2018 Virginia Science Standards of Learning

Curriculum Framework

Board of Education

Commonwealth of Virginia

Superintendent of Public Instruction
James F. Lane, Ed.D.

Assistant Superintendent of Learning
Gena Keller

Office of Science, Technology, Engineering, and Mathematics
Tina Manglicmot, Ed.D., Director
Anne Petersen, Ph.D., Science Coordinator
Joshua Bearman, Science Specialist
Myra Thayer, Science Specialist

NOTICE
The Virginia Department of Education does not discriminate on the basis of race, sex, color, national origin, religion, age, political affiliation, veteran status, or against otherwise qualified persons with disabilities in its programs and activities.

The *2018 Virginia Science Standards of Learning Curriculum Framework* can be found on the Virginia Department of Education's website at http://www.doe.virginia.gov/testing/sol/standards_docs/science/index.shtml.

Introduction

The *2018 Virginia Science Standards of Learning Curriculum Framework* amplifies the *Science Standards of Learning for Virginia Public Schools* (SOL) and defines the content knowledge, skills, and understandings that provide a foundation in science concepts and practices. The framework provides additional guidance to school divisions and their teachers as they develop an instructional program appropriate for their students. It assists teachers as they plan their lessons by identifying enduring understandings and defining the essential science and engineering practices students need to master. This framework delineates in greater specificity the minimum content requirements that all teachers should teach and all students should learn.

School divisions should use the framework as a resource for developing sound curricular and instructional programs. This framework should not limit the scope of instructional programs. Additional knowledge and skills that can enrich instruction and enhance students' understanding of the content identified in the SOL should be included in quality learning experiences.

The framework serves as a guide for SOL assessment development. Assessment items may not and should not be a verbatim reflection of the information presented in the framework. Students are expected to continue to apply knowledge and skills from the SOL presented in previous grades as they build scientific expertise.

The Board of Education recognizes that school divisions will adopt a K–12 instructional sequence that best serves their students. The design of the SOL assessment program, however, requires that all Virginia school divisions prepare students to demonstrate achievement of the standards for elementary and middle school by the time they complete the grade levels tested. The high school end-of-course SOL tests, for which students may earn verified units of credit, are administered in a locally determined sequence.

Each topic in the framework is developed around the SOL. The format of the framework facilitates teacher planning by identifying the enduring understandings and the scientific and engineering practices that should be the focus of instruction for each standard. The categories of scientific and engineering practices appear across all grade levels and content areas. Those categories are: asking questions and defining problems; planning and carrying out investigations; interpreting, analyzing, and evaluating data; constructing and critiquing conclusions and explanations; developing and using models; and obtaining, evaluating, and communicating information. These science and engineering practices are embedded in instruction to support the development and application of science content.

Science and Engineering Practices

Science utilizes observation and experimentation along with existing scientific knowledge, mathematics, and engineering technologies to answer questions about the natural world. Engineering employs existing scientific knowledge, mathematics, and technology to create, design, and develop new devices, objects, or technology to meet the needs of society. By utilizing both scientific and engineering practices in the science classroom, students develop a deeper understanding and competence with techniques at the heart of each discipline.

Engineering Design Practices

Engineering design practices are similar to those used in an inquiry cycle; both use a system of problem solving and testing to come to a conclusion. However, unlike the inquiry cycle in which students ask a question and use the scientific method to answer it, in the engineering and design process, students use existing scientific knowledge to solve a problem. Both include research and experimentation; however, the engineering design process has a goal of a solving a societal problem and may have multiple solutions. More information on the engineering and design process can be found at https://www.eie.org/overview/engineering-design-process.

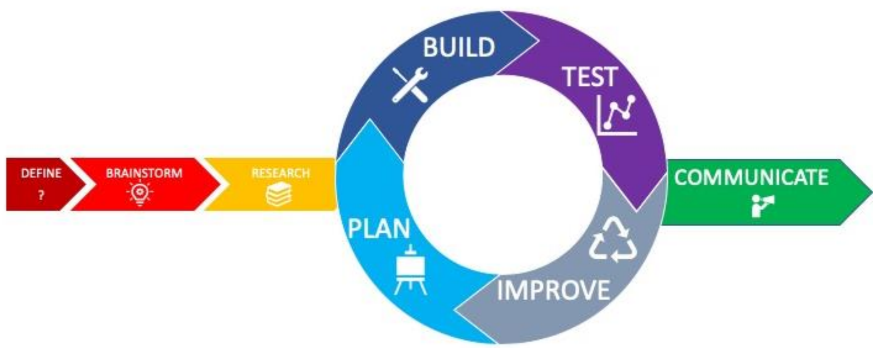

Figure 1: Engineering Design Process image based on the National Aeronautics and Space Administration (NASA) engineering design model.

The Engineering Design Process:

- Define: Define the problem, ask a question
- Imagine: Brainstorm possible solutions
- Research: Research the problem to determine the feasibility of possible solutions
- Plan: Plan a device/model to address the problem or answer the question
- Build: Build a device/model to address the problem or answer the question
- Test: Test the device/model in a series of trials
    - Does the design meet the criteria and constraints defined in the problem?
        - Yes? Go to Share (#8)
        - No? Go to Improve (#7)
- Improve: Using the results of the test, brainstorm improvements to the device/model; return to #3
- Share: Communicate your results to stakeholders and the public

Computational Thinking

The term *computational thinking* is used throughout this framework. Computational thinking is a way of solving problems that involves logically organizing and classifying data and using a series of steps (algorithms). Computational thinking is an integral part of Virginia's computer science standards and is explained as such in the *Computer Science Standards of Learning*:

> *Computational thinking is an approach to solving problems that can be implemented with a computer. It involves the use of concepts, such as abstraction, recursion, and iteration, to process and analyze data, and to create real and virtual artifacts. Computational thinking practices such as abstraction, modeling, and decomposition connect with computer science concepts such as algorithms, automation, and data visualization. [Computer Science Teachers Association & Association for Computing Machinery]*

Students engage in computational thinking in the science classroom when using both inquiry and the engineering design process. Computational thinking is used in laboratory experiences as students develop and follow procedures to conduct an investigation.

Structure of the *2018 Virginia Science Standards of Learning Curriculum Framework*

The framework is divided into two columns: Enduring Understandings and Essential Knowledge and Practices. The purpose of each column is explained below.

Enduring Understandings
The Enduring Understandings highlight the key concepts and the big ideas of science that are applicable to the standard. These key concepts and big ideas build as students advance in their scientific and engineering understanding. The bullets provide the context of those big ideas at that grade or content level.

Essential Knowledge and Practices
Each standard is expanded in the Essential Knowledge and Practices column. What each student should know and be able to do as evidence of understanding of the standard is identified here. This is not meant to be an exhaustive list nor is a list that limits what is taught in the classroom. It is meant to be the key knowledge and practices that define the standard. Science and engineering practices are highlighted with a leaf bullet (see footer).

The *2018 Virginia Science Standards of Learning Curriculum Framework* is informed by the Next Generation Science Standards (https://www.nextgenscience.org/).

Chemistry

The Chemistry standards are designed to provide students with a detailed understanding of the interaction between matter and energy. This interaction is investigated using experimentation, mathematical reasoning, and problem solving. Areas of study include atomic theory, chemical bonding, chemical reactions, molar relationships, kinetic molecular theory, and thermodynamics. Concepts are illustrated with current practical applications that should include examples from environmental, nuclear, organic, and biochemistry content areas. Technology, including graphing calculators, computers, simulations, and probeware are used when feasible. Students will use chemicals and equipment safely. Mathematics, computational thinking, and experience with the engineering design process are essential as students advance in their scientific thinking.

Scientific and Engineering Practices

Engaging in the practices of science and engineering helps students understand how scientific knowledge develops; such direct involvement gives them an appreciation of the many ways to investigate, model, and explain the world. These scientific and engineering practices include the use of scientific skills and processes to explore the content of science as outlined in the *Science Standards of Learning*. The engineering design practices are the application of science content to solve a problem or design an object, tool, process, or system. These scientific and engineering practices are critical to science instruction and are to be embedded throughout the year.

CH.1 The student will demonstrate an understanding of scientific and engineering practices by

a) asking questions and defining problems

- **ask questions that arise from careful observation of phenomena, examination of a model or theory, unexpected results, and/or to seek additional information**
- **determine which questions can be investigated within the scope of the school laboratory**
- **make hypotheses that specify what happens to a dependent variable when an independent variable is manipulated**
- **generate hypotheses based on research and scientific principles**
- **define design problems that involve the development of a process or system with interacting components, criteria and constraints**

b) planning and carrying out investigations

- **individually and collaboratively plan and conduct observational and experimental investigations**

- **plan and conduct investigations or test design solutions in a safe manner, including planning for response to emergency situations**
- **select and use appropriate tools and technology to collect, record, analyze, and evaluate data**

c) interpreting, analyzing and evaluating data

- **record and present data in an organized format that communicates relationships and quantities in appropriate mathematical or algebraic forms**
- **use data in building and revising models, supporting explanations for phenomena, or testing solutions to problems**
- **solve problems using mathematical manipulations including the International System of Units (SI), scientific notation, derived units, significant digits, and dimensional analysis**
- **analyze data using tools, technologies, and/or models (e.g., computational, mathematical) to make valid and reliable scientific claims or determine an optimal design solution**
- **analyze data graphically and use graphs to make predictions**
- **differentiate between accuracy and precision of measurements**
- **consider limitations of data analysis when analyzing and interpreting data**
- **analyze data to optimize a design**

d) constructing and critiquing conclusions and explanations

- **construct and revise explanations based on valid and reliable evidence obtained from a variety of sources**
- **apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena or design solutions**
- **compare and evaluate competing arguments in light of currently accepted explanations and new scientific evidence**
- **construct arguments or counterarguments based on data and evidence**
- **differentiate between scientific hypothesis, theory, and law**

e) developing and using models

- **evaluate the merits and limitations of models**
- **develop, revise, and/or use models based on evidence to illustrate or predict relationships**
- **use models and simulations to visualize and explain the movement of particles, to represent chemical reactions, to formulate mathematical equations, and to interpret data sets**

f) obtaining, evaluating, and communicating information

- **compare, integrate, and evaluate sources of information presented in different media or formats to address a scientific question or solve a problem**

- **gather, read, and evaluate scientific and/or technical information from multiple authoritative sources, assessing the evidence and credibility of each source**
- **communicate scientific and/or technical information about phenomena and/or a design process in multiple formats**

Chemistry Content

CH.2 The student will investigate and understand that elements have properties based on their atomic structure. The periodic table is an organizational tool for elements based on these properties. Key information pertaining to the periodic table includes

a) average atomic mass, isotopes, mass number, and atomic number;
b) nuclear decay;
c) trends within groups and periods including atomic radii, electronegativity, shielding effect, and ionization energy;
d) electron configurations, valence electrons, excited electrons, and ions; and
e) historical and quantum models.

Central Idea: The properties of elements, to include the periodic trends, are based on their atomic structure. The periodic table is an organizational tool that allows for the prediction of chemical and physical properties.

Vertical Alignment: Students are introduced to the periodic table as a tool that can be used to predict chemical and physical properties in Physical Science (PS.2, PS.4). Students used the periodic tool to identify groups, periods, atomic numbers, atomic masses, and valence electrons.

Enduring Understandings	Essential Knowledge and Practices
Atoms are the basic building blocks of all matter. The properties of an atom are based on the number and arrangement of its parts. • The subatomic particles have specific characteristics of mass, charge, and location (CH.2). • An isotope is an atom that has the same number of protons as another atom of the same element but has a different number of neutrons. Some isotopes are radioactive. The	In order to meet this standard, it is expected that students will • differentiate among a proton, neutron, and electron in terms of relative size, composition, charge, and location in the atom (CH.2) • calculate the number of electrons in an ion given its charge (CH.2 a)

Enduring Understandings	**Essential Knowledge and Practices**
average atomic mass for each element is the weighted average of that element's naturally occurring isotopes (CH.2 a). • Nuclear changes involve a change in the composition of the nucleus of an atom and may result in a new element (CH.2 b). • Half–life is the amount of time it takes for half of the substance to undergo nuclear change and is important in the use and storage of radioactive materials (CH.2 b). • Electron configuration is a numeric representation of the arrangement of electrons around the nucleus of an atom based on their energy levels. The number of paired and unpaired electrons determine chemical properties, particularly bonding (CH.2 d). • Ions form when atoms gain or lose an electron (CH.2 d). • A valence electron can absorb energy and become excited, thus moving to a higher principal energy level. The subsequent return of the valence electron to the ground state emits energy that is used in many applications (CH.2 d). • Electrons occupy equal-energy orbitals, resulting in a maximum number of unpaired electrons (CH.2 d). Predictable patterns of properties emerge when elements are arranged according to the number of valence electrons. The periodic table models these patterns and can be used to predict properties of elements. • The periodic table is a tool that shows an organization of elements and allows predictions about physical and chemical	• calculate the *weighted* average atomic mass (CH.2 a) • calculate the number of neutrons in an isotope, given its mass number (CH.2 a) • use equations to predict products of nuclear decay, to include those that emit alpha, beta, and gamma radiation (CH.2 b) • use half-life calculations to determine the amount of a radioactive substance that remains after a designated period (CH.2 b) • use the periodic table as a model to predict relative properties of elements based on the patterns of valence electrons; relate the position of an element on the periodic table to its electron configuration (CH.2 c) • compare elements on the periodic table within a single group or single period in terms of electronegativity, shielding effect, and ionization energy (CH.2 c) • relate the roles of principal energy levels and number of protons to the periodic trends (CH.2 c) • use electron configurations to predict bonding (CH.2 d) • identify the number of valence electrons using an element's electron configuration (CH.2 d) • determine the ions formed when selected atoms gain or lose electrons (CH.2 d) • explain how excited electrons result in the release of electromagnetic radiation (CH.2 d)

Enduring Understandings	Essential Knowledge and Practices
properties. The periodic table is arranged in order of increasing atomic numbers (CH.2 a). • Groups (families) have similar properties because of their similar valence electron configurations (CH.2 a, d). • Periods have predictable properties due to an increasing number of electrons in the outer energy levels (CH.2 c). • The periodic trends (i.e., electronegativity, ionization energy, shielding, and atomic radius) are determined by both the number of principal energy levels of the element and the number of protons of an element (CH.2 c). • Atomic radius, electronegativity, ionization energy, and shielding are periodic trends that explain the chemical properties of elements (CH.2 c). • The periodic table changes as new elements are made in laboratory settings (CH.2). The Quantum-mechanical model of the atom encapsulates our current understanding of the atom. The development of these models illustrates the nature of science (LS.2). • Discoveries and insights related to the atom's structure have changed the model of the atom (CH.2 e). *Students are not responsible for describing the contributions of specific scientists.*	• explain how the development of the modern atomic theory reflects the nature of science (CH.2 e).

CH.3 The student will investigate and understand that atoms are conserved in chemical reactions. Knowledge of chemical properties of the elements can be used to describe and predict chemical interactions. Key ideas include
a) chemical formulas are models used to represent the number of each type of atom in a substance;
b) substances are named based on the number of atoms and the type of interactions between atoms;
c) balanced chemical equations model rearrangement of atoms in chemical reactions;

d) **atoms bond based on electron interactions;**
e) **molecular geometry is predictive of physical and chemical properties; and**
f) **reaction types can be predicted and classified.**

Central Idea: The law of conservation of mass governs all interactions among atoms. These interactions occur as valence electrons are shared and transferred between atoms in the process of bonding. Chemical equations model the interactions of atoms in a chemical reaction and these interactions can be predicted and classified.

Vertical Alignment: Students are introduced to bonding and use simple balanced equations to model chemical reactions in Physical Science. The practice of balancing equations is used to support the law of conservation of mass (PS.3).

Enduring Understandings	**Essential Knowledge and Practices**
Matter is conserved because atoms are conserved in chemical and physical processes. The law of conservation of matter (mass) states that, regardless of how substances within a closed system are changed, the total mass remains the same. • Conservation of matter is represented in balanced chemical equations. A coefficient indicates the relative number of particles involved in the reaction (CH.3). • The products formed in a chemical reaction have different properties than the original reactants (CH.3 c). • Chemical formulas are used to represent compounds. Subscripts represent the relative number of each type of atom in a molecule or formula unit (CH.3 a). Matter consists of atoms held together by electromagnetic forces and exists as different substances which can be utilized based on their properties. • The strong electrostatic forces of attraction between atoms in a compound are called *chemical bonds* (CH.3 d).	In order to meet this standard, it is expected that students will • use particulate models and mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction (CH.3) • name and write the chemical formulas for binary covalent (molecular) and ionic compounds (CH.3 b) • name and write the chemical formula for ionic compounds containing polyatomic ions (CH.3 b) • explain how chemical equations support the law of conservation of mass (CH.3 c) • transform word equations into balanced chemical equations (CH.3 b, c) • construct and revise an explanation for the outcome of a simple chemical reaction, based on the outermost electron states of the atom, trends in the periodic table, and knowledge of the periodic properties (CH.2, CH.3 c)

Enduring Understandings	Essential Knowledge and Practices
• Intramolecular bonds form between atoms to achieve stability. Covalent bonds involve the sharing of electrons between nonmetal atoms. Ionic bonds involve the transfer of electrons between metal and nonmetal ions. Elements with low ionization energy form positive ions (cations) easily. Elements with high ionization energy form negative ions (anions) easily (CH.3 d). • Polar bonds form between covalently bonded elements with very different electronegativities. Non-polar bonds form between covalently bonded elements with similar electronegativities (CH.3 d). • Some elements, such as hydrogen, oxygen, nitrogen, fluorine, chlorine, bromine, and iodine naturally occur as diatomic molecules (CH.3 b). Bonded and non-bonded pairs of electrons can be used to predict molecular geometry. • Lewis dot diagrams are used to represent valence electrons in an element. Lewis structures can be used to determine the shape of molecules using the valence shell electron pair repulsion (VSEPR) model (bent, linear, trigonal planar, tetrahedral, and trigonal pyramidal) (CH.3 e). Carbon is an important element in biological systems and combines with oxygen and hydrogen, as well as other elements, to form compounds that are essential for living processes. This class of bonds are called *organic compounds*. • Carbon atoms can form single, double, and triple bonds with other carbon atoms (CH.3 e).	• identify the intramolecular bonds in compounds and predict their physical properties based on the type of bond (CH.3 d) • conduct an investigation to determine the trends and properties of compounds with ionic and covalent bonds (investigation may include melting point, solubility, and conductivity) (CH.3 d) • draw Lewis dot diagrams to represent valence electrons in elements and show covalent bonding (CH.3 d) • compare covalently bonded molecules to determine if the intramolecular bonds are polar or non-polar (CH.3 d) • explain the molecular shape of a covalently bonded molecule using the VSEPR model (CH.3 e) • describe how the valence electrons of carbon impact its bonding and molecular geometry, allowing it to be important in both biological and technological applications (CH.3 e) • classify chemical reactions as one of six major types: synthesis, decomposition, single replacement, double replacement, combustion, or neutralization (CH.3 f) • predict products of single and double replacement reactions, given the reactants (CH.3 f).

Enduring Understandings	Essential Knowledge and Practices
• Carbon-based compounds have different shapes based on their bonding (CH.3 e). • The flexibility of carbon to bond in various shapes allows for a wide range of technological application (CH.3 e). Classification of chemical equations relies on careful observation of patterns. • In a chemical process, the atoms that make up the original substance are regrouped into different molecules (CH.3 c, f). • Many of the products of chemical reactions can be predicted by recognizing patterns (CH.3 f).	

CH.4 The student will investigate and understand that molar relationships compare and predict chemical quantities. Key ideas include

a) Avogadro's principle is the basis for molar relationships; and

b) stoichiometry mathematically describes quantities in chemical composition and in chemical reactions.

Central Idea: For chemical equations to be useful, quantities of reactants and products must be able to be measured. Stoichiometry allows for the quantification of chemical relationships.

Vertical Alignment: Students are introduced to the law of conservation of mass and balanced equations in Physical Science (PS.3). These topics are covered conceptually; students have no experience with molar relationships prior to Chemistry.

Enduring Understandings	Essential Knowledge and Practices
Matter can be tracked in terms of the weight of the substances before and after a process occurs. The total weight of the substances does not change.	In order to meet this standard, it is expected that students will • use particulate models and mathematical representations to model the number of moles in a substance (CH.4 a)

Enduring Understandings	Essential Knowledge and Practices
• Atoms and molecules are too small to count by usual means. A *mole* is a fundamental unit for counting particles (atoms, molecules, and formula units) (CH.4 a). • Stoichiometry involves quantitative relationships in a balanced equation, which are based on mole ratios (CH.4 b). • When two elements combine to form two or more compounds, the ratios of the masses of one element that combines with the fixed mass of the other are simple whole numbers (law of multiple proportions) (CH.4 b). • Empirical and molecular formulas are used to show the chemical composition of a compound. These are useful in determining the formula of a substance based on the mass of the elements of an unknown substance (CH.4 b). • The limiting reactant (reagent) is the reactant that determines the moles of product(s) that can be produced in a reaction. The limiting reactant can be identified by comparing calculated ratios of moles and coefficients of reactants available at the beginning of the reaction (CH.4 b). • Although matter is conserved, chemical reactions rarely convert all the reactions to products. Percent yield can be used to determine the efficiency of a reaction as well as the percent error (CH.4 b).	• understand the significance of Avogadro's number and relate Avogadro's number to the mole (CH.4 a) • convert among mass, volume, and moles of a substance (CH.4 a) • determine the empirical and molecular formulas of a compound, given masses of elements that compose it (CH.4 b) • conduct an investigation to determine the percent composition and/or the empirical formula of a substance (CH.4 b) • perform stoichiometric calculations to quantify reactants and/or products in balanced chemical reactions (CH.4 b) • use particulate models and mathematical representations to identify the limiting reactant in a reaction (CH.4 b) • conduct an investigation to determine the percent yield of a reaction (CH.4 b) • plan and conduct an investigation to show how mass or moles are conserved in a chemical reaction (CH.4 b) • explain how and why limiting reagents affect the production of industrial products (CH.4 b).

CH.5 The student will investigate and understand that solutions behave in predictable and quantifiable ways. Key ideas include

a) molar relationships determine solution concentration;

b) changes in temperature can affect solubility;
c) extent of dissociation defines types of electrolytes;
d) pH and pOH quantify acid and base dissociation; and
e) colligative properties depend on the extent of dissociation.

Central Idea: Solutions are homogeneous mixtures in which the physical properties are dependent on concentration of the solute and the strength of the interactions among the particles of solute and solvent. Molarity is used to quantify the amount of solute in the liters of solution.

Vertical Alignment: Students are introduced to solutions in elementary school and have exposure to acids and bases in Physical Science (PS.3). The concepts in this standard are novel to most students in Chemistry.

Enduring Understandings	**Essential Knowledge and Practices**
Solutions are homogeneous mixtures in which the physical properties are dependent on the concentration of the solute and the strengths of all interactions among the particles of solutes and solvents. These forces of attraction are important in determining properties of a substance. • Temperature influences the solubility of a solute. A solubility chart indicates the effect of temperature on the solubility of a substance (CH.5 c). • Colligative properties are properties dependent on the amount of solute dissolved in a solution (CH.5 e). • As solute particle numbers increase, the boiling point of a solution increases and the freezing point decreases (CH.5 e). *Students are not responsible for calculating boiling point elevation and freezing point depression.* • Many substances with ionic bonds dissociate when added to a polar solvent. This dissociation is caused as the different ions of the solute are attracted to the polar solvent (CH.5 c).	In order to meet this standard, it is expected that students will • calculate the molarity of a solution (CH.5 a) • interpret solubility curves to determine the effect of temperature on solution concentration (CH.5 b) • apply the terms *dilute*, *saturated*, and *supersaturated* to solutions (CH.5 c) • explain the phrase *like dissolves like* and use it to predict solubility (CH.5 c) • apply the terms *strong electrolyte*, *weak electrolyte*, and *non-electrolyte* to different solutions (CH.5 c) • write balanced chemical equations of neutralization reactions between strong acids and strong bases (CH.5 d) • explain the difference between strength and concentration of acids and bases (CH.5 d)

Enduring Understandings	**Essential Knowledge and Practices**
• Polar substances dissolve ionic or polar substances; nonpolar substances dissolve nonpolar substances (CH.5 c). Acids and bases are a subset of solutions and react chemically in characteristic ways. • Acids and bases form when ionic compounds dissociate, producing hydrogen ion (H^+) or hydroxide ion (OH^-) (CH.5 d). • The pH scale allows for a comparison of the dissociation of an acid or base (CH.5 d). • Acids and bases are described through several theories (Arrhenius and Bronsted-Lowry theories). The construction and revising of these theories demonstrate the nature of science (CH.5 d). • Titrations are conducted in the laboratory in conjunction with calculations to determine the concentration of an acid or base (CH.5 d). • Indicators can be used to determine the pH of a solution (CH.5 d).	• relate the hydronium ion concentration to the pH scale (CH.5 d) • differentiate between the pH and pOH scales and determine acid and base concentrations using each scale (CH.5 d) • perform strong acid-strong base titrations, using indicators, and calculate the concentration of the unknown molarity solution (CH.5 d) • explain the role of indicators in titrations (CH.5 d) • explain how the development of the acid-base theories reflects the nature of science (CH.5 d) • explain the role of dissociation of solutes in the boiling point and freezing point of a solution (CH.5 e) • describe how colligative properties are used in everyday applications (CH.5 e).

CH.6 The student will investigate and understand that the phases of matter are explained by the kinetic molecular theory. Key ideas include

a) pressure and temperature define the phase of a substance;
b) properties of ideal gases are described by gas laws; and
c) intermolecular forces affect physical properties.

Central Idea: The movement of atoms and the relationship of energy and the phases is outlined in the kinetic molecular theory. The gas laws describe the relationships among pressure, volume, temperature, and number of particles of a gas.

Vertical Alignment: In Physical Science, students are introduced to the constant movement of atoms and the relationship of the kinetic energy in a substance and Kelvin temperature, through the study of the kinetic molecular theory. The role of energy in phase changes is discussed (PS.2).

Enduring Understandings	Essential Knowledge and Practices
The kinetic molecular theory (KMT) of gases is a model that helps understand the physical properties of gases at the molecular level (CH.6). • Gases have mass and occupy space. Gas particles are in constant, rapid, random motion and exert pressure as they collide with the walls of their containers. Gas molecules with the lightest mass travel fastest. Relatively large distances separate gas particles from each other (CH.6). • Equal volumes of gases at the same temperature and pressure contain an equal number of particles (CH.6 a). • Solid, liquid, and gas phases of a substance have different energy content. Pressure, temperature, and volume changes can cause a change in physical state. Specific amounts of energy are absorbed or released during phase changes (CH.6 a). The gaseous state can be modeled through mathematical equations, relating macroscopic properties. • An ideal gas does not exist, but this concept is used to model gas behavior. A real gas exists, has intermolecular forces and particle volume, and can change states. The ideal gas law states that PV = nRT and includes the relationship among pressure, volume, temperature, and the number of moles (CH.6 b).	In order to meet this standard, it is expected that students will • explain the behavior of gases, using the kinetic molecular theory (CH.6) • explain deviations in the behavior of real gases from the ideal gas law, using the kinetic molecular theory (CH.6 b) • use the kinetic molecular theory to describe the relationships among volume, temperature, pressure, and the number of moles in a sample of gas (CH.6 b) • solve problems and interpret graphs, including pressure, temperature, volume, and moles of a gas (CH.6 b) • plan and conduct an experiment that confirms the effect of a change in pressure, temperature, and/or volume of a gas (CH.6 a, b) • create a particulate model that shows the relationship among temperature, pressure, volume, and/or the number of moles of a gas (CH.6 a, b) • explain how intermolecular forces account for the physical properties of matter (CH.6 c) • explain how intermolecular forces differ from intramolecular bonds (CH.6 c).

Enduring Understandings	Essential Knowledge and Practices
• The pressure and volume of a sample of a gas at constant temperature are inversely proportional (Boyle's law: $P_1V_1 = P_2V_2$) (CH.6 b). • At constant pressure, the volume of a fixed amount of gas is directly proportional to its absolute temperature (Charles' law: $V_1/T_1 = V_2/T_2$) (CH.6 b). • The combined gas law ($P_1V_1/T_1 = P_2V_2/T_2$) relates pressure, volume, and temperature of a gas (CH.6 b). • The sum of the partial pressures of all the components in a gas mixture is equal to the total pressure of a gas mixture (Dalton's law of partial pressures) (CH.6 b). Intermolecular forces play a key role in determining the properties of a substance. • Forces of attraction (intermolecular forces) among molecules determine their state of matter at a given temperature. Forces of attraction include hydrogen bonding, dipole-dipole attraction, and London dispersion (van der Waals) forces (CH.6 c). • Intermolecular forces are significantly weaker than intramolecular forces (CH.6 c). • Vapor pressure is the pressure of the vapor found directly above a liquid in a closed container. When the vapor pressure equals the atmospheric pressure, the liquid boils. Volatile liquids have high vapor pressures, weak intermolecular forces, and low boiling points. Nonvolatile liquids have low vapor pressures, strong intermolecular forces, and high boiling points (CH.6 c).	

Enduring Understandings	Essential Knowledge and Practices
• Energy is required to break intermolecular forces to allow a phase change to occur from solid to liquid and from liquid to gas (CH.6 c).	

CH.7 The student will investigate and understand that thermodynamics explains the relationship between matter and energy. Key ideas include

a) heat energy affects matter and interactions of matter;
b) heating curves provide information about a substance;
c) reactions are endothermic or exothermic;
d) energy changes in reactions occur as bonds are broken and formed;
e) collision theory predicts the rate of reactions;
f) rates of reactions depend on catalysts and activation energy; and
g) enthalpy and entropy determine the extent of a reaction.

Central Idea: Thermodynamics is the branch of science that deals with the relationship between heat and other forms of energy. Chemical systems undergo three main processes that use thermal energy: phase changes, heating/cooling, and chemical reactions.

Vertical Alignment: In Physical Science, students were introduced to energy transfer and transformation to include chemical energy. The dissolution and formation of bonds during chemical reactions involves chemical energy. Terms such as *exothermic* and *endothermic* are used to explain whether energy is absorbed or released in a chemical reaction (PS.5).

Enduring Understandings	Essential Knowledge and Practices
Chemical systems undergo three main processes that change their energy: heating/cooling, phase transitions, and chemical reactions. • Temperature is a measurement of the average kinetic energy in a sample. There is a direct relationship between temperature and average kinetic energy (CH.7 a).	In order to meet this standard, it is expected that students will • contrast temperature and heat (CH.7 a) • explain how energy transfer plays a role in the heating and cooling of a system, in phase transitions, and in chemical reactions (CH.7 a, c)

Enduring Understandings	Essential Knowledge and Practices
• A heating curve graphically describes the relationship between temperature and energy (heat). It can be used to identify a substance's phase of matter at a given temperature as well as the temperature(s) at which it changes phase. It also shows the strength of the intermolecular forces present in a substance (CH.7 b). • The energy changes in chemical reactions occurs when atoms rearrange to form new substances. Breaking bonds requires energy and making bonds releases energy (CH.7 d). Chemical and physical transformations typically involve a change in energy. The relationship between the temperature and the total energy of a system depends on the types, states, and amount of matter. • All reactions involve the transfer of energy. *Enthalpy* is a measure of the energy of a chemical or physical system. Since enthalpy cannot be directly measured, the change in enthalpy is used to determine the heat given off or absorbed in a given reaction (CH.7 a, g) • Endothermic reactions require an input of energy to proceed and are signified by a positive enthalpy (CH.7 c, g). • Exothermic reactions release energy upon completion and are signified by a negative enthalpy (CH.7 c, g). • The enthalpy (ΔH) of a reaction can be determined through a variety of ways, to include calorimetry and calculating bond energies (CH.7 c, d, g). *Students are not responsible for calculations of bond energy and the use of Hess's law.*	• interpret heating curves and reaction diagrams to draw conclusions about energy transfers with a system (CH.7 b) • predict the phase of water if pressure or temperature of a substance changes by interpreting a phase diagram of water (CH.7 b) • create a particulate model of a phase change (CH.7 a) • calculate energy changes, using specific heat capacity (CH.7 a) • use calorimetry to measure the amount of thermal energy released or absorbed during a chemical reaction (CH.7 a, c) • explain the role of energy in bond formation and the breaking of bonds (CH.7 d) • create a particulate model that describes necessary particle interactions needed for a chemical reaction to occur (collision theory) (CH.7 e) • describe the factors that affect the rate of a chemical reaction (CH.7 e) • apply scientific principles and evidence to provide an explanation for the effects of changing temperature or concentration of the reacting particles on the rate of a reaction (CH.7 e) • explain the role of catalysts in a reaction and describe the effect on a system if a catalyst is not present (CH.7 f) • distinguish between enthalpy and entropy (CH.7 g) • recognize that there is a natural tendency for systems to increase entropy (CH.7 g).

Enduring Understandings	Essential Knowledge and Practices
• Calorimetry is an experimental technique that is used to determine the thermal energy exchanged/transferred in a chemical system (CH.7 a). • Bond energy is the energy required to break a chemical bond. One way the enthalpy of a reaction can be determined is by comparing the bond energies associated with the breaking (endothermic) and forming of bonds (exothermic) in a reaction (CH.7 d). *Students are not responsible for calculations of bond energy and the use of Hess's law.* • Molar heat of fusion is a property that describes the amount of energy needed to convert one mole of a substance between its solid and liquid states. Molar heat of vaporization is a property that describes the amount of energy needed to convert one mole of a substance between its liquid and gas states (CH.7 a). • Specific heat capacity is a property of a substance that tells the amount of energy needed to raise one gram of a substance by one degree Celsius. The values of these properties are related to the strength of their intermolecular forces (CH.7 a). The rates of reactions are influenced by the concentration or pressure of the reactants, the phase of the reactants or products, and the environmental factors such as temperature. • The collision theory is used to predict the rate of chemical reactions. It assumes that for a reaction to occur, it is necessary for the reacting species (atoms or molecules) to come together with the right amount of energy and the	

Enduring Understandings	Essential Knowledge and Practices
geometric orientation needed to break existing bonds and to reform new bonds (CH.7 e). • *Activation energy* is the amount of energy needed to start a chemical reaction (CH.7 f). • A *catalyst* is a chemical agent that can lower the activation needed to start a chemical reaction. The catalyst is not consumed or altered in a chemical reaction (CH.7 f). • *Entropy* (S) is a thermodynamic quantity representing the degree of disorderliness or randomness in a chemical system (CH.7 g). • Enthalpy (H) is related to the internal energy. When a process occurs at constant pressure, the heat evolved (either released or absorbed) is equal to the change in enthalpy. Exothermic reactions are favored (CH.7 g). *Students are not responsible for determining enthalpy that occurs with changes in pressure*.	