula and thus arrive back at the original formula. Students could see that a compound cannot be identified by its empirical formula only. To determine the molecular formula, molar mass information is needed and questions should be solved involving this. Teachers might check students' work for appropriate choice of compounds, clear layout of the question, and correct molar masses and units.

The Laboratory outcomes (213-3, 213-4, 213-8, 214-10, 214-13) as well as 213-5 are addressed by completing, *Determining the Empirical Formula of* $Mg(OH)_2$ OR *Determing the Chemical Formula of a Hydrate*, CORE LAB #1.

Students should perform Core Laboratory #1 to determine the empirical formula of a hydrate or an oxide. For elaboration students could calculate, based on their measurements and calculations, which hydrate they have from a choice of hydrates.

Prior to completing their first Core Laboratory students should be instructed in safety procedures and location of safety equipment. Teachers might have students write a safety quiz, watch a safety video, or present safety simulations in order to demonstrate their knowledge of safety procedures that should be followed in the lab. Students' knowledge and attitudes about lab safety will be reflected in their behaviour during the lab activity.

The Mole and Molar Mass *(continued)*

Tasks for Instruction and/or Assessment

Performance/Presentation

- Your teacher will give you a card with one of the following formulae on it:

Sample Hydrates

$NaCH_3COO{\bullet}3H_2O$	$MgSO_4{\bullet}7H_2O$
$MgCl_2{\bullet}6H_2O$	$LiC_2H_3O_2{\bullet}2H_2O$

The question to answer is "What percentage of water is contained in your compound?" Design an experiment to determine the percentage of water by mass in the hydrated salt described by the formula. Explain the steps you would take to dry the salt completely. If your design is approved, obtain the salt and do the experiment. (323-1)

- Students could demonstrate how to use a crucible, an evaporating dish and a balance properly (213-3)

Paper and Pencil

- Determine the percent composition by mass of each element in:

a) caffeine, $C_8H_{10}N_4O_2$
b) vitamin C, $C_6H_8O_6$
c) adrenaline, $C_9H_{13}NO_3$
d) chlorophyll, $C_{40}H_{30}O_5N_4$
e) baking soda, $NaHCO_3$
f) Epsom Salts, $MgSO_4$*$7H_2O$

- Vanillin has a molar mass of 152.16g/mol and the following percent composition: C: 63.14%; H:5.31%, O:31.55%. Determine the molecular formula of vanillin. (323-1)

Journal

- When a metal ore deposit is discovered, percent composition is used to determine whether or not a mine would be viable. With this in mind, choose and research a mining operation to determine what the threshold percentage of metal is for the particular mine and the actual percent composition for the metal in the ore. (323-1)

Resources/Notes

MGH Chemistry, pp. 83-85

MGH Chemistry, pp. 87-91, 101-103

MGH Chemistry, pp. 95-97

Core Lab #1: *"Determining the Empirical Formula of Mg(OH)$_2$"*, pp. 92-93 OR *"Determing the Chemical Formula of a Hydrate"* pp. 104-105

Solutions and the Mole

Outcomes

Students will be expected to

- use solution data and data treatments to facilitate interpretation of solubility (213-5)
  – explain and give examples of solutes, solvents, and solutions
  – use a chart of solubility to determine if an ionic compound will have high or low solubility
  – explain and give examples of these terms: electrolytes and non-electrolytes
  – provide examples, from living and nonliving systems, of how dissolving substances in water is sometimes a prerequisite for chemical change
  – define the terms "concentrated" and "dilute"
  – define concentration in terms of molarity (moles per litre of solution)
  – use simple calculations to show different ways of expressing concentration
    (i) mass/volume percent
    (ii) volume/volume percent
    (iii) ppm
    (iv) ppb

Elaborations—Strategies for Learning and Teaching

A brief qualitative investigation of solutions and solution chemistry is necessary to prepare students to understand solution calculations ($C = \frac{n}{v}$, etc.) and solution stoichiometry. Students have been introduced to solutions and some of the terminology associated with them in intermediate science. Perhaps some of the outcomes pertaining to solutions will only need to be reviewed.

Determining precipitates (i.e, the solid phase) is important for gravimetric calculations and laboratories. It is expected that students will be able to use a solubility chart to determine whether a product will be aqueous or precipitate. The solubility of molecular compounds depends on polarity and will be covered in Unit 2.

Students could observe the apparent lack of reactivity between solid crystals of $AgNO_{3(s)}$ and $KI_{(s)}$, only then to see the relatively instant reactivity of solutions of the two substances.

Students sometimes have difficulty picturing a solution at a molecular level and then applying this image to explain solution properties. A good analogy to use is a group of people in a room - concentration becomes a measure of "crowdedness" in the room. How can we make the room less crowded? More crowded? Can 10 people fit in the room? Can 100? Can 1000? The maximum that can "fit" would be the saturation point. This analogy could be extended to include the dynamics of a saturated solution, other methods of expressing concentration and so on.

Teachers should note that the concepts of mass/volume percent, volume/volume percent, ppm and ppb are included simply to illustrate to the students that there are alternative, acceptable ways to quantitatively express concentrations in terms other than molarity. Students should have encountered these terms during their intermediate science studies. These units are commonly used on consumer products and in the media to describe concentrations.

Solutions and the Mole

Tasks for Instruction and/or Assessment

Performance/Presentation

- Choose a career related to working with solutions. Present to the class using audio-visual, multimedia, or by acting the part of your career by dressing appropriately. (213-5)

Paper and Pencil

- Given the following formulae, which would be a precipitate when produced by a chemical reaction?

  a) $Al(NO_3)_3$ b) K_2S c) AgCl d) PbS (213-5)
- For a mass of 10.0g of sodium chloride in 20.0mL of water, calculate the:

  a) molarity c) molality b) mole fraction (213-5)

Presentation

- Students could dramatize the concepts of dilute, concentrated and saturated solutions (as illustrated by the example in the elaboration column). (213-5)

Resources/Notes

MGH Chemistry, p. 257

MGH Chemistry, p. 285

MGH Chemistry, pp. 246-247

MGH Chemistry, pp. 236-238

MGH Chemistry, p. 237

MGH Chemistry, p. 266

MGH Chemistry, pp. 255-258
MGH Chemistry, pp. 261-263

MGH Chemistry, pp. 263-265

Solutions and the Mole *(continued)*

Outcomes

Students will be expected to

- use solution data and data treatments to facilitate interpretation of solubility (213-5) (**Cont'd**)
  - calculate, from empirical data, the concentration of solutions in moles per litre, and determine mass or volume from such concentrations
  - calculate, from empirical data, the concentration of diluted solutions, and the quantities of a solution and water to use when diluting
  - outline the steps required to prepare a solution and a dilution of a solution, including necessary calculations
  - define the terms unsaturated, saturated and supersaturated solutions
  - describe an equilibrium system in a saturated solution in terms of equal rates of dissolving and crystallization
- determine the molar solubility of a pure substance in water (323-6)
  - define molar solubility quantitatively

Elaborations—Strategies for Learning and Teaching

Teachers should ensure that students are capable of calculating the necessary quantities to make up a solution from scratch (i.e., from a solid or more concentrated solution). Students should be able to observe how the physical properties of a solution change upon dilution. Examples of such properties include; colour intensity, conductivity, and rate reaction. Teachers might consider using coloured ionic salts such as $CuSO_4 \bullet 5H_2O$ or $CuCl_2 \bullet 5H_2O$ reacted with $Al_{(s)}$. These reactions are easy to observe and relatively safe. One or more of these may be demonstrated at the end of dilution lab activity.

Students should have hands-on experience in standard procedures for preparing a solution from a calculated mass and by dilution. Teachers could use this opportunity to ask students to prepare solutions required for other laboratory work or demonstrations (particularly if the exact concentration is not important).

A detailed discussion of equilibrium is not required. It is important for students to realize that dissolving and recrystallization does not stop in a saturated solution

Students may confuse molar solubility and molar concentration since calculating both involve similar steps. Teachers should reinforce to students that molar solubility does not mean molar concentration. Molar solubility can be defined as the maximum amount of solute, in moles, which may be dissolved per litre of solvent.

Solutions and the Mole *(continued)*

Tasks for Instruction and/or Assessment

Performance

- Prepare 1.0L of a 0.50M solution of NaOH. (213-5)
- Outline the steps required to prepare or dilute a solution to a specific concentration. (213-5)

Journal

- What do I need to know in order to calculate the molarity of a solution? Explain. (213-5)

Paper and Pencil

- Which solution would contain the largest mass of solute? The solute is Na_2SO_4 and the solvent is H_2O. (213-5)
  a) 0.12M in 500mL c) 0.67M in 199mL
  b) 0.23M in 200mL d) 0.080M in 1000mL
- Which solution would contain the largest mass of solute? The solvent is H_2O. (213-5)
  a) 0.13M of Na_2SO_4 in 100mL c) 0.62M of $AlCl_3$ in 500mL
  b) 0.42M of NaCl in 100mL d) 0.87M of AlF_3 in 1.20L
- Calculate the molarity, M, of a sodium chloride solution that has a volume of 300.0mL and contains 25.0g of NaCl? (323-6)
- Explain the difference between molar concentration and molar solubility. (323-6)
- How are solubility and equilibrium related? (213-5)
- What is the general meaning of dynamic? What is meant by dynamic equilibrium? Give examples. (213-5)

Presentation

- With a partner, take different sized beakers and make a solution of $CuSO_4$*$5H_2O$ of a known molarity. Pour the blue liquid into the beakers using various volumes. Answer the following questions:

  - Which contains the most solute?
  - Which has the highest concentration?
  - How was this judgement made?
  - Do these solutions have the same or different number of ions per unit volume?
  - Why are there varying depths of colour? (213-5)

Resources/Notes

MGH Chemistry, pp. 266-268

MGH Chemistry, pp. 272-273

MGH Chemistry, pp. 271-273

MGH Chemistry, p. 239

MGH Chemistry, p. 240

MGH Chemistry, p. 239

Calculations and Chemical Equations

Outcomes

Students will be expected to

- identify mole ratios of reactants and products from balanced chemical equations (323-10)
  - identify the mole ratios of reactants and products in a chemical reaction as the coefficients in a balanced equation
  - define mole ratio, and use mole ratios to represent the relative amounts of reactants and products involved in a chemical reaction
  - write dissociation equations for dissolved substances
  - use the mole ratios from dissociation equations for ionic solids to calculate the concentration of an ion in solution
  - understand the Law of Conservation of Mass

Elaborations—Strategies for Learning and Teaching

Teachers might use this opportunity for students to look at various types of chemical equations, balance them, and compare mole ratios. This might be done through worksheets, chemical models, or balancing games. This will allow students to practise the mole ratio while they refresh their memories about equations. Students could read chemical equations to identify the conditions of the chemical reaction, the information about the reactants and products, and the number of molecules and/or moles involved.

Multiples of Moles of Air Bag

$2NaN_3(s) \rightarrow 2Na(s) + 3\ N_2(g)$

2	→	2	+	3
6	→	6	+	9
10	→	10	+	15

Students might increase or decrease the number of moles of substances in an equation and check to see that the ratio stays the same. The Law of Conservation of Mass could be checked.

It is important for students to realize that mass is conserved in a chemical reaction, however, not the number of moles. Students might use a chart to organize the information and to check the total mass of reactants and of products.

Balanced Chemical Equation Information: Air Bag Inflation Reaction

equation	2 $NaN_{3(s)}$	→	2 $Na_{(s)}$	+	3 $N_{2(g)}$
molar mass of each substance (g/mol)		→			
moles of each substance (mol)	2	→	2		3
total mass of each substance (g)		→			
total moles (mol)		→			
total mass (g)		→			
words	2 moles of solid sodium azide decompose to 2 moles of solid sodium plus 3 moles of nitrogen gas				

Calculations and Chemical Equations

Tasks for Instruction and/or Assessment

Paper and Pencil

- What information does the following balanced chemical equation provide about the cellular respiration equation?

  $C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O\,(l)$ + heat (323-10)

Presentation

- Design an experiment to confirm the Law of Conservation of Mass. Show your plan to your teacher. If approved, do the lab. Present your findings with a purpose, data chart and analysis. (323-10, 323-11, 212-4, 214-14)

Resources/Notes

MGH Chemistry, p. 112

MGH Chemistry, p. 114-115

MGH Chemistry, pp. 299-300

MGH Chemistry, p. 118

Calculations and Chemical Equations *(continued)*

Outcomes

Students will be expected to

- identify mole ratios of reactants and products from balanced chemical equations (323-10) (**Cont'd**)
  - do calculations using mole-to-mole stoichiometric problems

- perform stoichiometric calculations related to chemical equations (323-11)
  - define stoichiometry, gravimetric stoichiometry solution stoichiometry and gas stoichiometry (at STP)

Elaborations—Strategies for Learning and Teaching

Students could calculate mole-to-mole gravimetric stoichiometric problems by doing a lab to show the ratio of reactants to products. The equation using limestone, $CaCO_{3(s)}$, yielding quicklime, $CaO_{(s)}$, and carbon dioxide, $CO_{2(g)}$, or the equation using anhydrous Na_2CO_3 plus HCl(aq) could be used. The reaction between antacid tablets and stomach acid might be used in the lab as a relevant example for students:

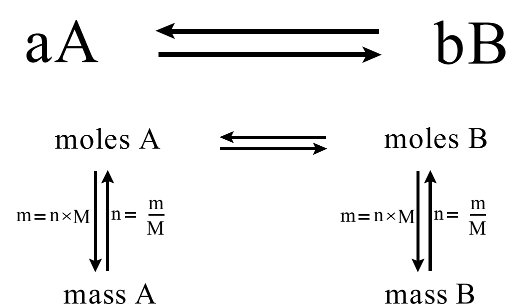
$$CaCO_{3(s)} + 2HCl_{(aq)} \rightarrow CaCl_{2(s)} + H_2O_{(l)} + CO_{2(g)}$$

antacid + stomach acid → salt + water + carbon dioxide

Proper lab safety procedures and proper use of instruments should always be followed. Students might need demonstrations and information on safety for these labs.

Teachers might use strategies to help students to organize their calculations as shown in the elaborations under outcome 323-1, completed previously in this unit. Students could use the conversion factor method or direct formula method established earlier. Students could work in groups to practise their problems and calculations; this would help students develop their problem-solving strategies.

Students could draw a diagram (similar to below) to set up their problem-solving method.



$$\text{moles of UnKwn} = \text{moles of Kwn} \times \frac{\text{coeff of UnKwn}}{\text{coeff of Kwn}}$$

Teachers should ensure that students are proficient in writing balanced chemical equations, including states of matter and predicting products.

A good enrichment activity for stoichiometry is to have students do particle to particle stoichiometry. Complex stoichiometry problems such as these reinforce the fact that there is one underlying process in all stoichiometry problems.

Calculations and Chemical Equations *(continued)*

Tasks for Instruction and/or Assessment

Performance/Presentation

- Plan a lab on the relationships of reactants and products in a chemical reaction. Show your plan to your teacher. If approved, do the lab. Present your findings with a purpose, data chart, and analysis. State a general format about the relationship of the mole in a chemical reaction. (323-10, 323-11, 212-4, 214-13)

Resources/Notes

MGH Chemistry, pp. 114-117

MGH Chemistry, p. 119

Calculations and Chemical Equations *(continued)*

Outcomes

Students will be expected to

- perform stoichiometric calculations related to chemical equations (323-11) (**Cont'd**)
  - perform stoichiometric calculations among the following: moles, mass, volume of a solution, volume of a gas (STP) and concentration
  - define theoretical, actual, and percent difference and performing calculations that involve these terms
  - perform calculations involving limiting reagents in chemical reactions

Elaborations—Strategies for Learning and Teaching

Because of the many types of calculations possible, stoichiometric problem-solving may be a difficult task for students to master. Basically all stoichiometry problems have three steps (some of which may not even be necessary). Step one: calculate the moles of the known substance. Of course, this depends on what information is given. Step two: predict moles of the unknown (mole ratio). Step three: calculate the amount of the unknown required (depends on what the problem asks).

While teaching stoichiometric problem-solving teachers should discuss laboratory procedures used in measuring amounts of products produced in any worked examples used. For example, discuss how the mass of $AgSO_4$ might be determined from the reaction of solutions of Na_2SO_4 with $AgNO_3$:

$$Na_2SO_{4(aq)} + 2\ AgNO_{3(aq)} \rightarrow Ag_2SO_{4(s)} + 2\ NaNO_{3(aq)}$$

This example could be done as a demonstration/worked example.

Students could perform stoichiometric calculations to show the limiting reagent and the conservation of mass in a chemical change. For example, tin(II) fluoride is added to some dental products to help prevent cavities. A potential question in experimental design might be "What mass of tin(II) fluoride can be made from 100.0 g of hydrofluoric acid, $HF_{(aq)}$, reacting with excess tin?" OR "If 5.00 g of Sn reacts with 100.0 mL of 2.00 mol/L HCl(aq), what volume of hydrogen gas is produced at STP?" This would incorporate all aspects of stoichiometric calculations.

Calculations and Chemical Equations *(continued)*

Tasks for Instruction and/or Assessment

Informal Observation

- Look for evidence in the problem solutions of variables identified, answers in correct units, logical sequence of steps, information needed to be collected elsewhere, and completed solutions to word problems. (323-11)

Journal

- What is the difficulty in using a calculator for mass-mass problems? (323-11)
- What is the reasoning used that does not allow you to just convert grams to grams when doing stoichiometric problems? (323-11)

Paper and Pencil

- Propane, $C_3H_8(g)$, burns in oxygen, O_2, to produce $CO_2(g)$ and $H_2O(g)$. What mass of propane is needed to burn 25.0 mol of oxygen? (323-11)
- Calculate the mass of CaO(s) produced when 40.0 g of $CaCO_3$ is heated. (323-11)
- How many moles of $NH_3(g)$ are formed when 42.0 g of nitrogen gas react with enough hydrogen gas? (323-11)

Paper and Pencil

- The equation to make aspirin is acetic anhydride plus salicylic acid yields aspirin plus acetic acid

  $C_4H_6O_3 + C_7H_6O_3 \rightarrow C_9H_8O_4 + CH_3COOH$

  Using this information, write the steps to solve the following problem: what mass of salicylic acid is needed to make two aspirin tablets, each 0.35 g? You have 50.0 g of salicylic acid. Is it enough? Justify. (212-4, 323-11)
- Calculate the theoretical and percent yield if you have 300.0 g of salicylic acid and 240.0 g of aspirin are produced. (212-4, 214-13, 323-11)
- Distinguish between the limiting reagent (reaction) and the excess reactant in a chemical equation. (323-11, 212-4)
- The theoretical yield of a precipitation reaction is 3.26 g. The actual yield is 3.45 g. Account for this difference.
- The theoretical yield of a precipitation reaction is 2.86 g. The actual yield is 2.45 g. Account for this difference.
- Explain, in words, how you would intend to solve the problem: How many grams of NaCl are needed to react with 50.0 g of HCl? (323-11)

Resources/Notes

MGH Chemistry, pp. 114-117, pp. 120-124, pp. 303-304

MGH Chemistry, pp. 137-141

MGH Chemistry, pp. 128-131, pp. 304-307

Stoichiometric Experimentation

Outcomes

Students will be expected to

- use instruments effectively and accurately for collecting data (213-3)
- explain how data support or refute the hypotheses or prediction of chemical reactions (214-12)
- design stoichiometric experiments identifying and controlling major variables (212-3)
  - choose an appropriate chemical reaction (produces a gas or a precipitate)
  - choose appropriate laboratory equipment necessary for performing the experiment
  - determine data table, including sample amounts (masses of reactants and products)
  - describe how to carry out the filtration of a precipitate
  - complete sample calculations of theoretical yield and percent yield
  - recognize when to use a gravimetric or solution stoichiometry approach to problem solving
  - identify safety concerns with sample gravimetric analysis and list precautions taken

Elaborations—Strategies for Learning and Teaching

The Laboratory outcomes (212-3, 213-3, 214-10, 214-12, 215-1) as well as 323-11 and 323-13 are addressed by completing *Determining Percent Yield of a Chemical Reaction*, CORE LAB #2. Students will carry out a precipitation reaction and determine: (i) limiting reagent; (ii) theoretical yield; (iii) actual yield (through filtration); and (iv) percent yield.

Students should realize that experiments do not always result in 100% actual yield. The percent yield is dependent upon other factors. Teachers may want to address these factors by examining students' percentage yields from the Core Lab. Students could use a chart to show variations in the amounts of reactants and the effect on the yields and the difference between a theoretical and actual yield. Actual yield might be done in the lab with groups of students testing different amounts of reactants. Students could use their example reaction to predict or test for purity or cost effectiveness.

The next four Pan-Canadian outcomes are discussed as a group for stoichiometric experimentation. The 'Activity' associated with the STSE module "Gypsum" also addresses some of these outcomes.

Students might design their own experiments to identify the limiting species in chemical reactions. This planning might show students the connections between chemistry and industry. By changing the amount of one reactant while the other is constant, students could calculate the effect on the product(s) yield. Students could use a chart to show these variations in the amounts of reactants and the effect on yields. This could be done by gathering data from students' Core Lab (by starting students with different amounts of one reactant, then sharing the results with other students).

Students should only do the procedure if the teacher approves. Students should follow safety procedures that have been discussed in class, such as wearing goggles and a lab apron/coat. Students should practise the proper techniques for using lab equipment. Disposal of materials could be discussed with reference to WHMIS. Students should consider how they record their data in a table, list their procedure, and analyze their results.

Stoichiometric Experimentation

Tasks for Instruction and/or Assessment

Performance

- Do a lab on theoretical and percent yield. (212-3, 213-3, 214-10, 215-1)

Paper and Pencil

- Write a summary report of a plan for the production of a chemical. Include the list of equipment needed, the cost, the chemical equation with masses and moles, and the theoretical and percent yields of the product. Possible sources of error should be included. (212-3, 214-10, 215-1, 114-4)

Presentation

- Do an oral report of two to five minutes detailing your stoichiometric experiment. (212-3, 215-1, 114-4)

Resources/Notes

Core Lab #2: *"Determining Percent Yield of a Chemical Reaction"* pp. 142-143.

Throughout **Core Lab #2:** *"Determining Percent Yield of a Chemical Reaction"* pp. 142-143.

MGH Chemistry, p. 143

MGH Chemistry, pp. 137-141

MGH Chemistry, p. 119

Stoichiometric Experimentation *(continued)*

Outcomes

Students will be expected to

- identify and explain sources of error and uncertainty in measurement using precision and accuracy (214-10)
  - distinguish between precision and accuracy in the context of gravimetric stoichiometry

Elaborations—Strategies for Learning and Teaching

Accuracy and precision were covered in the Motion Unit of Science 1206. Teachers should review these concepts and relate them in a chemistry context. An excellent graphic that students often find helpful is a target with darts in it. Draw three images showing a person who is precise not accurate, inaccurate and not imprecise, and accurate and precise.

Students could evaluate the method used to collect data and what sources of error could be identified. Discussion could involve the minimum loss of product(s) and techniques used to collect information. Students should realize that sources of error are associated with the limitations of the procedure and equipment and not on the experimenter's ability. Students do not need to do uncertainty of mass in terms of "±" at this level; teachers might want to discuss this with reference to the uncertainty of a student's mass on a balance.

- communicate questions, ideas, and intentions, and receive, interpret, understand, support, and respond to the ideas of others (215-1)

A lab could be reported in a variety of formats, such as a lab report, discussion among peers, a memo, or an abstract. Students could present and defend their experimental designs, highlighting the reasons for their decisions. A class discussion could follow to determine the best practices. For example; one group could have a good filtration technique while another good safety procedures. A combination of best practices would possibly produce the basis of another stoichiometry laboratory.

- predict how the yield of a particular chemical process can be maximized (323-13)

The prediction of maximum yield should be based upon performing correct quantitative laboratory techniques (i.e., decanting, washing and drying product, etc.) and not on chemical principles of kinetics and equilibrium. The determination of maximum yield based upon kinetics and equilibrium will be discussed in Chemistry 3202.

Stoichiometric Experimentation *(continued)*

Tasks for Instruction and/or Assessment

Presentation

- Work in small groups to design two or more experiments to demonstrate stoichiometric relationships. As each group presents its experimental design to the class, classmates should assess the design, using criteria developed collaboratively before the activity. Criteria might include correct use of chemistry principles and of lab equipment, identification of variables, creativity, proper vocabulary, safety, and possible error sources. (212-3, 213-3, 214-10, 215-1)
- Using multimedia, present an industrial process. Include data, yield of the product, technology information, and the chemistry involved. (323-13, 323-12, 214-12, 114-7)

Resources/Notes

MGH Chemistry, pp. 137-140

Applications of Stoichiometry

Outcomes

Students will be expected to

- identify practical problems that involve technology where chemical equations are used (214-13)
- state a prediction and a hypothesis based on available evidence and background information (212-4)

Elaborations—Strategies for Learning and Teaching

Students should look at an industrial processes that has solved a practical problem and discuss a hypothesis based on collected information about the process. For example, discuss any excess mass in a spacecraft or synthesizing flavouring for foods. The STSE module "Gypsum" also addresses this outcome.

Students might look at different equations that produce the same product for an industrial application. Students might predict which equation would be the best to use to produce a certain product(s). Students, in groups, might collect information about the reactants and products for the various equations and decide which equation would be the most cost-efficient to use. Students' evidence might include the availability of materials, the cost of production, and the demand for the products. The equation, with evidence, that makes the most money might be the hypothesis that some students favour. Others might look at health or safety as a goal. Students' information about a chemical process in an industrial/technological application connects chemistry to their lives. It describes how industries use stoichiometric principles in their day-to-day functions.

Examples might include heating camping meals using the equation

$CaO_{(s)} + H_2O_{(l)} \rightarrow Ca(OH)_{2(s)}$ + heat,

synthesizing flavoured bubble gum using groups of organic compounds called esters,

or removing CO_2 in a spacecraft using the equation

$CO_{2(g)} + 2LiOH_{(s)} \rightarrow Li_2CO_{3(s)} + H_2O_{(l)}$. Interesting compounds, such as esters used in flavouring foods, might be introduced to the students here.

Students should identify various applications of stoichiometry and be able to discuss the maximum yield with reference to supporting data.

Applications of Stoichiometry

Tasks for Instruction and/or Assessment

Journal

- How does the stoichiometry you have studied help your understanding of chemical processes? (117-2, 323-12)

Resources/Notes

Core STSE #1: *"Gypsum"*, **Appendix A**

MGH Chemistry, pp. 145-146

MGH Chemistry, p. 141

Applications of Stoichiometry

Outcomes

Students will be expected to

- identify various stoichiometric applications (323-12)

- analyze a given practical problem, identify the potential strengths and weaknesses of solutions, and select one as the basis for a plan (214-15)
  - perform percent purity calculations
  - list three factors that affect the viability of an industrial process. Include:
    (i) raw material quality
    (ii) cost of process
    (iii) cost of environmental issues

Elaborations—Strategies for Learning and Teaching

The CORE STSE component of this unit incorporates a broad range of Chemistry 2202 outcomes. More specifically it targets 323-12, 214-18, 114-7, 232-1, 117-2, 213-3, 114-4, 323-13, 215-1 and 215-1. The STSE component, *Chemistry of Gypsum*, can be found in Apppendix A.

Teachers could make the study of stoichiometry interesting by using examples students might be familiar with in their daily activities. Examples that could be considered are commercial production of H_2O_2, production of Kevlar, cis-Pt $(NH_3)_2Cl_2$, which is used in cancer therapy, $CaCO_3$ or $Mg(OH)_2$ antacid production, pollution clean-up, or photography,

$$I_{2(aq)} + 2S_2O_3{}^{2-}{}_{(aq)} \rightarrow 2I^-{}_{(aq)} + S_4O_6{}^{2-}{}_{(aq)}$$

Students could predict how to maximize the yield of a chemical process. Students could defend an hypotheses or a prediction by explaining supporting data. One example that could be used is the workings of the breathalyzer that uses dichromate to measure the amount of alcohol in the body:

$$16H^+ + 2Cr_2O_7{}^{2-} + 3C_2H_5OH \rightarrow 3CH_3COOH + 4Cr^{3+} + 11H_2O$$

orange → green

The colour change of orange to green indicates the presence of alcohol. Students could discuss the quantitative and qualitative aspects of this reaction. Students could explain the differences between the predicted yield and the actual yield and how quantity is not the only factor to consider. This might lead students to look at other factors that might influence a chemical reaction. These will be addressed further in Chemistry 3202.

Students might look at safe commercial examples of chemical processes and discuss these reactions in terms of the usefulness to society, technology tradeoffs, and the intentions of the producer of the products. The commercial preparation of urea or water softeners or aspirin or replacement of CFCs might be examples of interest to students.

Students could investigate issues related to the profitability of a mining operation. For example, ore purity, refining method and cost of refining are all contributing factors to the establishment of a mine. The Voisey's Bay project would be an excellent example of the complexities of setting up a mining operation.

Applications of Stoichiometry

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could also conduct research on a variety of industrial processes such as extraction of gold, production of aspirin, neutralization of acidic lakes, and electroplating. (114-7, 114-4)

Performance/Presentation

- Using a memo format to your CEO, present your findings about an industrial process that you researched. (212-4, 214-13)

Resources/Notes

Core STSE #1: *"Gypsum"*, **Appendix A**

MGH Chemistry, pp. 145-146

Applications of Stoichiometry *(continued)*

Outcomes

Students will be expected to

- compare processes used in science with those used in technology (114-7)
- identify various constraints that result in tradeoffs during the development and improvement of technologies (114-4)

Elaborations—Strategies for Learning and Teaching

In burning fossil fuels to produce electrical energy, $SO_{3(g)}$ and $SO_{2(g)}$ within the emissions cause environmental problems such as acid rain.

In a coal generating plant, $SO_{3(g)}$ is a product that can be removed from the emissions by treating it with calcium hydroxide:

$SO_{3(g)} + Ca(OH)_{2(s)} + H_2O_{(l)} \rightarrow CaSO_4 \bullet 2H_2O_{(s)}$

The product calcium sulfate could be used for other products (such as gypsum board) and is not considered an environmental problem.

In an oil generated plant as in Holyrood, $SO_{2(g)}$ in emissions cause similar environmental problems. $SO_{2(g)}$ can be treated with limewater ($Ca(OH)_{2(aq)}$) to produce calcium sulfite (this process is known as scrubbing):

$SO_{2(g)} + Ca(OH)_{2(s)} \rightarrow CaSO_{3(s)} + H_2O_{(l)}$

Without this or a similar reaction, $SO_{3(g)}$ and/or $SO_{2(g)}$ would be released and would contribute to the problem of acid rain. Knowing how much of these gases are released from the fuel combustion can help the industry provide adequate calcium hydroxide for the reaction.

- analyze society's influence on science and technology (117-2)

Students could report on how society influences science and technology. A report on aspirin could include aspects such as how to maximize purity, commercial potential, costs, and amounts. Students might include chemical equations for evidence in their report.

Applications of Stoichiometry *(continued)*

Tasks for Instruction and/or Assessment

Paper and Pencil

- Identify and explain two stoichiometric applications. How does/did society influence the science and technology of the applications? (117-2)

Journal

- Identify industrial constraints where an increased yield is technologically feasible but not cost-effective. (114-4)
- Write about a safe commercial chemical process. (114-4)
- Is the technology involved in chemical production always helpful to society? (114-4)

Resources/Notes

Core STSE #1: *"Gypsum"*, **Appendix A**