# Chemistry Subject Matter Requirements

Complete the matrix below by including links to course syllabi. Within each subdomain include direct links to supporting evidence addressing the subject matter requirement. These links must go directly the point in the syllabus where the subject matter requirement is addressed. Only submissions meeting this requirement will be sent to a team for review. Submissions not meeting this requirement will be returned to the institution.

In addition to the chemistry subject matter requirements, single subject matter programs in chemistry include the foundational-level general science subject matter requirements (included in this document), which apply to all science content areas

## Domains in Foundational-Level General Science

| **Domain 1: Scientific Practices, Engineering Design and Applications, and Crosscutting Concepts** | **Syllabi, Coursework, Assignments, Assessments** |
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| **1.1 Understand scientific practices**1. Demonstrate knowledge of how to ask questions that can be addressed by scientific investigation, help further understanding of observed phenomena, and help clarify scientific explanations and relationships.
2. Apply knowledge of the development of important scientific ideas and models over time and of how history shows that evaluating a model's merits and limitations leads to its improvement.
3. Apply knowledge of planning and conducting scientific investigations, including safety considerations and the use of appropriate tools and technology.
4. Apply modeling and the mathematical concepts of statistics and probability to the analysis and interpretation of data, including analysis of errors and their origins.
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| 1. Demonstrate the ability to analyze scientific data and information and draw appropriate and logical conclusions.
2. Use mathematics (e.g., dimensional analysis, statistics, proportional thinking) and computational thinking to represent and solve scientific problems and to assess scientific simulations.
3. Demonstrate the ability to construct and analyze scientific explanations.
4. Demonstrate the ability to evaluate scientific arguments in terms of their supporting evidence and reasoning.
5. Demonstrate knowledge of the ability to obtain, evaluate, interpret, and communicate scientific information (e.g., determining central ideas, integrating information from multiple sources, evaluating the validity of claims, using multiple formats to communicate scientific results).
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| **1.2 Understand engineering practices, design, and applications**1. Apply knowledge of engineering practices to define problems, determine specifications of designed systems, and identify constraints.
2. Evaluate design solutions in terms of their scientific and engineering constraints and the environmental, social, and cultural impacts of these solutions.
3. Apply knowledge of the roles of models (e.g., mathematical, physical, computer simulations) in the engineering design process.
4. Demonstrate knowledge of the process used to optimize a design solution (e.g., prioritizing criteria, refining a design due to test results).
5. Apply knowledge of the interdependence of science, engineering, and technology (e.g., in agriculture, health care, and communications).
6. Demonstrate knowledge of the influence of engineering, technology, and science on society and the natural world (e.g., in land use, transportation, and energy production).
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| **1.3 Understand crosscutting concepts among the sciences and engineering**1. Apply knowledge of patterns characteristic of natural phenomena and engineered systems.
2. Analyze cause-and-effect relationships and their mechanisms in natural phenomena and engineered systems.
3. Apply knowledge of the concepts of scale, proportion, and quantity to describe and compare natural and engineered systems.
4. Apply knowledge of how systems are defined and studied and of how system models are used to make predictions.
5. Apply knowledge of the flow, cycling, and conservation of energy and matter to analyze natural and engineered systems.
6. Analyze the relationship between structure and function in natural and engineered systems.
7. Analyze the factors contributing to stability and change in systems (e.g., static and dynamic equilibrium, feedback) and the rates at which systems change.
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| **Domain 2: Physical Science** | **Syllabi, Coursework, Assignments, Assessments** |
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| **2.1 Understand structure and properties of matter**1. Analyze the basic substructure of an atom (i.e., protons, neutrons, and electrons).
2. Differentiate between atoms and their isotopes, ions, molecules, elements, and compounds.
3. Apply knowledge of the development and organization of the periodic table and predict the properties of elements on the basis of their positions in the periodic table.
4. Demonstrate knowledge of nuclear forces that hold nuclei together and are responsible for nuclear processes (e.g., fission, fusion) and radioactivity (e.g., alpha, beta, and gamma decay).
5. Demonstrate knowledge of the characteristics of the different states of matter.
6. Apply knowledge of physical changes of matter and physical properties of matter.
7. Demonstrate knowledge of the physical and chemical characteristics, including pH, of acids, bases, and neutral solutions.
8. Apply knowledge of the physical and chemical properties of water.
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| **2.2 Understand chemical reactions and biochemistry**1. Recognize that chemical reactions can be understood in terms of the collisions between ions, atoms, or molecules and the rearrangement of particles.
2. Apply knowledge of the principles of conservation of matter to chemical reactions, including balancing chemical equations.
3. Describe the effect of temperature, pressure, and concentration on chemical equilibrium (Le Chatelier's principle) and reaction rate.
4. Analyze chemical bonding with respect to an element's position in the periodic table.
5. Demonstrate knowledge of the central role of carbon in the chemistry of living systems.
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| **2.3 Understand motion and stability: forces and interactions*** + 1. Apply knowledge of Newton's laws of motion and law of universal gravitation and recognize the relationship between these laws and the laws

of conservation of energy and momentum.* + 1. Demonstrate knowledge of the definition of pressure and how pressure relates to fluid flow and buoyancy, including describing everyday phenomena (e.g., the functioning of heart valves, atmospheric pressure).
		2. Identify the separate forces that act on a system (e.g., gravity, tension/compression, normal force, friction), describe the net force on the system, and describe the effect on the stability of the system.
		3. Analyze displacement, motion, and forces using models (e.g., vector, graphic representation, equations).
		4. Identify fundamental forces, including gravity, nuclear forces, and electromagnetic forces (magnetic and electric), and recognize their roles in nature, such as the role of gravity in maintaining the structure of the universe.
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| **2.4 Understand waves and their applications in technologies for information transfer*** 1. Compare the characteristics of mechanical and electromagnetic waves (e.g., transverse/longitudinal, travel through various media, relative speed).
	2. Demonstrate knowledge of the relationship between wave frequency, wavelength, and amplitude and energy.
	3. Demonstrate knowledge of resonance and of the reflection, refraction, and transmission of waves.
	4. Apply knowledge of electromagnetic radiation, including analyzing evidence that supports the wave and particle models that explain the properties of electromagnetic radiation.
	5. Evaluate evidence that indicates that certain wavelengths of electromagnetic radiation may affect living cells.
	6. Demonstrate knowledge of how lenses are used in simple optical systems, including the camera, telescope, microscope, and eye.
	7. Compare and contrast the transmission, reflection, and absorption of light in matter.
	8. Demonstrate knowledge of how energy and information are transferred by waves without mass transfer, including recognizing technology that employ this phenomenon.
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| **2.5 Understand Energy*** 1. Demonstrate knowledge of kinetic and potential energy.
	2. Demonstrate knowledge of the ways in which energy manifests itself at the macroscopic level (e.g., motion, sound, light, thermal energy).
	3. Demonstrate knowledge of the principle of conservation of energy, including analyzing energy transfers.
	4. Demonstrate knowledge of how the transfer of energy as heat is related to changes in temperature and interpret the direction of heat flow in a system.
	5. Apply knowledge of heat transfer by conduction, convection, and radiation, including analyzing examples of each mode of heat transfer.
	6. Analyze how chemical energy in fuel is transformed to heat.
	7. Demonstrate knowledge of the energy changes that accompany changes in states of matter.
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| **2.6 Understand electricity and magnetism*** 1. Demonstrate knowledge of electrostatic and magnetostatic phenomena, including evaluating examples of each type of phenomenon.
	2. Predict charges or poles on the basis of attraction/repulsion observations.
	3. Relate electric currents to magnetic fields and describe the application of these relationships, such as in electromagnets, electric current generators, motors, and transformers.
	4. Demonstrate knowledge of how energy is stored and can change in electric and magnetic fields.
	5. Interpret simple series and parallel circuits.
	6. Demonstrate knowledge of the definitions of power, voltage differences, current, and resistance and calculate their values in simple circuits.
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| **Domain 3: Life Sciences** | **Syllabi, Coursework, Assignments, Assessments** |
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| **3.1 Understand the structure and function of cells**1. Demonstrate understanding that a small subset of elements (C, H, O, N, P, S) makes up most of the chemical compounds in living organisms by combining in many ways.
2. Recognize and differentiate the structure and function of molecules in living organisms, including carbohydrates, lipids, proteins, and nucleic acids.
3. Demonstrate knowledge of evidence that living things are made of cells.
4. Analyze the similarities and differences among prokaryotic and eukaryotic cells and viruses.
5. Demonstrate knowledge of organelles and their structures and functions in the cell and how differences in the structure of cells are related to cell function.
6. Demonstrate knowledge of the process and significance of protein synthesis.
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| **3.2 Understand growth, development, and energy flow in organisms*** 1. Demonstrate knowledge of the importance of mitosis and meiosis as processes of cellular and organismal reproduction.
	2. Compare single-celled and multicellular organisms, including the role of cell differentiation in the development of multicellular organisms.
	3. Recognize the hierarchical levels of organization (e.g., cells, tissues, organs, systems, organisms) in plants and animals.
	4. Demonstrate knowledge of the major anatomical structures and life processes (e.g., reproduction, photosynthesis, cellular respiration, transpiration) of various plant groups.
	5. Demonstrate knowledge of feedback mechanisms responsible for maintaining homeostasis in animals, including humans, and plants, including the anatomical structures and systems involved in regulating internal conditions.
	6. Analyze the processes of cellular respiration (anaerobic and aerobic).
	7. Demonstrate knowledge of the conversion, flow, and storage of energy in the cell.
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| **3.3 Understand ecosystems: interactions, energy, and dynamics*** + 1. Demonstrate knowledge of the abiotic and biotic factors in an ecosystem and their relationship to the growth of individual organisms.
		2. Demonstrate knowledge of the interrelationships within and among ecosystems and recognize factors that affect population types, size, and carrying capacity in ecosystems (e.g., availability of biotic and abiotic resources, predation, competition, disease).
		3. Apply knowledge of energy flow, nutrient cycling, and matter transfer in ecosystems (e.g., food webs, biogeochemical cycles), including recognizing the roles played by photosynthesis and aerobic and anaerobic respiration.
		4. Demonstrate knowledge of possible solutions for minimizing human impact on ecosystem resources and biodiversity.
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| **3.4 Understand heredity: inheritance and variation of traits*** + 1. Demonstrate knowledge of the roles of DNA (deoxyribonucleic acid) molecules in cells (e.g., storing genetic information, coding for proteins, regulatory functions, structural functions).
		2. Apply knowledge of the structure of DNA and the process of DNA replication.
		3. Apply knowledge of how genetic variation may be the result of errors that occur during DNA replication or mutations caused by environmental factors and explain their causes and effects.
		4. Demonstrate knowledge of how the coding of DNA controls the expression of traits by genes and influences essential life functions (e.g., how DNA determines protein structure and other heritable genetic variations).
		5. Demonstrate knowledge of the relationship between genes and their interaction with the environment in terms of organisms' development and functions.
		6. Compare and contrast sexual and asexual reproduction.
		7. Apply knowledge of genotypes and phenotypes and the inheritance of traits that are determined by one or more genes (e.g., dominant, recessive, and sex-linked alleles; incomplete dominance).
		8. Solve problems from representations of monohybrid and dihybrid crosses.
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| **3.5 Understand biological evolution: unity and diversity*** 1. Apply knowledge of anatomical, embryological, and genetic evidence of biological evolution and common ancestry and interpret branching diagrams (cladograms).
	2. Demonstrate knowledge of the theory of natural selection, including how genetic variation and its expression leads to differences in characteristics among individuals in a population, adaptation, speciation, and extinction.
	3. Demonstrate knowledge of major events that affected the evolution of life on Earth (e.g., climate changes, asteroid impacts).
	4. Demonstrate knowledge of technologies that allow humans to influence the genetic traits of organisms.
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| **Domain 4: Earth and Space Sciences** | **Syllabi, Coursework, Assignments, Assessments** |
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| **4.1 Understand Earth’s place in the universe**1. Demonstrate knowledge of the evidence for the Big Bang model (e.g., light spectra, motion of distant galaxies, spectra of primordial radiation).
2. Demonstrate knowledge of how astronomical instruments are used to collect data and how astronomical units are used to describe distances.
3. Demonstrate knowledge of the factors that contribute to a star's color, size, and luminosity and how a star's light spectrum and brightness can be used to identify compositional elements, movements, and distance from Earth.
4. Demonstrate knowledge of nuclear fusion in stars, including the relationship between a star's mass and stage of its lifetime and the elements produced.
5. Demonstrate knowledge of the formation and structure of the solar system, its place in the Milky Way galaxy, and the characteristics of various objects in the solar system.
6. Recognize how evidence from the study of lunar rocks, asteroids, and meteorites provides information about Earth's formation and history.
7. Compare and contrast uniformitarianism and catastrophism.
8. Demonstrate knowledge of the regular and predictable patterns of movements of stars, planets, and the moon and their effects on Earth's systems (e.g., seasons, eclipses, tides).
9. Apply knowledge of how Kepler's laws are used to predict the motion of orbiting objects.
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| **4.2 Understand Earth’s materials and systems and surface processes**1. Recognize various forms of evidence (e.g., seismic waves, iron meteorites, magnetic field data) that led to the current model of Earth's structure (i.e., hot but solid inner core, a liquid outer core, a solid mantle and crust).
2. Demonstrate knowledge of the dynamic processes of erosion, deposition, and transport, including evidence for connections between these processes and the formation of Earth's materials.
3. Demonstrate knowledge of relative and absolute dating techniques, including how half-lives are used in radiometric dating and of how evidence from rock strata is used to establish the geologic timescale.
4. Recognize the factors that can alter the flow of energy into and out of Earth's systems (e.g., tectonic events, ocean circulation, volcanic activity, vegetation).
5. Relate the abundance of liquid water on Earth's surface and water's physical and chemical properties to the dynamic processes shaping the planet's materials and surface.
6. Demonstrate knowledge of surficial processes that form geographic features of Earth's surface (e.g., mechanical, chemical, and biological weathering).
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| **4.3 Understanding plate tectonics and large-scale system interactions*** 1. Demonstrate knowledge of the evidence for plate tectonics (e.g., the ages of crustal rocks, distribution of fossils and rocks, continental shapes) and relate plate movements to continental and ocean-floor features.
	2. Demonstrate knowledge of the thermal processes driving plate movement and relate density and buoyancy to plate tectonics.
	3. Demonstrate knowledge of the differences between types of plate boundaries, causes of volcanoes, earthquakes, and how Earth's resources relate to tectonic processes.
	4. Demonstrate knowledge of the factors contributing to the extent of damage caused by an earthquake (e.g., epicenter, focal mechanism, distance, geologic substrate).
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| **4.4 Understand weather and climate*** 1. Demonstrate knowledge of the water cycle and the interrelationships of surface and subsurface reservoirs.
	2. Demonstrate knowledge of the causes of daily, seasonal, and climatic changes and analyze the uneven heating of Earth by the sun.
	3. Analyze the effects of air movements on weather and interpret weather maps to predict weather patterns.
	4. Demonstrate knowledge of the energy transfer processes of convection, conduction, and radiation in relation to the atmosphere/ocean and Earth's interior structure.
	5. Demonstrate knowledge of the mechanisms and the significance of the greenhouse effect on Earth, including the roles of the oceans and biosphere in absorbing greenhouse gases.
	6. Demonstrate knowledge of human activities and their impact on global climate change.
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| **4.5 Understand natural resources and natural hazards*** 1. Demonstrate knowledge of renewable and nonrenewable energy resources (e.g., fossil fuels, nuclear fuels, solar, biomass).
	2. Demonstrate knowledge of Earth's materials as resources (e.g., rocks, minerals, soils, water) that have a global distribution affected by past and current geological processes.
	3. Analyze extraction and recycling processes in relation to energy, cost, and demand.
	4. Demonstrate knowledge of sustainable uses of resources with respect to utility, cost, and demand.
	5. Demonstrate knowledge of the effects of natural hazards (e.g., earthquakes, landslides, floods) on natural and human-made habitats.
	6. Demonstrate knowledge of how the availability of natural resources and the existence of natural hazards and other geologic events have influenced the development of human society.
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## Domains in Chemistry

| **Domain 1: Structure and Properties of Matter** | **Syllabi, Coursework, Assignments, Assessments** |
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| **1.1 Understand the structure of matter** 1. Analyze the evidence used in the development of the quantum model of the atom (e.g., the Bohr model, atomic spectroscopy, and the photoelectric effect).
2. Demonstrate knowledge of the positions of protons, neutrons, and electrons within atoms and their properties.
3. Differentiate periodic groups and families of elements and their properties.
4. Relate valence electrons and the electron shell structure (*s*, *p*, *d*, *f* orbitals) to an element's chemical properties and position in the periodic table.
5. Predict periodic trends, including electronegativity, ionization energy, reactivity, and the relative sizes of ions and atoms.
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| **1.2 Understand the properties of matter*** 1. Use the kinetic molecular theory to compare and contrast solids, liquids, and gases and to interpret phase diagrams.
	2. Relate the electrostatic interactions between particles in a substance, such as types of intramolecular and intermolecular forces, to the substance's physical and chemical properties (e.g., melting point, solubility, vapor pressure, flammability).
	3. Solve problems involving the ideal gas law under standard temperature and pressure (STP) and non-STP conditions and predict the relationships between pressure and volume, pressure and temperature, and volume and temperature for ideal gases (e.g., Boyle's law, Charles's law).
	4. Demonstrate the ability to convert between the Kelvin and Celsius temperature scales and knowledge of the significance of absolute zero.
	5. Solve problems using Dalton's law of partial pressures and Graham's law of effusion.
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| **1.3 Understand behavior and properties of solutions*** 1. Demonstrate knowledge of the behavior of solutions, including identifying solutes and solvents and methods of calculating concentration (e.g., molarity, parts per million, percent composition).
	2. Demonstrate knowledge of the process of dissolution at the molecular level, including factors that affect solubility (e.g., temperature, pressure, surface area).
	3. Apply knowledge of simple methods for the separation of mixtures (e.g., chromatography, distillation).
	4. Distinguish between strong and weak acids and bases on the basis of degree of dissociation and their chemical properties.
	5. Calculate pH and hydrogen ion concentration in strong and weak acid or base solutions.
	6. Use Arrhenius, Brønsted-Lowry, and Lewis acid-base definitions appropriately to characterize acids and bases and in acid-base reactions.
	7. Apply knowledge of buffer solutions, including solving problems related to buffer solutions.
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| **1.4 Understand nuclear processes*** 1. Demonstrate knowledge of mass-energy relationships in nuclear reactions and radioactive decay (*E* = *mc*2).
	2. Compare and contrast alpha, beta, and gamma decay, including changes in the nucleus, balancing nuclear reactions, and the relative kinds of damage to matter caused by alpha, beta, and gamma rays.
	3. Compare and contrast fission and fusion.
	4. Perform calculations involving half-life.
	5. Apply knowledge of the radiometric dating of rocks and other materials.
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| **Domain 2: Chemical Reactions and Chemical Bonding** | **Syllabi, Coursework, Assignments, Assessments** |
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| **2.1 Understand chemical reactions*** 1. Demonstrate knowledge of different types of chemical reactions, including predicting the products of chemical reactions.
	2. Interpret potential energy diagrams of reactions (e.g., determining activation energies with and without catalysts, identifying reactions as endothermic or exothermic).
	3. Demonstrate knowledge of collision theory and factors that influence reaction rate, including catalysts.
	4. Predict the effect of temperature, pressure, and concentration on chemical equilibrium (Le Chatelier's principle).
	5. Demonstrate knowledge of chemical equilibrium, including determining equilibrium constant expressions and/or values for given reactions.
	6. Apply knowledge of Gibbs energy to analyze the spontaneity of chemical reactions and predict the relative amounts of products and reactants.
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| **2.2 Understand chemical bonding**1. Compare and contrast ionic, covalent, and metallic bonding.
2. Demonstrate knowledge of models representing the structure of molecules and compounds and the bonding between atoms (e.g., Lewis electron dot structures for compounds and ions).
3. Predict molecular geometries using Lewis electron dot structures and hybridized atomic orbitals (e.g., valence shell electron pair repulsion [VSEPR] model).
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| **2.3 Understand conservation of matter and stoichiometry** 1. Calculate molar mass, mass, moles, number of particles, and volume at standard temperature and pressure (STP) for elements and compounds.
2. Calculate quantities of reactants and products and percent yield using balanced chemical equations, including problems with a limiting reagent.
3. Use the law of conservation of matter to balance chemical equations, including oxidation-reduction reactions.
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| **2.4 Understand organic chemistry and biochemistry** 1. Demonstrate knowledge of the bonding characteristics of carbon.
2. Recognize the chemical structure of various organic functional groups (e.g., alcohols, ketones, ethers, amines, esters, aldehydes, organic acids).
3. Demonstrate knowledge of basic chemical reactions involving organic functional groups (e.g., substitution, addition, esterification).
4. Recognize the ten simplest hydrocarbons that contain single bonds, multiple bonds, and benzene rings.
5. Analyze the differences in structures and properties between biologically significant monomers and their polymers (e.g., sugars forming carbohydrates, amino acids forming proteins, glycerol/fatty acids forming lipids, nucleotides forming nucleic acids).
6. Demonstrate knowledge of materials (e.g., medicine, synthetics) produced from natural resources.
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| **Domain 3: Energy**  | **Syllabi, Coursework, Assignments, Assessments** |
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| **3.1 Understand the definitions of energy, conservation of energy, and energy transfer*** 1. Analyze the energy in a system, including describing energy in terms of the motion and interactions of matter and radiation and recognizing that energy in systems is continually transferred from one object to another and between its possible forms (e.g., kinetic, potential).
	2. Demonstrate knowledge of how different manifestations of energy (e.g., sound, light, thermal energy) can be modeled as a combination of energy associated with the motion of particles and energy associated with the relative position of these particles.
	3. Apply knowledge of heat, specific heat, enthalpy of fusion, enthalpy of vaporization, and enthalpy of reaction to perform calculations (e.g., calorimetry) and explain phenomena.
	4. Interpret heating and cooling curves.
	5. Apply knowledge of the energy changes associated with the breaking or forming of chemical bonds during a chemical process.
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| **3.2 Understand energy in chemical processes and everyday life*** 1. Analyze the benefits and hazards of the use of radiation, radioactivity, and nuclear energy, in comparison to nonnuclear processes.
	2. Demonstrate knowledge of electric power generation from fossil fuels and alternative fuels (e.g., solar, tidal, nuclear).
	3. Apply knowledge of the source of the energy produced by the sun and how this energy is captured on Earth.
	4. Demonstrate knowledge of energy production and use associated with photosynthesis and cellular respiration.
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