Chemistry

INTRODUCTION AND SYLLABUS

COURSE DESCRIPTION

Chemistry is a high school level course, which satisfies the Ohio Core science graduation requirements of Ohio Revised Code Section 3313.603. This section of Ohio law requires three units of science. Each course should include inquiry-based laboratory experience that engages students in asking valid scientific questions and gathering and analyzing information.

This course introduces students to key concepts and theories that provide a foundation for further study in other sciences as well as advanced science disciplines. Chemistry comprises a systematic study of the predictive physical interactions of matter and subsequent events that occur in the natural world. The study of matter through the exploration of classification, its structure and its interactions is how this course is organized.

Investigations are used to understand and explain the behavior of matter in a variety of inquiry and design scenarios that incorporate scientific reasoning, analysis, communication skills and real-world applications. An understanding of leading theories and how they have informed current knowledge prepares students with higher order cognitive capabilities of evaluation, prediction and application.

COURSE CONTENT

The following information may be taught in any order; there is no ODE-recommended sequence.

C.PM: STRUCTURE AND PROPERTIES OF MATTER

C.PM.1: Atomic structure
- Evolution of atomic models/theory
- Electrons
- Electron configurations

C.PM.2: Periodic Table
- Properties
- Trends

C.PM.3: Chemical bonding
- Ionic
- Polar/covalent

C.PM.4: Representing compounds
- Formula writing
- Nomenclature
- Models and shapes (Lewis structures, ball and stick, molecular geometries)

C.PM.5: Quantifying matter

C.PM.6: Intermolecular forces of attraction
- Types and strengths
- Implications for properties of substances
    - Melting and boiling point
    - Solubility
    - Vapor pressure

C.IM: INTERACTIONS OF MATTER

C.IM.1: Chemical reactions
- Types of reactions
- Kinetics
- Energy
- Equilibrium
- Acids/bases

C.IM.2: Gas laws
- Pressure, volume and temperature
- Ideal gas law

C.IM.3: Stoichiometry
- Molecular calculations
- Solutions
- Limiting reagents

NATURE OF SCIENCE HIGH SCHOOL

Nature of Science
One goal of science education is to help students become scientifically literate citizens able to use science as a way of knowing about the natural and material world. All students should have sufficient understanding of scientific knowledge and scientific processes to enable them to distinguish what is science from what is not science and to make informed decisions about career choices, health maintenance, quality of life, community and other decisions that impact both themselves and others.

Categories	High School
Scientific Inquiry, Practice and Applications All students must use these scientific processes with appropriate laboratory safety techniques to construct their knowledge and understanding in all science content areas.	• Identify questions and concepts that guide scientific investigations. • Design and conduct scientific investigations using a variety of methods and tools to collect empirical evidence, observing appropriate safety techniques. • Use technology and mathematics to improve investigations and communications. • Formulate and revise explanations and models using logic and scientific evidence (critical thinking). • Recognize and analyze explanations and models. • Communicate and support scientific arguments.

Science is a Way of Knowing
Science assumes the universe is a vast single system in which basic laws are consistent. Natural laws operate today as they did in the past and they will continue to do so in the future. Science is both a body of knowledge that represents a current understanding of natural systems and the processes used to refine, elaborate, revise and extend this knowledge.
	• Various science disciplines use diverse methods to obtain evidence and do not always use the same set of procedures to obtain and analyze data (i.e., there is no one scientific method).
	  ○ Make observations and look for patterns.
	  ○ Determine relevant independent variables affecting observed patterns.
	  ○ Manipulate an independent variable to affect a dependent variable.
	  ○ Conduct an experiment with controlled variables based on a question or hypothesis.
	  ○ Analyze data graphically and mathematically.
	• Science disciplines share common rules of evidence used to evaluate explanations about natural phenomenon by using empirical standards, logical arguments and peer reviews.
	  ○ Empirical standards include objectivity, reproducibility, and honest and ethical reporting of findings.
	  ○ Logical arguments should be evaluated with open-mindedness, objectivity and skepticism.
	• Science arguments are strengthened by multiple lines of evidence supporting a single explanation.
	• The various scientific disciplines have practices, methods, and modes of thinking that are used in the process of developing new science knowledge and critiquing existing knowledge.

Science is a Human Endeavor Science has been, and continues to be, advanced by individuals of various races, genders, ethnicities, languages, abilities, family backgrounds and incomes.	• Science depends on curiosity, imagination, creativity and persistence. • Individuals from different social, cultural, and ethnic backgrounds work as scientists and engineers. • Science and engineering are influenced by technological advances and society; technological advances and society are influenced by science and engineering. • Science and technology might raise ethical, social and cultural issues for which science, by itself, does not provide answers and solutions.
Scientific Knowledge is Open to Revision in Light of New Evidence Science is not static. Science is constantly changing as we acquire more knowledge.	• Science can advance through critical thinking about existing evidence. • Science includes the process of comparing patterns of evidence with current theory. • Some science knowledge pertains to probabilities or tendencies. • Science should carefully consider and evaluate anomalies (persistent outliers) in data and evidence. • Improvements in technology allow us to gather new scientific evidence.

*Adapted from Appendix H – Understanding the Scientific Enterprise: The Nature of Science in the Next Generation Science Standards

Chemistry continued

C.PM: STRUCTURE AND PROPERTIES OF MATTER
C.PM.1: Atomic structure

- Evolution of atomic models/theory
- Electrons
- Electron configurations

CONTENT ELABORATION: STRUCTURE AND PROPERTIES OF MATTER

C.PM.1: Atomic structure
Physical Science included properties and locations of protons, neutrons and electrons, atomic number, mass number, cations and anions, isotopes and the strong nuclear force which holds the nucleus together. In this course, the historical development of the atomic model and the positions of electrons are explored in greater detail.

Atomic models are constructed to explain experimental evidence and make predictions. The changes in the atomic model over time exemplify how scientific knowledge changes as new evidence emerges and how technological advancements like electricity extend the boundaries of scientific knowledge. Thompson's study of electrical discharges in cathode-ray tubes led to the discovery of the electron and the development of the plum pudding model of the atom. Rutherford's experiment, in which he bombarded gold foil with α-particles, led to the discovery that most of the atom consists of empty space with a relatively small, positively charged nucleus. Bohr used data from atomic spectra to propose a planetary model of the atom in which electrons orbit the nucleus, like planets around the sun. Later, Schrödinger used the idea that electrons travel in waves to develop a model in which electrons travel randomly in regions of space called orbitals (quantum mechanical model).

Based on the quantum mechanical model, it is not possible to predict exactly where electrons are located but there is a region of space surrounding the nucleus in which there is a high probability of finding an electron (electron cloud or orbital). Data from atomic spectra (emission and absorption) gives evidence that electrons can only exist at certain discrete energy levels and not at energies between these levels.

Atoms are usually in the ground state where the electrons occupy orbitals with the lowest available energy. However, the atom can become excited when the electrons absorb a photon with the precise amount of energy (indicated by the frequency of the photon) to move to an orbital with higher energy. Any photon without this precise amount of energy will be ignored by the electron. The atom exists in the excited state for a very short amount of time. When an electron drops back down to the lower energy level, it emits a photon that has energy equal to the energy difference between the levels. The amount of energy is indicated by the frequency of the light that is given off and can be measured. Each element has a unique emission and absorption spectrum due to its unique electron configuration and specific electron energy jumps that are possible for that element.

Being aware of the quantum mechanical model as the currently accepted model for the atom is important for science literacy as it explains and predicts subatomic interactions, but details should be reserved for more advanced study.

Electron energy levels consist of sublevels (s, p, d and f), each with a characteristic number and shape of orbitals. Orbital diagrams and electron configuration can be constructed to show the location of the electrons in an atom using established rules. Valence electrons are responsible for most of the chemical properties of elements. In this course, electron configuration (extended and noble gas notation) and orbital diagrams can be shown for any element in the first three periods.

Although the quantum mechanical model of the atom explains the most experimental evidence, other models can still be helpful. Thinking of atoms as indivisible spheres is useful in explaining many physical properties of substances, such as the state (solid, liquid or gas) of a substance at room temperature. Bohr's planetary model is useful to explain and predict periodic trends in the properties of elements.

Note: *Quantum numbers and equations of de Broglie, Schrödinger and Plank are beyond the scope of this course.*

EXPECTATIONS FOR LEARNING

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VISIONS INTO PRACTICE: CLASSROOM EXAMPLES

This section provides guidance for developing classroom tasks that go beyond traditional approaches to instruction. It is a springboard for generating innovative ideas to address the cognitive demands. A variety of activities are presented so that teachers can select those that best meet the needs of their students. This is not an all-inclusive checklist and is not intended to cover every aspect of the standards. **These activities are suggestions and are not mandatory.**

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
C.PM.1: Atomic structure			
Evolution of atomic models/atomic structure			
		Compare the nature of protons, neutrons and electrons among different atomic models. Compare the strengths and limitations of particular atomic models. Investigate the principles used to develop atomic models (e.g. a black-box problem). Create a timeline that shows major discoveries in atomic history. Predict which isotope is most abundant given an element's atomic mass and the mass numbers of its isotopes.	Identify atomic models (e.g., Dalton's, Thomson's, Rutherford's, Bohr's) and the work used to produce each of these models. Interpret the classic historical experiments that were used to identify the components of an atom and behavior of electrons. Calculate atomic mass given the abundance of various isotopes. Determine the atomic number, mass number, number of protons, neutrons and electrons.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
Electrons			
Using knowledge and/or understanding of various ions and their electron location, construct a plan or proposal for a community firework show. Proposal must contain a list of materials, including the chemicals, safety procedures, environmental impact and possible cost. Design a toy that is based on the idea of excited electrons.	Design an investigation using group 2 elements that illustrates the reactivity of the elements as you move down the group. Interpret data to explain this reasoning based on the electron configurations of each element.	Compare the electron configuration of various ions based on data from an experiment (e.g., flame test, spectral tubes). Explore the color of various salts by looking at the electromagnetic spectrum.	Identify the extended and noble gas notation electron configurations for elements in the first three periods. Using the periodic table, determine the electron configuration of an atom. Construct an orbital diagram or electron configuration to show the probable arrangement of electrons in an atom.

Chemistry continued

C.PM: STRUCTURE AND PROPERTIES OF MATTER
C.PM.2: Periodic table

- Properties
- Trends

CONTENT ELABORATION: STRUCTURE AND PROPERTIES OF MATTER

C.PM.2: Periodic table
In the Physical Science course, the concept that elements are placed in order of increasing atomic number in the periodic table such that elements with similar properties are placed in the same column is introduced. How the periodic table is divided into groups, families, periods, metals, nonmetals and metalloids is also included and will be revisited here. In this course, with more information about the electron configuration of elements, similarities in the configuration of the valence electrons for a particular group can be observed. The electron configuration of an atom can be determined from the position on the periodic table. The repeating pattern in the electron configuration for elements on the periodic table explains many of the trends in the properties observed. Atomic theory is used to describe and explain trends in properties across periods or down columns including atomic radii, ionic radii, first ionization energies, electronegativities and whether the element is a solid or gas at room temperature. Additional ionization energies, electron affinities and periodic properties of the transition elements, and the lanthanide and actinide series are reserved for more advanced study.

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Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
C.PM.2: Periodic table			
Properties			
Develop a proposal for the construction of an outdoor art installation in various environments/climates. Determine which metal(s) would have the optimal properties for your project. Present and defend your proposal to a panel of experts.		Predict the placement of an element on the periodic table given only a list of its properties. Given a metalloid, judge whether the metalloid is more likely to behave as a metal or nonmetal. Defend your choice.	Create a product that explains the organization of the periodic table (e.g., increasing atomic number, groups, periods, metals, metalloid, nonmetals) to middle school students.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
Trends			
		Create a graphic to show the relationships between the trends of the periodic table and electron configurations.	Describe ionization energy and relate it to atomic structure. Describe electronegativity and relate it to atomic structure. Describe periodic trends in ionic radii and electron affinity and relate them to atomic structure. Describe atomic radius and relate to atomic structure. Describe how shielding effect explains the trend in atomic size. For two atoms, identify the one that is larger, more electronegative, or more easily ionized based on where they are on the periodic table. Justify your answer.

Chemistry continued

C.PM: STRUCTURE AND PROPERTIES OF MATTER
C.PM.3: Chemical bonding

- Ionic
- Polar/covalent

CONTENT ELABORATION: STRUCTURE AND PROPERTIES OF MATTER

C.PM.3: Chemical bonding
Content in the Physical Science course included recognizing that atoms with unpaired electrons tend to form ionic and covalent bonds with other atoms, forming molecules, ionic lattices or network covalent structures. In this course, electron configuration, electronegativity values and energy considerations will be applied to bonding and the properties of materials with different types of bonding.

Atoms of many elements are more stable when they are bonded to other atoms. In such cases, as atoms bond, energy is released to the surroundings, resulting in a system with lower energy. An atom's electron configuration, particularly the valence electrons, determines how an atom interacts with other atoms. Molecules, ionic lattices and network covalent structures have different, yet predictable, properties that depend on the identity of the elements and the types of bonds formed.

Differences in electronegativity values can be used to predict where a bond fits on the continuum between ionic and covalent bonds. The polarity of a bond depends on the electronegativity difference and the distance between the atoms (bond length). Polar covalent bonds are introduced as an intermediary between ionic and pure covalent bonds. The concept of metallic bonding is also introduced to explain many of the properties of metals (e.g., conductivity). Since most compounds contain multiple bonds, a substance may contain more than one type of bond. Carbon atoms can bond together and with other atoms, especially hydrogen, oxygen, nitrogen and sulfur, to form chains, rings and branching networks that are present in a variety of important compounds, including synthetic polymers, fossil fuels and the large molecules essential to life. Detailed study of the structure of molecules responsible for life is reserved for more advanced courses.

EXPECTATIONS FOR LEARNING

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Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
C.PM.3: Chemical bonding			
Ionic bonds			
Design a theoretical pharmaceutical with an appropriate shape to interact with a provided enzyme or receptor designed by the teacher. The designed molecule would need to contact the enzyme or receptor in three different loci. Design an investigation to evaluate the claims of a commercial product (e.g., ionic-tourmaline, a mineral that is said to emit quick-drying ions; a hair dryer; a shake weight dumbbell; a type of strong-bond glue). Determine function, intent and any potential bias with the product. Present findings in multiple formats.	Design and conduct an investigation to distinguish between ionic, polar covalent, nonpolar covalent and metallic bonds based on material properties (e.g., melting point, solubility, conductivity). Design an experiment to test the effectiveness of a water softener system's ability to remove ions from water.	Compare the stability of ions when they are separated vs. when they are in their lattice. Construct models or diagrams (e.g., Lewis dot structures, ball and stick models) of common compounds and molecules (e.g., NaCl, SiO_2, O_2, H_2, CO_2) and distinguish between ionically and covalently bonded compounds. Using electron configurations, hypothesize how an atom becomes a cation or anion and illustrate how and why they would form ionic compounds.	Define bond energy and recognize that bond-breaking is an endothermic process and bond-forming is an exothermic process. Represent the formation of a bond using electron configurations of individual atoms. Explain the tendency of elements to transfer or share electrons based on their location on the periodic table. Identify valence electrons as the highest energy electrons in the atom and use the octet rule to predict the most stable ion formed.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
	Polar/covalent bonds		
Propose a method to evaluate the ability of plastics to be recycled based on the understanding of the plastic's polarity. Evaluate and critique the impact of a synthetic polymer, fossil fuel or biological macromolecule on society, the environment or health.	Devise a procedure to evaluate physical and chemical properties to develop predictions and support claims about compounds' classification as ionic, polar or covalent. Evaluate the properties of DNA based on the bonds (polar and nonpolar) within its chemical structure and how it relates to DNA sequencing and/or forensic/medical applications.	Determine if bonds and molecules are polar by determining the direction of dipole moment of the individual bonds. Using electron dot diagrams, generate models showing that molecular compounds result from atoms sharing electrons. Include carbon bonds showing the formation of chains, rings and branching networks. Distinguish between bond polarity and molecular polarity. Construct models illustrating how a nonpolar molecule can be formed from polar bonds. Compare the stability of atoms when they are separated vs. when they are bonded. Using experimental evidence, explain how the properties of macromolecules depend on the properties of the molecules used in their formation and the length and structure of the polymer chain.	Distinguish between ionic and polar/nonpolar covalent bonds based on their electronegativity values. Write equations for covalent bond formation between two atoms using Lewis structures. Explain the difference between a single, double and triple bond in terms of electrons shared. Compare the bond energies and lengths for single, double and triple bonds conceptually (no numbers). Explain how polymerization forms long chains of macromolecules (polymers) from small molecules (monomers). Provide examples of natural and synthetic polymers.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
Metallic bonds			
Critique the advantages and disadvantages of different metals and alloys for bridge construction.		Illustrate how freely moving electrons in metallic bonds affect properties such as conductivity, malleability and ductility. Explain how the structure of metal atoms give them the ability to conduct heat and electricity. Explore the extent to which a variety of solid materials conduct electricity and rank the materials from good conductors to poor conductors. Based on the conductivity data, determine patterns of location on the Periodic Table for the good conductors vs. the poor conductors.	Compare electrons in a metallic bond and in a covalent bond.

Chemistry continued

C.PM: STRUCTURE AND PROPERTIES OF MATTER
C.PM.4: Representing compounds

- Formula writing
- Nomenclature
- Models and shapes (Lewis structures, ball and stick, molecular geometries)

CONTENT ELABORATION: STRUCTURE AND PROPERTIES OF MATTER

C.PM.4: Representing compounds
Using the periodic table, formulas of ionic compounds containing specific elements can be predicted. This can include ionic compounds made up of elements from groups 1, 2, 17, hydrogen, oxygen and polyatomic ions (given the formula and charge of the polyatomic ion). Given the formula, a compound can be named using conventional systems that include Greek prefixes and Roman numerals where appropriate. Given the name of an ionic or covalent substance, formulas can be written.

Many different models can be used to represent compounds including chemical formulas, Lewis structures, and ball and stick models. These models can be used to visualize atoms and molecules and to predict the properties of substances. Each type of representation provides unique information about the compound. Different representations are better suited for particular substances. Lewis structures can be drawn to represent covalent compounds using a simple set of rules and can be combined with valence shell electron pair repulsion (VSEPR) theory to predict the three-dimensional electron pair and molecular geometry of compounds. Lewis structures and molecular geometries will only be constructed for the following combination of elements: hydrogen, carbon, nitrogen, oxygen, phosphorus, sulfur and the halogens. Organic nomenclature is reserved for more advanced courses.

EXPECTATIONS FOR LEARNING

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Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
C.PM.4: Representing compounds			
Formula writing			
		Develop the formulas for chemical compounds in household items based on their names. Construct a prototype of a game to enhance the understanding of formula writing and nomenclature. Allow other students to evaluate and critique the appropriateness of the game.	Given elements from the periodic table and/or polyatomic ions, predict the formula of a compound. Write a formula from the name of an acid.
Nomenclature			
			Given the formula of an ionic compound or a binary covalent compound, determine the compound's name. Name an acid based on its chemical formula.
Models and shapes (Lewis structures, ball and stick, molecular geometries)			
		Determine which type of model (e.g., chemical formula, Lewis structure, ball-and-stick model) is the best representation for a variety of compounds. Implementing VSEPR identify the different shapes within a large macromolecule (e.g., caffeine, dopamine, serotonin).	Construct simple Lewis structures of compounds made up of hydrogen, carbon, nitrogen, oxygen, phosphorus, sulfur and the halogens. Predict the three-dimensional shapes of simple Lewis structures using valence shell electron pair repulsion (VSEPR) theory. Construct three-dimensional ball-and-stick models to determine the shapes of simple covalent compounds.

Chemistry continued

C.PM: STRUCTURE AND PROPERTIES OF MATTER
C.PM.5: Quantifying matter

CONTENT ELABORATION: STRUCTURE AND PROPERTIES OF MATTER

C.PM.5: Quantifying matter
In earlier grades, properties of materials were quantified with measurements that were always associated with some error. In this course, scientific protocols for quantifying the properties of matter accurately and precisely are studied. Using the International System of Units (SI), significant digits or figures, scientific notation, error analysis and dimensional analysis are vital to scientific communication.

There are three domains of magnitude in size and time: the macroscopic (human) domain, the cosmic domain and the submicroscopic (atomic and subatomic) domain. Measurements in the cosmic domain and submicroscopic domains require complex instruments and/or procedures.

Matter can be quantified in a way that macroscopic properties such as mass can reflect the number of particles present. Elemental samples are a mixture of several isotopes with different masses. The atomic mass of an element is calculated given the mass and relative abundance of each isotope of the element as it exists in nature. Because the mass of an atom is very small, the mole is used to translate between the atomic and macroscopic levels. A mole is equal to the number of atoms in exactly 12 grams of the isotope carbon-12. The mass of one mole of a substance is equal to its molar mass in grams. The molar mass for a substance can be used in conjunction with Avogadro's number and the density of a substance to convert between mass, moles, volume and number of particles of a sample.

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Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
		C.PM.5: Quantifying matter	
Devise a method to indirectly determine the value of a measurement that common laboratory tools cannot provide (e.g., thickness of aluminum foil, number of sand particles, moles of chalk used to write your name, drop from a pipet).	Design a method to determine the empirical formula or percent composition of an unknown hydrate/compound. Determine the percent by mass of water content in popcorn. Correlate its effect on the amount of popcorn produced (or time it takes to start the batch popping). Compare three brands, isolate other variables (e.g., popping method, use of different types of oil) and present findings in multiple formats.	Using a Socratic seminar, research and discuss the pros and cons of the International System of Units (SI) vs. the English measuring system. Use calculations to compare the ratios of the size of the atom to the size of different objects (e.g., cell, person, tree). Compare moles and mass. Identify situations where each is most appropriate to use. Design an investigation to show that the volume of any liquid sample is constant when divided by its mass.	Measure the volume of an irregular solid using SI units. Provide your answer using correct significant figures and unit. Distinguish accuracy from precision. Carry out laboratory measurements with a variety of equipment (e.g., graduated cylinders, beakers, balances) and report measurements to the correct number of significant figures. Compare the accuracy of each measuring device. Apply the rules for determining significant digits when performing mathematical operations. Determine the average atomic mass of an element based on the percent abundance of its naturally occurring isotopes. Convert between mass, moles, volume and number of representative particles using Avogadro's number, molar mass and density using dimensional analysis.

Chemistry continued

C.PM: STRUCTURE AND PROPERTIES OF MATTER
C.PM.6: Intermolecular forces of attraction

- Types and strengths
- Implications for properties of substances
  - Melting and boiling point
  - Solubility
  - Vapor pressure

CONTENT ELABORATION: STRUCTURE AND PROPERTIES OF MATTER

C.PM.6: Intermolecular forces of attraction
In middle school, solids, liquids and gases were explored in relation to the spacing of the particles, motion of the particles and strength of attraction between the particles that make up the substance. The intermolecular forces of attraction between particles that determine whether a substance is a solid, liquid or gas at room temperature are addressed in greater detail in this course. Intermolecular attractions are generally weak when compared to intramolecular bonds, but span a wide range of strengths.

The composition of a substance and the shape and polarity of a molecule are particularly important in determining the type and strength of bonding and intermolecular interactions. Types of intermolecular attractions include London dispersion forces (present between all molecules), dipole-dipole forces (present between polar molecules) and hydrogen bonding (a special case of dipole-dipole where hydrogen is bonded to a highly electronegative atom such as fluorine, oxygen or nitrogen), each with its own characteristic relative strength.

The configuration of atoms in a molecule determines the strength of the forces (bonds or intermolecular forces) between the particles and therefore the physical properties (e.g., melting point, boiling point, solubility, vapor pressure) of a material. For a given substance, the average kinetic energy (temperature) needed for a change of state to occur depends upon the strength of the intermolecular forces between the particles. Therefore, the melting point and boiling point depend upon the amount of energy that is needed to overcome the attractions between the particles. Substances that have strong intermolecular forces or are made up of three-dimensional networks of ionic or covalent bonds, tend to be solids at room temperature and have high melting and boiling points. Nonpolar organic molecules are held together by weak London dispersion forces. However, substances with longer chains provide more opportunities for these attractions and tend to have higher melting and boiling points. Increased branching of organic molecules results in lower melting and boiling points due to interference with the intermolecular attractions.

Substances will have a greater solubility when dissolving in a solvent with similar intermolecular forces. If the substances have different intermolecular forces, they are more likely to interact with themselves than the other substance and remain separated from each other. Water is a polar molecule and it is often used as a solvent since most ionic and polar covalent substances will dissolve in it. In order for an ionic substance to dissolve in water, the attractive forces between the ions must be overcome by the dipole-dipole interactions with the water. Dissolving of a solute in water is an example of a process that is difficult to classify as a chemical or physical change and it is not appropriate to have students classify it one way or another.

Evaporation occurs when the particles with enough kinetic energy to overcome the attractive forces separate from the rest of the sample to become a gas. The pressure of these particles is called vapor pressure. Vapor pressure increases with temperature. Particles with larger intermolecular forces have lower vapor pressures at a given temperature since the particles require more energy to overcome the attractive forces between them. Molecular substances often evaporate more due to the weak attractions between the particles and can often be detected by their odor. Ionic or network covalent substances have stronger forces and are not as likely to volatilize. These substances often have little, if any, odor. Liquids boil when their vapor pressure is equal to atmospheric pressure. In solid water, there is a network of hydrogen bonds between the particles that gives it an open structure. This is why water expands as it freezes and why solid water has a lower density than liquid water. This has important implications for life (e.g., ice floating on water acts as an insulator in bodies of water to keep the temperature of the rest of the water above freezing).

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Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
C.PM.6: Intermolecular forces of attraction			
Types and strengths			
	Design an investigation to identify which solvent would be best to dissolve a particular solute. Design a procedure to determine the polarity of a substance. Investigate why water doesn't follow predicted trends (e.g., surface tension, density, vapor pressure, boiling point) based on its intermolecular interactions (e.g. drops on a penny, capillary tube, mixing oil and water, water on glass vs. wax paper). Summarize your findings.	Apply the idea of intermolecular forces to biological implications (e.g., hydrogen bonding between two DNA strands, cell membrane formation of lipids). Construct a chromatography technique to separate the components of different dyes (e.g., hair color, food additives, skittles) applying principles of inter- and intra-molecular forces. Illustrate the differences between intermolecular forces. Represent the cause of intermolecular forces between molecules using models. Explain the effect that branching has on London dispersion forces in nonpolar organic molecules (e.g., long chains have greater forces and branching decreases the forces). Identify real-world implications.	Explain the importance of molecular-level structure in the functioning of designed materials (e.g., why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, pharmaceuticals are designed to interact with specific receptors). Describe intermolecular forces for molecular compounds. • H-bond as attraction between molecules when H is bonded to O, N, or F. • Dipole-dipole attractions between polar molecules. • London dispersion forces (electrons of one molecule attracted to nucleus of another molecule) – i.e. liquefied inert gases. • Relative strengths (H>dipole>London/van der Waals).

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
			Explain why intermolecular forces are weaker than ionic, covalent or metallic bonds. Identify the intermolecular forces that exist in a given compound.
Implications for properties of substances (melting and boiling point, solubility, vapor pressure)			
Make a soap and evaluate its effectiveness on hard water. Compare the effectiveness of various soaps. Evaluate the composition of shampoo samples using properties (e.g., viscosity, pH) to determine their effectiveness.	Evaluate the properties of sweeteners (e.g., regular table sugar, high fructose corn syrup, stevia, aspartame, saccharin, sucralose, honey, agave). Research these products and potential impacts. A variation for this could be evaluating oils (e.g., canola, coconut, olive, vegetable). Design an investigation to determine if a molecule is polar or nonpolar. Devise an investigation to show that the addition of a solute affects the density of a liquid.	Explain how a graph of vapor pressure vs. temperature can be used to determine boiling point and strength of intermolecular forces. Demonstrate the effect the strength of intermolecular forces has on various properties (e.g., change in evaporation temperature, polarizability, viscosity). Predict which compound will have the highest/lowest vapor pressure and melting/boiling point based on intermolecular forces. Sketch the solvation of a solute in an appropriate solvent and explain how the solute separates and interacts with the solvent.	Differentiate between bond polarity and molecular polarity. Explain why greater solubility occurs when dissolving a substance in a solvent with similar intermolecular forces ("like dissolves like").

Chemistry continued

C.IM: INTERACTIONS OF MATTER
C.IM.1: Chemical reactions

- Types of reactions
- Kinetics
- Energy
- Equilibrium
- Acids/bases

CONTENT ELABORATION: INTERACTIONS OF MATTER

C.IM.1: Chemical reactions
In the Physical Science course, coefficients were used to balance simple equations. Other representations, including Lewis structures and three-dimensional models, were also used and manipulated to demonstrate the conservation of matter in chemical reactions. In this course, more complex reactions will be studied, classified and represented with balanced chemical equations and three-dimensional models.

Classifying reactions into types can be a helpful organizational tool for recognizing patterns of what may happen when two substances are mixed. Teachers should be aware that the common reaction classifications that are often used in high school chemistry courses may lead to misconceptions because they are not based on the actual chemistry, but on surface features that can be similar from one system to another (e.g., exchanging partners), even though the underlying chemistry is not the same. However, these classifications may be useful in making predictions about what happens when two substances are mixed.

Some general types of chemical reactions are oxidation/reduction, synthesis, decomposition, single replacement, double replacement (including precipitation reactions and some acid-base neutralizations) and combustion reactions. Some reactions can fit into more than one category. For example, a single replacement reaction can also be classified as an oxidation/reduction reaction. Identification of reactions involving oxidation and reduction as well as indicating what substance is being oxidized and what is being reduced are appropriate in this course. However, balancing complex oxidation/reduction reactions is reserved for more advanced study.

Organic molecules release energy when undergoing combustion reactions and are used to meet the energy needs of society (e.g., oil, gasoline, natural gas) and to provide the energy needs of biological organisms (e.g., cellular respiration). When a reaction between two ionic compounds in aqueous solution results in the formation of a precipitate or molecular compound, the reaction often occurs because the new ionic or covalent bonds are stronger than the original ion-dipole interactions of the ions in solution. Laboratory experiences (3-D or virtual) with different types of chemical reactions should be provided.

Reactions occur when reacting particles collide in an appropriate orientation and with sufficient energy. The rate of a chemical reaction is the change in the amount of the reactants or products in a specific period of time. Increasing the probability or effectiveness of the collisions between the particles increases the rate of the reaction. Therefore, changing the concentration of the reactants, changing the temperature or the pressure of gaseous reactants, or using a catalyst, can change the reaction rate. Likewise, the collision theory can be applied to dissolving solids in a liquid solvent and can be used to explain why reactions are more likely to occur between reactants in the aqueous or gaseous state than between solids. The rate at which a substance dissolves should not be confused with the amount of solute that can dissolve in a given amount of solvent (solubility). Mathematical treatment of reaction rates is reserved for more advanced study. Computer simulations can help visualize reactions from the perspective of the kinetic-molecular theory.

In middle school, the differences between potential and kinetic energy and the particle nature of thermal energy were introduced. For chemical systems, potential energy is in the form of chemical energy and kinetic energy is in the form of thermal energy. The total amount of chemical energy and/or thermal energy in a system is impossible to measure. However, the energy change of a system can be calculated from measurements (mass and change in temperature) from calorimetry experiments in the laboratory. Conservation of energy is an important component of calorimetry equations. Thermal energy is the energy of a system due to the movement of its particles. The thermal energy of an object depends upon the amount of matter present (mass), temperature and chemical composition.

Some materials require little energy to change their temperature and other materials require a great deal to change their temperature by the same amount. Specific heat is a measure of how much energy is needed to change the temperature of a specific mass of material a specific amount. Specific heat values can be used to calculate the thermal energy change, the temperature (initial, final or change in) or mass of a material in calorimetry. Water has a particularly high specific heat capacity, which is important in regulating Earth's temperature.

As studied in middle school, chemical energy is the potential energy associated with chemical systems. Chemical reactions involve valence electrons forming bonds to yield more stable products with lower energies. Energy is required to break interactions and bonds between the reactant atoms and energy is released when an interaction or bond is formed between the atoms in the products. Molecules with weak bonds (e.g., ATP) are less stable and tend to react to produce more stable products, releasing energy in the process. Generally, energy is transferred out of the system (exothermic) when the products have stronger bonds than the reactants and is transferred into the system (endothermic) when the reactants have stronger bonds than the products. Predictions of the energy requirements (endothermic or exothermic) of a reaction can be made given a table of bond energies. Graphic representations can be drawn and interpreted to represent the energy changes during a reaction. The role of energy in determining the spontaneity of chemical reactions is dealt with conceptually in this course. Entropy and its influence on the spontaneity of reactions are reserved for more advanced study.

All reactions are reversible to a degree and many reactions do not proceed completely toward products but appear to stop progressing before the reactants are all used up. At this point, the amounts of the reactants and the products appear to be constant and the reaction can be said to have reached dynamic equilibrium. Dynamic equilibrium means the rate of the reverse reaction is equal to the rate of the forward reaction so there is no apparent change in the reaction.

If a chemical system at equilibrium is disturbed by a change in the conditions of the system (e.g., increase or decrease in the temperature, pressure on gaseous equilibrium systems, concentration of a reactant or product), then the equilibrium system will respond by shifting to a new equilibrium state, reducing the effect of the change (Le Chatelier's Principle). If products are removed as they are formed during a reaction, then the equilibrium position of the system is forced to shift to favor the products. In this way, an otherwise unfavorable reaction can be made to occur. Mathematical treatment of equilibrium reactions is reserved for advanced study. Computer simulations can help visualize the progression of a reaction to dynamic equilibrium and the continuation of both the forward and reverse reactions after equilibrium has been attained.

Properties of acids and bases and the ranges of the pH scale were introduced in Physical Science. In this course, the structural features of molecules are explored to further understand acids and bases. Acids often result when hydrogen is covalently bonded to an electronegative element and is easily dissociated from the rest of the molecule to bind with water to form a hydronium ion (H3O+). The acidity of an aqueous solution can be expressed as pH, where pH can be calculated from the concentration of the hydronium ion. Bases are likely to dissociate in water to form a hydroxide ion. Acids can react with bases to form a salt and water. Such neutralization reactions can be studied quantitatively by performing titration experiments. Detailed instruction about the equilibrium of acids and bases and the concept of Brønsted-Lowry and Lewis acids and bases is not the focus at this level.

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C.IM.1: Chemical reactions			
Types of reactions			
Evaluate oxidation-reduction reactions occurring in real-world settings (e.g., rusting, electroplating) that cause engineering/manufacturing challenges and propose a solution.	Generate a process for recycling a metal including the uses and possible limitations of the recycled metal.	Apply knowledge of reactions to determine the appropriate fire extinguisher for a given scenario. Examine living organisms to identify and explain biological chemical reactions (e.g., metabolism, respiration, photosynthesis) within the organism. Compare different reaction types. Explain the energy changes in photosynthesis and in the combustion of sugar in terms of bond breaking and bond formation. Using activity series and solubility rules construct an outcome for single replacement and double replacement reactions. Draw a particle diagram representing the interactions of particles in a chemical reaction.	Classify a chemical reaction as synthesis, decomposition, single-replacement, double replacement or organic combustion. Identify which substance is oxidized and which substance is reduced in an oxidation/reduction reaction.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
Kinetics			
Critique the effects of a catalyst on everyday chemical reactions (e.g., biological enzymes, catalytic converters). Redesign a process which is more cost effective and/or environmentally friendly.	Design an experiment to determine the effect of concentration, surface area or temperature on reaction rate.	Apply scientific principles and evidence to provide an explanation about the effects of changing concentration, temperature and pressure on the rate of a chemical reaction. Through experimentation, generate qualitative potential energy diagrams for endothermic and exothermic reactions with and without the presence of a catalyst (e.g., decomposition of H_2O_2 with KI and without KI). Include reactants, products and activated complex. Illustrate collision theory using particle diagrams showing that molecules must collide in the proper orientation and with sufficient energy to equal or exceed the activation energy in order to react.	Identify the ways the rate of a chemical reaction can be affected (e.g., concentrations of reactions, surface area, changing temperature or pressure of gaseous substances, using a catalyst).
Energy			
Design a better (e.g., less expensive, more environmentally friendly) safe hand warmer using ionic substances.	Design a method to determine the identity of a metal by calculating the heat transfer from the hot metal to cold water.	Compare how the specific heat of different substances impacts temperature change. Develop a model to illustrate that the release or absorption of energy from a chemical reaction system depends upon the changes in total bond energy. Use household materials to show the difference between endothermic and exothermic reactions.	Calculate the thermal energy change (q), the change of temperature (ΔT), initial or final temperature and mass of a material using specific heat. Given a table of bond energies, determine whether a given reaction is exothermic or endothermic. Track the flow of energy and explain why a reaction is an exothermic or endothermic process.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
Equilibrium			
Propose a procedure to shift a commercial equilibrium process to maximize a desired product and construct a risk assessment for its implications on society (e.g., Haber process).		In a laboratory setting, illustrate equilibrium shift due to disturbances. Indicate whether the forward or reverse reaction is favored to reach equilibrium based on different disturbances (e.g., increase or decrease in temperature, pressure on gaseous equilibrium systems, change in concentration of a reactant or product).	Show that equilibrium is dynamic and that the rates of the forward and reverse reactions are equal. Describe key features of equilibrium (two opposing processes occur simultaneously at the same rate).
Acids/bases			
Conduct an experiment to determine what type of roof materials would be appropriate in areas with high acid rain. Evaluate and critique why lakes with limestone or calcium carbonate experience less adverse effects from acid rain than lakes with granite beds. Then invent a product or process to minimize these effects.	Design an investigation to determine the effective pH range of natural and synthetic indicators. Devise a method to evaluate the Vitamin C content of commercial products. Design an investigation to determine the most effective antacid (e.g., baking soda ($NaHCO_3$) or magnesium hydroxide ($Mg(OH)_2$) per gram for neutralizing stomach acid (HCl).	Evaluate neutralization reactions quantitatively by performing titration experiments.	Perform calculations relating pH to hydronium ion concentration. Identify acids based on the formation of the hydronium ion in water. Identify bases by their dissociation in water to form the hydroxide ion.

Chemistry continued

C.IM: INTERACTIONS OF MATTER
C.IM.2: Gas laws

- Pressure, volume and temperature
- Ideal gas law

CONTENT ELABORATION: INTERACTIONS OF MATTER

C.IM.2: Gas laws
The kinetic-molecular theory can be used to explain the properties of gases (pressure, temperature and volume) through the motion and interactions of its particles. Problems can also be solved involving the changes in temperature, pressure, volume and amount of a gas. When two of these four are kept constant, the relationship between the other two can be quantified, described and explained using the kinetic-molecular theory. Real-world phenomena (e.g., why tire pressure increases in hot weather, why a hot air balloon rises) can be explained using this theory. When solving gas problems, the Kelvin temperature scale must be used since only in this scale is the temperature directly proportional to the average kinetic energy. The Kelvin temperature is based on a scale that has its minimum temperature at absolute zero, a temperature at which all motion theoretically stops. Since equal volumes of gases at the same temperature and pressure contain an equal number of particles (Avogadro's law), problems can be solved for an unchanging gaseous system using the ideal gas law ($PV = nRT$) where R is the ideal gas constant (e.g., represented in multiple formats, 8.31 joules/(mole·K). The focus in this course is solving problems using the gas laws and understanding their applications, rather than memorizing the specific names and formulas. Deviations from ideal gaseous behavior are reserved for more advanced study. Relationships between the volume, temperature and pressure can be explored in the laboratory or through computer simulations or virtual experiments.

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C.IM.2: Gas laws			
Pressure, volume and temperature			
Design a device that measures tire pressure under changing temperature conditions. Design a toy that is an application of a gas law.	Using simulations and/or laboratory experiences, determine the relationships between pressure and volume, pressure and temperature, and temperature and volume.	Explain both the quantitative and qualitative relationships between pressure, volume and temperature. Construct models representing the relationship of pressure, volume and temperature related to collisions and energy of particles. Apply gas laws to common scenarios (e.g. hot air balloons, tire blowouts) Use the kinetic molecular theory to explain the motion of gas particles and how they are affected by changes in pressure, temperature and/or volume.	Identify units of pressure, volume and temperature. Convert between different pressure units. Solve problems using appropriate gas law equations. Determine whether pressure, temperature and volume are increasing or decreasing in a given situation.
Ideal gas law			
	Create a model airbag with baking soda and vinegar in a plastic bag. Use the ideal gas law to figure the amount of the reactants necessary to fill a given plastic bag. Test the prediction and provide possible explanations for any discrepancy between the theoretical and actual results. Detect and measure the volume of a gas produced during a chemical reaction and relate to molar volume at standard temperature and pressure.	Use an Ideal Gas Law Simulator to represent and interpret the connection between pressure, volume, temperature and number of particles.	Apply the ideal gas law to solve for an appropriate variable.

Chemistry continued

C.IM: INTERACTIONS OF MATTER
C.IM.3: Stoichiometry

- Molar calculations
- Solutions
- Limiting reagents

CONTENT ELABORATION: INTERACTIONS OF MATTER

C.IM.3: Stoichiometry
A stoichiometric calculation involves the conversion from the amount of one substance in a chemical reaction to the amount of another substance. The coefficients of the balanced equation indicate the ratios of the substances involved in the reaction in terms of both particles and moles.

Once the number of moles of a substance is known, amounts can be changed to mass, volume of a gas, volume of solutions and/or number of particles. Molarity is a measure of the concentration of a solution that can be used in stoichiometric calculations. When performing a reaction in the lab, the experimental yield can be compared to the theoretical yield to calculate percent yield. The concept of limiting reagents is treated conceptually. Mathematical applications can be utilized, but it is important to address the symbolic representations as well. Molality and normality are concepts reserved for more advanced study.

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C.IM.3: Stoichiometry			
Molar Calculations			
Evaluate the efficiency, cost and environmental impacts of multiple possible chemical processes to determine which process would be best to use. Sustainability and green chemistry should be considered.	Calculate the reactants needed to produce an exact amount of a product (e.g., produce silver through the reaction of silver nitrate and copper or zinc and hydrochloric acid). Produce the product in the laboratory. Calculate the percent difference between the theoretical amount and the amount actually produced. Provide possible explanations for the discrepancy.		Using data collected from a multi-step chemical reaction, calculate percent yield. Use mole ratios from a balanced equation to calculate the quantity of one substance in a reaction, given the quantity of another substance in the reaction (e.g., given moles, particles, mass or volume and ending with moles, particles, mass or volume of the desired substance). Interpret the coefficients of a balanced equation in terms of moles and particles.
Solutions			
	Plan and implement a process to test concentration of pollutants in water (e.g., lead, mercury).	Explain how the creation of a standardized solution (a solution of known molarity) allows you to determine the concentration of an unknown solution.	Create a solution and a dilution of a known concentration. Calculate the molarity of an aqueous solution. Distinguish between solute, solvent and solution. Determine the concentration of an unknown solution through titration.

Designing technological/engineering solutions using science concepts	Demonstrating science knowledge	Interpreting and communicating science concepts	Recalling accurate science
Limiting reagents			
Evaluate an environmental problem through the lens of limiting reagents (e.g., algae growths impacted by available phosphates and nitrates). Investigate the role that limiting reagents play in an industrial process (e.g., pharmacology, cosmetics, chemical industries). Evaluate techniques to optimize production, including how costs and waste products are taken into consideration.	Plan and carry out an investigation to demonstrate the conceptual principle of limiting reactants.	Compare limiting to excess reagents in a chemical reaction (e.g., copper (II) sulfate and an iron nail).	Determine which reactant is limited using particle diagrams. Use BCA tables to calculate the quantities of products and excess reactants.