Chemistry 2202
Course Outline

Unit 1 – Stoichiometry

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. Skills will be developed in single step problem solving (finding molar mass) and multi-level problem solving (finding percent yield).

Explain how a major scientific milestone, the mole, changed chemistry.

- Define an isotope and use isotopic notation (carbon-12 or 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 (Avogadro's number) in exactly 12 g of carbon-12.
- Explain how the mole allowed chemists to write equation for chemical reactions.
- Explain how the mole allowed chemists to make accurate predictions using balanced chemical equations.

Define molar mass and perform mole-mass inter-conversions for pure substances.

- 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.
- Perform calculations between the number of particles, moles, volume of gas at STP and mass of various substances.
- 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. Estimate quantities. Identify and explain sources of error and uncertainty in measurement and express results in a form that acknowledges the degree of uncertainty. Select and use apparatus and materials safely.

Core Lab 1: Determining the Empirical Formula of $Mg(OH)_2$ or Determining the Chemical Formula of a Hydrate

Use solution data and data treatments to facilitate interpretation of solubility.

- 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 non-living 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 liter of solution).
- Use simple calculations to show different ways of expressing concentration. Include mass/volume percent, volume/volume percent, ppm, ppb, molality and mole fraction.
- Calculate, from empirical data, the concentration of solutions in moles per liter and determine mass or volume from such calculations.
- 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.

- Define molar solubility quantitatively.

Identify mole ratios of reactants and products from balanced chemical equations.

- Identify the mole ratios of reactants and products in a chemical reaction as the coefficients in a chemical reaction.
- Define mole ratio and use mole ratios to represent the relative amounts of reactants and products in a chemical reaction.
- Write dissociation equations for dissolved substances.
- Use the mole ratio from dissociation equations for ionic solids to calculate the concentration of an ion in solution.
- Understand the Law of Conservation of Mass.
- Understand that mass is conserved in a chemical reaction but not the number of moles.
- Do calculations using mole-to-mole stoichiometry problems.

Perform stoichiometric calculations related to chemical equations.

- Define stoichiometry, gravimetric stoichiometry, solution stoichiometry and gas stoichiometry.
- 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 perform calculations that involve these terms.
- Perform calculations involving limiting reagents in chemical reactions.

Design stoichiometric experiments identifying and controlling major variables. Use instruments effectively and accurately for collecting data. Explain how data support or refute the hypotheses or prediction of chemical reactions.

- 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.
- Distinguish between precision and accuracy in the context of gravimetric stoichiometry.
- Predict how the yield of a particular chemical process can be maximized.

Core Lab 2: Determining Percent Yield of a Chemical Reaction

Identify various stoichiometric applications. Identify practical problems that involve technology where chemical equations are used.

Core STSE 1: Gypsum

Analyze a given practical problem, identify the potential strengths and weaknesses of solutions and select one as the basis for a plan.

- Perform percent purity calculations.
- List three factors that affect the viability of an industrial process. Include raw material quality, cost of process and cost of environmental issues.

Compare processes used in science with those used in technology. Identify various constraints that result in tradeoffs during the development and improvement of technologies. Analyze society's influence on science and technology.

- Use the burning of fossil fuels as an example.

Unit 2 – From Structures to Properties

All matter is held together by chemical bonding. Bonding is discussed in detail in this unit. The different forces of attraction involved in matter and how it influences their properties will be studied. Questions such as why does water have the formula H_2O and why does NaCl have such a high melting point will be addressed.

Students will begin by identifying and describing properties of ionic and molecular compounds as well as metallic substances. Using chemicals that would be found in their own homes, students will then differentiate among and classify these compounds and substances as being ionic, molecular or metallic. Students will compare the strengths of intermolecular and intramolecular forces.

Identify and describe the properties of ionic and molecular compounds and metallic substances.

- ➢ Observe the physical properties of representative samples of molecular, ionic and metallic substances.
- ➢ Tabulate the properties of molecular, ionic and metallic substances.

Classify ionic, molecular and metallic substances according to their properties.

- ➢ Use the periodic table as a tool for predicting the formation of ionic and molecular compounds.
- ➢ Classify an unknown compound according to its physical properties by performing tests and collecting observations.

Illustrate and explain the formation of covalent bonds.

- ➢ Understand that chemical bonds are attractive forces that hold substances together.
- ➢ Define valence electrons, electronegativity, electron pairing, ionic bond and covalent bond.
- ➢ Identify the maximum number of electrons that occupy each energy level.
- ➢ Define valence energy level, bonding (unpaired electrons), nonbonding electrons (lone pairs) and bonding capacity and be able to relate these terms to atoms of the representative elements.
- ➢ Draw electron dot diagrams of atoms of the representative elements.
- ➢ Explain why noble gases are unreactive and stable.
- ➢ Explain the special nature of hydrogen as an exception to the octet rule.
- ➢ Define single, double and triple covalent bonds.
- ➢ Given the molecular formula, draw Lewis dot diagrams and structural formulas for simple molecules containing single, double or triple bonds.

Explain the structural model of a substance in terms of the various bonds that define it.

- ➢ Explain the three-dimensional nature of molecules using VSEPR theory.
- ➢ Determine the shapes about central atoms in simple molecules by applying VSEPR theory.

- Build models depicting the shape of simple covalent molecules.

Explain, in simple terms, the energy changes of bond breaking and bond formation and relate this to why some changes are exothermic while others are endothermic.

- Explain the energy changes for exothermic and endothermic reactions in terms of bond breaking and bond formation.

Analyze an example of a Canadian contribution to bonding knowledge, the discovery of noble Gas compounds.

Core STSE 2: Common Bonds

Explain the evidence from an intermolecular forces experiment and from collected data.

Core Lab 3: Modeling Molecules

Illustrate and explain hydrogen bonds and van der Waals' forces.

- Compare and contrast intramolecular (covalent bonds) with intermolecular forces, simply in terms of strength and species involved.
- Define polar and non-polar covalent bonds.
- Use bond dipoles and the shapes of molecules as predicted by VSEPR to determine if a molecule has a molecular dipole.
- Define London dispersion forces, dipole-dipole forces (van der Waals' forces) and hydrogen bonding and explain how they form.
- Relate the strength of London dispersion forces to the molecular mass (number of electrons) and shape (complexity).
- Identify trends in electronegativity within periods and families of the periodic table.
- Identify the relationship between the electronegativity difference between atoms and the degree of bond polarity.
- Compare the strength of London dispersion forces, dipole-dipole forces and hydrogen bonding.

Apply bonding knowledge to a particular problem, the structure of DNA, and analyze the benefits to society to be able to solve this problem using bonding knowledge.

Describe how the type of attractions account for the properties of molecular compounds.

- Identify the types of intermolecular forces between molecules in a substance.
- Compare the melting points or boiling points of simple molecular substances by comparing the strengths of their intermolecular forces.

Elective Lab: Naphthalene Melting Point

Illustrate and explain the formation of network covalent bonding and macromolecules.

- Identify three network covalent solids (SiO_2, SiC, $C_{diamond}$, $C_{graphite}$).
- Explain the high melting points and extreme hardness of network covalent solids.
- Build/design models or find images to represent network covalent bonding in order to distinguish it from ionic and molecular covalent structures.

Propose possible technologies which may be developed based upon bonding.

Explain how bonding theory may evolve and become revised as new evidence arises, using the discovery of the structure of Buckministerfullerenes.

Illustrate and explain the formation of ionic bonds.

- Predict the ionic charge for ions in the main group elements from their group number and using the octet rule.
- Explain the importance of electron transfer in ionic bond formation.
- Define ionic crystal lattice, formula unit and empirical formulae as they apply to ionic compounds.
- Build models or find images to depict the lattice structure of an ionic compound e.g. NaCl.
- Explain why formulae for ionic compounds refer to the simplest whole number ratio of ions that results in a net charge of zero, while the formulae for molecular compounds refer to the number of atoms of each constituent element.

Describe how the type of bonding accounts for the properties of ionic compounds.

- Use the theory of ionic bonding to explain the general properties of ionic compounds: brittleness, high melting and boiling points and the ability to conduct electricity when molten or in aqueous solution.

Identify limitations of categorizing bond types based on differences in electronegativities between the elements of compounds.

- Recognize the relationship between electronegativities of the atoms and the type of bonding in a compound.
- Describe bonding as a continuum ranging from complete electron transfer (ionic) to unequal sharing of electrons (polar covalent) to equal sharing of electrons (non-polar covalent).

Compare the strengths of ionic and covalent bonds.

- Use table salt and sugar as examples.

Explain the variations in the solubility of various pure substances, given the same solvent.

- Describe the solubility of ionic and molecular compounds in polar and non-polar solvents.
- Explain how molecular and ionic compounds form solutions by relating it to intermolecular forces (dipole-dipole) and forces of attraction (ion-dipole), respectively.
- Understand that solutions are mixtures at the particle level and do not involve a chemical change.
- State that for different substances, solubility occurs to varying degrees.
- Apply the phrase “like dissolves in like” to determine if a substance will dissolve in another substance.
- Explain, with the help of a diagram, the forces of attraction between solute and solvent particles.

Illustrate and explain the formation of metallic bonds.

- Define a metallic bond and use it to explain bonding within metals.
- Build models or find images to represent metallic bonding in order to distinguish it from ionic and molecular covalent structures.

Describe how the type of bond accounts for the properties of metallic substances.

- Using the theory of metallic bonding, explain why metals are malleable, ductile, good conductors of heat and electricity and have a wide range of melting and boiling points.
- Emphasize that metallic bonding is dependent upon the low electronegativities of metal atoms.

Compare the melting or boiling points of network solids, ionic compounds, metals and molecular compounds by comparing the relative strengths of the forces of attraction between their particles.

Unit 3 – Organic Chemistry

Organic chemistry is the study of molecular compounds of carbon. In this unit, the bonding capacity of carbon, hydrogen, oxygen, nitrogen and the halogens will be reviewed, as will the potential for these atoms to form covalent compounds. The vastness of the number of organic molecules will be explored using isomers and polymers as examples. With so many different organic molecules to consider, students will come to appreciate the need for a systematic naming scheme. Students will be given opportunities to discover how the classification of organic molecules into different family groups depends upon the type of bonding and atoms present. The students will also examine how these factors influence the reactivity of representative molecules from each of the different families.

Humans and all living organisms are made up of molecules that contain carbon. Carbon provides the backbone for many molecules essential for life. Deoxyribonucleic acid (DNA), proteins, carbohydrates, cellulose, fats and petroleum products all contain organic molecules. Having students consider the chemistry that exists within their own bodies can make the study of organic molecules more relevant and interesting. By studying the impact of technological applications of organic chemistry on the world around them, students will develop an appreciation for the nature of science and technology, of the relationship between science and technology and of the social and environmental contexts of science and technology. Using a context such as the problem of ozone depletion provides students with an opportunity for attitudinal growth. Furthermore, students should develop a sense of personal and shared responsibility for maintaining a sustainable environment. Ultimately, students should be aware of the direct and indirect consequences of their actions.

Explain the large number and diversity of organic compounds with reference to the unique nature of the carbon atom.

- Compare organic and inorganic compounds in terms of the presence of carbon, variety of compounds formed and relative molecular size and mass.
- Explain the wide diversity of organic compounds in terms of carbon's bonding capacity, ability to form multiple bonds and ability to bond in a variety of stable, relatively unreactive structures such as chains and rings.
- List natural sources of organic compounds.
- Briefly describe the origin of the term "organic": and how the conception of organic compounds changed since the first synthesis of an organic compound, urea from an inorganic compound.

Explain how synthesizing organic molecules revolutionized thinking in the scientific community.

Provide organic examples of how science and technology are an integral part of student lives and their community.

Analyze natural and technological systems to interpret and explain the influence of organic compounds on society.

- Understand that in today's world of rapid technological development, the concepts of organic chemistry are being applied to everything.
- Explore the use of organic chemicals to control pests in agriculture, CFCs or ozone depletion.

Classify organic compounds into hydrocarbons and hydrocarbon derivatives based on their names or structures.

- Differentiate between pure hydrocarbons and hydrocarbon derivatives on the basis of composition.

Classify hydrocarbon compounds into aliphatics and aromatics based on their names or structures.

- Defining aromatics as compounds that contain one or more benzene rings.

Classify aliphatic compounds into alkanes, alkenes and alkynes based on their names or structures.

- Describe and explain the trend in boiling points of hydrocarbons as the number of Cs increase.
- Describe the solubility of these compounds in polar and non-polar solvents.
- Define and be able to give examples of saturated and unsaturated hydrocarbons.
- Draw Lewis dot diagrams to show the bonding in ethane, ethane and ethyne.
- Describe the bonding shapes around each of the carbon atoms involved in a single, double or triple bond.
- Write the general formulae for alkanes, alkenes (1 double bond) and alkynes (1 triple bond), cycloalkanes and cycloalkenes and make predictions based on these formulae.
- Predict the chemical formula given the compound type and number of carbon atoms or hydrogen atoms, the possible compound type(s) given the complete chemical formula and cyclic isomers of alkenes or alkynes given a chemical formula or vice versa.

Write the formula and provide the IUPAC name for a variety of organic compounds.

- Name all the prefixes for 1 to 10 carbons in a compound or alkyl group.
- Write names and molecular formulae and draw structural formulae, complete structural diagrams, condensed structural diagrams, skeletal structural diagrams and line diagrams using the IUPAC rules for the alkanes, cycloalkanes, alkenes, cycloalkenes and alkynes.
- Name hydrocarbons with multiple alkyl branches.

Define isomers and illustrate the structural formulae for a variety of organic isomers.

- Define and give examples of structural isomerism.
- Compare the properties of a pair of organic isomers.
- Define geometric isomers (cis and trans).
- Draw and/or name geometric isomers (cis and trans) for ethane derivatives.

- Draw and name all structural isomers of alkanes (up to 6 carbons).
- Draw and name all structural isomers (including all cyclic) of hydrocarbons with general formula C_nH_{2n} (up to 5 carbons).
- Draw and name all structural isomers (including all cyclic) of hydrocarbons with general formula C_nH_{2n-2} (up to 4 carbons).

Perform and experiment identifying and controlling major variables.
Core Lab 4: Structures and Properties of Aliphatic Compounds

Write and balance chemical equations to predict the reactions of alkanes (and cycloalkanes), alkenes (and cycloalkenes) and alkynes.

- Define thermal and catalytic cracking.
- Compare hydrocarbon cracking and reforming.
- Draw structural diagrams of all organic reactants for: addition, substitution, cracking, reforming, complete combustion and incomplete combustion.
- Explain the addition of two moles of reactant to an alkyne to illustrate that two bonds of the triple bond may be broken (two steps).
- Given the reactants in an organic reaction, determine which type of reaction will proceed and predict the products, including the formation of any isomers. Where required, indicate that more isomeric products are possible and be able to draw no more than two of them.
- Determine the name and structure of a missing compound, given an organic reaction with one reactant or product missing.

Evaluate the design of a technology and the way it functions, on the basis of a variety of criteria that students have identified themselves.

- Explain the chemical and physical processes involved in oil refining (fractional distillation, cracking/reforming).

Elective Lab: Fractional Distillation

Identify various constraints that result in trade-offs during the development and improvement of technologies.

- Describe how modern oil refineries apply a fractional distillation process and cracking/reforming reactions to produce petroleum products.

Distinguish between scientific questions and technological problems.

- Compare fractional distillation, cracking/reforming done in a laboratory setting with the same process carried out in oil refining.

Classify various organic compounds as aromatics, based on their names or structures.

- Define aromatics as compounds that contain at least one benzene ring structure.
- Describe the bonding in benzene using the term "delocalized electrons" and explain how its unreactive nature and the equal C-C bond lengths in benzene are evidence that it does not have alternating single or double bonds.
- Draw structures for simple monosubstituted benzenes given the name and vice versa.

- Draw structures for simple polysubstituted benzenes given their names (IUPAC and ortho, meta or para when disubstituted) and vice versa.

Explain how organic chemistry evolved as new evidence comes to light.

- Explain how Kekule's invention of the concept of the ring structure of benzene revolutionized thinking in organic chemistry.

Write and balance chemical equations to predict the reactions of benzene.

- Draw structural diagrams of all organic reactants and products in substitution and complete combustion reactions.
- Given the reactants in an aromatic reaction, determine which type of reaction will proceed and predict what the products will be including the formation of any isomers. Where required, indicate that more isomeric products are possible and be able to draw no more than two of them.
- Determine the name and structure of a missing reactant or product in a reaction of an aromatic.

Classify hydrocarbon derivative compounds into alcohols, ethers, aldehydes, ketones, organic acids, organic halides, esters, amines and amides based on their names or structures.

- Define functional group.
- Define alkyl group.
- Identify alcohols, ethers, aldehydes, ketones, organic acids, organic halides, esters, amines and amides from their names and the functional groups in their structural formulae.
- Name and draw structures for derivatives of hydrocarbons (listed above) with only 1 functional group.
- Restrictions: alcohols, aldehydes, ketones, organic acids and organic halides: May contain one functional group only, only C-C bonds on the main chain, up to and including two branches off the main chain, alkyl and/or halide branches, no branching within an alkyl branch and alkyl branches no longer than three carbons.
- Restrictions: ethers, esters, amines and amides: May contain one functional group only, only single C-C bonds on the main chain, no branching of any kind off the main carbon chain, for amines and amides no alkyl groups off the N atom (i.e. NH_2 group only).

Identify limitations of the IUPAC naming system and identify reasons for alternative ways of naming.

Describe the relationship between intermolecular forces for organic structures investigated.

- Distinguish between the melting and boiling points of hydrocarbon derivatives and hydrocarbons (of the same size).

Write and balance chemical equations to predict the reactions of hydrocarbon derivatives.

- Define and give examples of elimination, esterification, and combustion reactions.

- Given reactants, determine the type of reaction that proceeds and the products including the formation of any isomers.
- Determine the name and structure of a missing reactant or product in a reaction of a hydrocarbon derivative.

Design an experiment identifying and controlling major variables. Select and use apparatus and materials safely.

- Synthesize a carboxylic acid.

Core Lab 5: Preparing a Carboxylic Acid Derivative

Describe the processes of polymerization and identify some important natural and synthetic polymers.

- Define and outline the structures of monomers, polymers and polymerization.
- Identify addition and condensation polymerization reactions.
- Build models depicting polymerization.
- Provide examples of polymerization in living and/or non-living systems.

Solve problems for writing complete balanced chemical polymerization reactions.

Define problems to facilitate investigation of polymers.

- Given a polymer, draw the monomer reactant(s).
- Describe environmental/health problems associated with the use of polymers.
- Design an experiment to prepare soap, acetlysalicyclic acid, vulcanized rubber nylon or rayon. Define the substances needed to make it and list problems associated with its formation, structure and use.

Core STSE 3: Polymers

Select, evaluate and integrate information concerning recyclable polymers from experimental, print and media sources and present an understanding of this information in a variety of formats such as lab reports, web pages or posters. Apply organic polymer knowledge to a particular problem and analyze the benefits to society by using organic polymers as the basis for recyclable materials.