

## **CHEMISTRY**

Chemistry is an elective course that provides students with an investigation of empirical concepts central to biology, earth science, environmental science, and physiology. Chemistry encompasses both qualitative and quantitative ideas derived using the scientific process. By its very nature, the study of chemistry encourages an inquiry-based approach to understanding the substances and processes that explain our world as well as ourselves. Using the practices of science, core ideas are explored in greater detail and refined with increased sophistication and rigor based upon knowledge acquired in earlier grades. Students use the academic language of science in context to communicate claims, evidence, and reasoning for chemical phenomena. The course provides high school students with more in-depth investigations on the properties and interactions of matter. Students acquire prerequisite skills for postsecondary studies and careers in science, technology, engineering, and mathematics (STEM) fields. Additional external resources, including evidence-based research found in scientific journals, should be utilized to provide students with a broad scientific experience that will adequately prepare them for college, career, and citizenship.

Content standards within this course are organized according to three of the core ideas for Physical Science. The first core idea, Matter and Its Interactions, deals with the substances and processes that encompass our universe on both microscopic and macroscopic levels. The second core idea, Motion and Stability: Forces and Interactions, concentrates on forces and motion, types of interactions, and stability and instability in chemical systems. The third core idea, Energy, involves the conservation of energy, energy transformations, and applications of energy to everyday life. Integrated within the disciplinary core ideas of Chemistry are the Engineering, Technology, and Applications of Science (ETS) core ideas, which are denoted with an asterisk (\*). The ETS core ideas require students to use tools to solve simple problems and to use representations to convey design solutions to a problem and determine which is most appropriate.

Advanced Chemistry will cover content at a higher depth of knowledge with a greater emphasis on mathematical relationships pertaining to chemical properties.

**Chemistry: Structure and Properties of Matter  
(Matter and Its Interactions)**

Students will:

AL. Chem.1 - Obtain and communicate information from historical experiments (e.g., work by Mendeleev and Moseley, Rutherford's gold foil experiment, Thomson's cathode ray experiment, Millikan's oil drop experiment, Bohr's interpretation of bright line spectra) to determine the structure and function of an atom and to analyze the patterns represented in the periodic table.

AL. Chem.2 - Develop and use models of atomic nuclei to explain why the abundance-weighted average of isotopes of an element yields the published atomic mass.

AL.Chem.3 - Use the periodic table as a systematic representation to predict properties of elements based on their valence electron arrangement.

- a. Analyze data such as physical properties to explain periodic trends of the elements, including metal/nonmetal/metalloid behavior, electrical/heat conductivity, electronegativity and electron affinity, ionization energy, and atomic-covalent/ionic radii and how they relate to position in the periodic table.
- b. Develop and use models (e.g., Lewis dot, 3-D ball-and-stick, space-filling, valence-shell electron-pair repulsion [VSEPR]) to predict the type of bonding and shape of simple compounds.
- c. Use the periodic table as a model to derive formulas and names of ionic and covalent compounds.

AL.Chem.4 - Plan and conduct an investigation to classify properties of matter as intensive (e.g., density, viscosity, specific heat, melting point, boiling point) or extensive (e.g., mass, volume, heat) and demonstrate how intensive properties can be used to identify a compound.

**Chemistry: Structure and Properties of Matter**  
**(Matter and Its Interactions)**

Students who demonstrate understanding can:

- HS-PS4-1** Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media. [Clarification Statement: Examples of data could include electromagnetic radiation traveling in a vacuum and glass, sound waves traveling through air and water, and seismic waves traveling through the Earth.] [Assessment Boundary: Assessment is limited to algebraic relationships and describing those relationships qualitatively.]
- HS-PS4-3** Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model, and that for some situations one model is more useful than the other. [Clarification Statement: Emphasis is on how the experimental evidence supports the claim and how a theory is generally modified in light of new evidence. Examples of a phenomenon could include resonance, interference, diffraction, and photoelectric effect.] [Assessment Boundary: Assessment does not include using quantum theory.]
- HS-PS1-1** Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms. [Clarification Statement: Examples of properties that could be predicted from patterns could include reactivity of metals, types of bonds formed, numbers of bonds formed, and reactions with oxygen.] [Assessment Boundary: Assessment is limited to main group elements. Assessment does not include quantitative understanding of ionization energy beyond relative trends.]
- HS-PS1-3** Plan and conduct an investigation to gather evidence to compare the structure of substances at the bulk scale to infer the strength of electrical forces between particles. [Clarification Statement: Emphasis is on understanding the strengths of forces between particles, not on naming specific intermolecular forces (such as dipole-dipole). Examples of particles could include ions, atoms, molecules, and networked materials (such as graphite). Examples of bulk properties of substances could include the melting point and boiling point, vapor pressure, and surface tension.] [Assessment Boundary: Assessment does not include Raoult's law calculations of vapor pressure.]
- HS-PS1-8** Develop models to illustrate the changes in the composition of the nucleus of the atom and the energy released during the processes of fission, fusion, and radioactive decay. [Clarification Statement: Emphasis is on simple qualitative models, such as pictures or diagrams, and on the scale of energy released in nuclear processes relative to other kinds of transformations.] [Assessment Boundary: Assessment does not include quantitative calculation of energy released. Assessment is limited to alpha, beta, and gamma radioactive decays.]
- HS-PS2-6** Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.\* [Clarification Statement: Emphasis is on the attractive and repulsive forces that determine the functioning of the material. Examples could include why electrically conductive materials are often made of metal, flexible but durable materials are made up of long chained molecules, and pharmaceuticals are designed to interact with specific receptors.] [Assessment Boundary: Assessment is limited to provided molecular structures of specific designed materials.]

## Chemistry: Structure and Properties of Matter (Matter and Its Interactions)

The performance expectations were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

### Science and Engineering Practices

#### Developing and Using Models

Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS1-8)
- Use a model to predict the relationships between systems or between components of a system. (HS-PS1-1)

#### Planning and Carrying Out Investigations

Planning and carrying out investigations in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.

- Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS1-3)

#### Obtaining, Evaluating, and Communicating Information

Obtaining, evaluating, and communicating information in 9–12 builds on K–8 and progresses to evaluating the validity and reliability of the claims, methods, and designs.

- Communicate scientific and technical information (e.g. about the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-PS2-6)

### Disciplinary Core Ideas

#### PS1.A: Structure and Properties of Matter

- Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons, surrounded by electrons. (HS-PS1-1)
- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (HS-PS1-1)
- The structure and interactions of matter at the bulk scale are determined by electrical forces within and between atoms. (HS-PS1-3),(secondary to HS-PS2-6)

#### PS1.C: Nuclear Processes

- Nuclear processes, including fusion, fission, and radioactive decays of unstable nuclei, involve release or absorption of energy. The total number of neutrons plus protons does not change in any nuclear process. (HS-PS1-8)

#### PS2.B: Types of Interactions

- Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter, as well as the contact forces between material objects.(secondary to HS-PS1-1),(secondary to HS-PS1-3),(HS-PS2-6)

#### PS4.A: Wave Properties

- The wavelength and frequency of a wave are related to one another by the speed of travel of the wave which depends on the type of wave and the medium through which it is passing. (HS-PPSF-1)

### Crosscutting Concepts

#### Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-1),(HS-PS1-3)

#### Energy and Matter

- In nuclear processes, atoms are not conserved, but the total number of protons plus neutrons is conserved. (HS-PS1-8)

#### Structure and Function

- Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem. (HS-PS2-6)

## Chemistry: Structure and Properties of Matter (Matter and Its Interactions)

<i>Connections to other DCIs in this grade-band:</i>	
<b><u>HS.PS3.A</u></b> (HS-PS1-8); <b><u>HS.PS3.B</u></b> (HS-PS1-8); <b><u>HS.PS3.C</u></b> (HS-PS1-8); <b><u>HS.PS3.D</u></b> (HS-PS1-8); <b><u>HS.LS1.C</u></b> (HS-PS1-1); <b><u>HS.ESS1.A</u></b> (HS-PS1-8); <b><u>HS.ESS1.C</u></b> (HS-PS1-8); <b><u>HS.ESS2.C</u></b> (HS-PS1-3)	
<i>Articulation of DCIs across grade-bands:</i>	
<b><u>MS.PS1.A</u></b> (HS-PS1-1),(HS-PS1-3),(HS-PS1-8),(HS-PS2-6); <b><u>MS.PS1.B</u></b> (HS-PS1-1),(HS-PS1-8); <b><u>MS.PS2.B</u></b> (HS-PS1-3),(HS-PS2-6); <b><u>MS.ESS2.A</u></b> (HS-PS1-8)	
<i>Common Core State Standards Connections:</i>	
<i>ELA/Literacy -</i>	
<b><u>RST.9-10.7</u></b>	Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words. (HS-PS1-1)
<b><u>RST.11-12.1</u></b>	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS1-3),(HS-PS2-6)
<b><u>WHST.9-12.2</u></b>	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-PS2-6)
<b><u>WHST.9-12.7</u></b>	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS1-3)
<b><u>WHST.11-12.8</u></b>	Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS1-3)
<b><u>WHST.9-12.9</u></b>	Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS1-3)
<i>Mathematics -</i>	
<b><u>MP.4</u></b>	Model with mathematics. (HS-PS1-8)
<b><u>HSN-Q.A.1</u></b>	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS1-3),(HS-PS1-8),(HS-PS2-6)
<b><u>HSN-Q.A.2</u></b>	Define appropriate quantities for the purpose of descriptive modeling. (HS-PS1-8),(HS-PS2-6)
<b><u>HSN-Q.A.3</u></b>	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS1-3),(HS-PS1-8),(HS-PS2-6)

\* The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

The section entitled "Disciplinary Core Ideas" is reproduced from *A Framework for K-12 Science Education: Practices, Cross-Cutting Concepts, and Core Ideas*. Integrated and reprinted with permission from the National Academy of Sciences.

**Chemistry: Chemical Reactions**  
**(Matter and Its Interactions)**

Students will:

AL.Chem.5 - Plan and conduct investigations to demonstrate different types of simple chemical reactions based on valence electron arrangements of the reactants and determine the quantity of products and reactants.

- a. Use mathematics and computational thinking to represent the ratio of reactants and products in terms of masses, molecules and moles.
- b. Use mathematics and computational thinking to support the claim that atoms, and therefore are conserved during a chemical reaction.

AL.Chem.6 - Use mathematics and computational thinking to express the concentrations of solutions quantitatively using molarity.

- a. Develop and use models to explain how solutes are dissolved in solvents.
- b. Analyze and interpret data to explain effects of temperature on the solubility of solid, liquid, and gaseous solutes in a solvent and the effects of pressure on the solubility of gaseous solutes.
- c. Design and conduct experiments to test the conductivity of common ionic and covalent substances in a solution.
- d. Use the concept of pH as a model to predict the relative properties of strong, weak, concentrated, and dilute acids and bases (e.g., Arrhenius and Brønsted-Lowry acids and bases).

AL.Chem.8 - Refine the design of a given chemical system to illustrate how LeChâtelier's principle affects a dynamic chemical equilibrium when subjected to an outside stress (e.g., heating and cooling a saturated sugar-water solution).\*

**Chemistry: Chemical Reactions**  
**(Matter and Its Interactions)**

Students who demonstrate understanding can:

- HS-PS1-2.** Construct and revise an explanation for the outcome of a simple chemical reaction based on the outermost electron states of atoms, trends in the periodic table, and knowledge of the patterns of chemical properties. [Clarification Statement: Examples of chemical reactions could include the reaction of sodium and chlorine, of carbon and oxygen, or of carbon and hydrogen.] [Assessment Boundary: Assessment is limited to chemical reactions involving main group elements and combustion reactions.]
- HS-PS1-4.** 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. [Clarification Statement: Emphasis is on the idea that a chemical reaction is a system that affects the energy change. Examples of models could include molecular-level drawings and diagrams of reactions, graphs showing the relative energies of reactants and products, and representations showing energy is conserved.] [Assessment Boundary: Assessment does not include calculating the total bond energy changes during a chemical reaction from the bond energies of reactants and products.]
- HS-PS1-5.** Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. [Clarification Statement: Emphasis is on student reasoning that focuses on the number and energy of collisions between molecules.] [Assessment Boundary: Assessment is limited to simple reactions in which there are only two reactants; evidence from temperature, concentration, and rate data; and qualitative relationships between rate and temperature.]
- HS-PS1-6.** Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.\* [Clarification Statement: Emphasis is on the application of Le Chatelier's Principle and on refining designs of chemical reaction systems, including descriptions of the connection between changes made at the macroscopic level and what happens at the molecular level. Examples of designs could include different ways to increase product formation including adding reactants or removing products.] [Assessment Boundary: Assessment is limited to specifying the change in only one variable at a time. Assessment does not include calculating equilibrium constants and concentrations.]
- HS-PS1-7.** Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. [Clarification Statement: Emphasis is on using mathematical ideas to communicate the proportional relationships between masses of atoms in the reactants and the products, and the translation of these relationships to the macroscopic scale using the mole as the conversion from the atomic to the macroscopic scale. Emphasis is on assessing students' use of mathematical thinking and not on memorization and rote application of problem-solving techniques.] [Assessment Boundary: Assessment does not include complex chemical reactions.]

## Chemistry: Chemical Reactions (Matter and Its Interactions)

The performance expectations were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

### Science and Engineering Practices

#### Developing and Using Models

Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.

- Develop a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS1-4)

#### Using Mathematics and Computational Thinking

Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- Use mathematical representations of phenomena to support claims. (HS-PS1-7)

#### Constructing Explanations and Designing Solutions

Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories.

- Apply scientific principles and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. (HS-PS1-5)
- Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-PS1-2)
- Refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS1-6)

### Disciplinary Core Ideas

#### PS1.A: Structure and Properties of Matter

- The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states. (HS-PS1-1) (Note: This Disciplinary Core Idea is also addressed by HS-PS1-1.)
- A stable molecule has less energy than the same set of atoms separated; one must provide at least this energy in order to take the molecule apart. (HS-PS1-4)

#### PS1.B: Chemical Reactions

- Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HS-PS1-4),(HS-PS1-5)
- In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (HS-PS1-6)
- The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-2),(HS-PS1-7)

#### ETS1.C: Optimizing the Design Solution

- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (secondary to HS-PS1-6)

### Crosscutting Concepts

#### Patterns

- Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-PS1-2),(HS-PS1-5)

#### Energy and Matter

- The total amount of energy and matter in closed systems is conserved. (HS-PS1-7)
- Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-PS1-4)

#### Stability and Change

- Much of science deals with constructing explanations of how things change and how they remain stable. (HS-PS1-6)

#### *Connections to Nature of Science*

#### Scientific Knowledge Assumes an Order and Consistency in Natural Systems

- Science assumes the universe is a vast single system in which basic laws are consistent. (HS-PS1-7)



## Chemistry: Chemical Reactions (Matter and Its Interactions)

<i>Connections to other DCIs in this grade-band:</i>	
<b>HS.PS3.A</b> (HS-PS1-4),(HS-PS1-5); <b>HS.PS3.B</b> (HS-PS1-4),(HS-PS1-6),(HS-PS1-7); <b>HS.PS3.D</b> (HS-PS1-4); <b>HS.LS1.C</b> (HS-PS1-2),(HS-PS1-4),(HS-PS1-7); <b>HS.LS2.B</b> (HS-PS1-7); <b>HS.ESS2.C</b> (HS-PS1-2)	
<i>Articulation of DCIs across grade-bands:</i>	
<b>MS.PS1.A</b> (HS-PS1-2),(HS-PS1-4),(HS-PS1-5),(HS-PS1-7); <b>MS.PS1.B</b> (HS-PS1-2),(HS-PS1-4),(HS-PS1-5),(HS-PS1-6),(HS-PS1-7); <b>MS.PS2.B</b> (HS-PS1-3),(HS-PS1-4),(HS-PS1-5); <b>MS.PS3.A</b> (HS-PS1-5); <b>MS.PS3.B</b> (HS-PS1-5); <b>MS.PS3.D</b> (HS-PS1-4); <b>MS.LS1.C</b> (HS-PS1-4),(HS-PS1-7); <b>MS.LS2.B</b> (HS-PS1-7); <b>MS.ESS2.A</b> (HS-PS1-7)	
<i>Common Core State Standards Connections:</i>	
<i>ELA/Literacy -</i>	
<b>RST.11-12.1</b>	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS1-5)
<b>WHST.9-12.2</b>	Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes. (HS-PS1-2),(HS-PS1-5)
<b>WHST.9-12.5</b>	Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience. (HS-PS1-2)
<b>WHST.9-12.7</b>	Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS1-6)
<b>SL.11-12.5</b>	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. (HS-PS1-4)
<i>Mathematics -</i>	
<b>MP.2</b>	Reason abstractly and quantitatively. (HS-PS1-5),(HS-PS1-7)
<b>MP.4</b>	Model with mathematics. (HS-PS1-4)
<b>HSN-Q.A.1</b>	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS1-2),(HS-PS1-4),(HS-PS1-5),(HS-PS1-7)
<b>HSN-Q.A.2</b>	Define appropriate quantities for the purpose of descriptive modeling. (HS-PS1-4),(HS-PS1-7)
<b>HSN-Q.A.3</b>	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS1-2),(HS-PS1-3),(HS-PS1-4),(HS-PS1-5),(HS-PS1-7)

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**Chemistry: Energy****(Matter and Its Interactions)****(Motion and Stability: Forces and Interactions)****(Energy)**

Students will:

AL.Chem.7 - Plan and carry out investigations to explain the behavior of ideal gases in terms of pressure, volume, temperature, and number of particles.

- a. Use mathematics to describe the relationships among pressure, temperature, and volume of an enclosed gas when only the amount of gas is constant.
- b. Use mathematical and computational thinking based on the ideal gas law to determine molar quantities.

AL.Chem.9 - Analyze and interpret data (e.g., melting point, boiling point, solubility, phase-change diagrams) to compare the strength of intermolecular forces and how these forces affect physical properties and changes.

AL.Chem.10 - Plan and conduct experiments that demonstrate how changes in a system (e.g., phase changes, pressure of a gas) validate the kinetic molecular theory.

- a. Develop a model to explain the relationship between the average kinetic energy of the particles in a substance and the temperature of the substance (e.g., no kinetic energy equaling absolute zero [0K or -273.15° C]).

AL.Chem.11 - Construct an explanation that describes how the release or absorption of energy from a system depends upon changes in the components of the system.

- a. Develop a model to illustrate how the changes in total bond energy determine whether a chemical reaction is endothermic or exothermic.
- b. Plan and conduct an investigation that demonstrates the transfer of thermal energy in a closed system (e.g., using heat capacities of two components of differing temperatures).

**Chemistry: Energy****(Matter and Its Interactions)****(Motion and Stability: Forces and Interactions)****(Energy)**

Students who demonstrate understanding can:

- HS-PS3-1** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known. [Clarification Statement: Emphasis is on explaining the meaning of mathematical expressions used in the model.] [Assessment Boundary: Assessment is limited to basic algebraic expressions or computations; to systems of two or three components; and to thermal energy, kinetic energy, and/or the energies in gravitational, magnetic, or electric fields.]
- HS-PS3-2** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motions of particles (objects) and energy associated with the relative positions of particles (objects). [Clarification Statement: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above the earth, and the energy stored between two electrically-charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]
- HS-PS3-3** Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.\* [Clarification Statement: Emphasis is on both qualitative and quantitative evaluations of devices. Examples of devices could include Rube Goldberg devices, wind turbines, solar cells, solar ovens, and generators. Examples of constraints could include use of renewable energy forms and efficiency.] [Assessment Boundary: Assessment for quantitative evaluations is limited to total output for a given input. Assessment is limited to devices constructed with materials provided to students.]
- HS-PS3-4** Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.]
- HS-PS3-5** Develop and use a model of two objects interacting through electric or magnetic fields to illustrate the forces between objects and the changes in energy of the objects due to the interaction. [Clarification Statement: Examples of models could include drawings, diagrams, and texts, such as drawings of what happens when two charges of opposite polarity are near each other.] [Assessment Boundary: Assessment is limited to systems containing two objects.]

**Chemistry: Energy**  
**(Matter and Its Interactions)**  
**(Motion and Stability: Forces and Interactions)**  
**(Energy)**

The performance expectations were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p><b>Developing and Using Models</b>  <u>Modeling in 9–12 builds on K–8 and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.</u></p> <ul style="list-style-type: none"> <li>Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system. (HS-PS3-2),(HS-PS3-5)</li> </ul> <p><b>Planning and Carrying Out Investigations</b>  <u>Planning and carrying out investigations to answer questions or test solutions to problems in 9–12 builds on K–8 experiences and progresses to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.</u></p> <ul style="list-style-type: none"> <li>Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS3-4)</li> </ul> <p><b>Using Mathematics and Computational Thinking</b>  <u>Mathematical and computational thinking at the 9–12 level builds on K–8 and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.</u></p> <ul style="list-style-type: none"> <li>Create a computational model or simulation of a phenomenon, designed device, process, or system. (HS-PS3-1)</li> </ul> <p><b>Constructing Explanations and Designing Solutions</b>  <u>Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of</u></p>	<p><b>PS3.A: Definitions of Energy</b></p> <ul style="list-style-type: none"> <li>Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system’s total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (HS-PS3-1),(HS-PS3-2)</li> <li>At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy. (HS-PS3-2) (HS-PS3-3)</li> <li>These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space. (HS-PS3-2)</li> </ul> <p><b>PS3.B: Conservation of Energy and Energy Transfer</b></p> <ul style="list-style-type: none"> <li>Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1)</li> <li>Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1),(HS-PS3-4)</li> <li>Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (HS-PS3-1)</li> <li>The availability of energy limits what can occur in any system. (HS-PS3-1)</li> <li>Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4)</li> </ul>	<p><b>Cause and Effect</b></p> <ul style="list-style-type: none"> <li>Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. (HS-PS3-5)</li> </ul> <p><b>Systems and System Models</b></p> <ul style="list-style-type: none"> <li>When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (HS-PS3-4)</li> <li>Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models. (HS-PS3-1)</li> </ul> <p><b>Energy and Matter</b></p> <ul style="list-style-type: none"> <li>Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (HS-PS3-3)</li> <li>Energy cannot be created or destroyed—only moves between one place and another place, between objects and/or fields, or between systems. (HS-PS3-2)</li> </ul> <p>-----</p> <p><b>Connections to Engineering, Technology, and Applications of Science</b></p> <p><b>Influence of Science, Engineering and Technology on Society and the Natural World</b></p> <ul style="list-style-type: none"> <li>Modern civilization depends on major technological systems. Engineers continuously modify these technological systems by applying scientific knowledge and engineering design practices to increase benefits while decreasing costs and risks. (HS-PS3-3)</li> </ul> <p>-----</p> <p><b>Connections to Nature of Science</b></p> <p><b>Scientific Knowledge Assumes an Order and Consistency in Natural Systems</b></p> <ul style="list-style-type: none"> <li>Science assumes the universe is a vast single system in which basic laws are consistent. (HS-PS3-1)</li> </ul>

<p>evidence consistent with scientific ideas, principles, and theories.</p> <ul style="list-style-type: none"> <li>Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-PS3-3)</li> </ul>	<p><b>PS3.C: Relationship Between Energy and Forces</b></p> <ul style="list-style-type: none"> <li>When two objects interacting through a field change relative position, the energy stored in the field is changed. (HS-PS3-5)</li> </ul> <p><b>PS3.D: Energy in Chemical Processes</b></p> <ul style="list-style-type: none"> <li>Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3),(HS-PS3-4)</li> </ul> <p><b>ETS1.A: Defining and Delimiting an Engineering Problem</b></p> <ul style="list-style-type: none"> <li>Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (secondary to HS-PS3-3)</li> </ul>	
<p><i>Connections to other DCIs in this grade-band:</i>  <b>HS.PS1.A</b> (HS-PS3-2); <b>HS.PS1.B</b> (HS-PS3-1),(HS-PS3-2); <b>HS.PS2.B</b> (HS-PS3-2),(HS-PS3-5); <b>HS.LS2.B</b> (HS-PS3-1); <b>HS.ESS1.A</b> (HS-PS3-1),(HS-PS3-4); <b>HS.ESS2.A</b>(HS-PS3-1),(HS-PS3-2),(HS-PS3-4); <b>HS.ESS2.D</b> (HS-PS3-4); <b>HS.ESS3.A</b> (HS-PS3-3)</p>		
<p><i>Articulation of DCIs across grade-bands:</i>  <b>MS.PS1.A</b> (HS-PS3-2); <b>MS.PS2.B</b> (HS-PS3-2),(HS-PS3-5); <b>MS.PS3.A</b> (HS-PS3-1),(HS-PS3-2),(HS-PS3-3); <b>MS.PS3.B</b> (HS-PS3-1),(HS-PS3-3),(HS-PS3-4); <b>MS.PS3.C</b>(HS-PS3-2),(HS-PS3-5); <b>MS.ESS2.A</b> (HS-PS3-1),(HS-PS3-3)</p>		
<p><i>Common Core State Standards Connections:</i></p> <p><b>ELA/Literacy -</b></p> <p><b>RST.11-12.1</b> Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-PS3-4)</p> <p><b>WHST.9-12.7</b> Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation. (HS-PS3-3),(HS-PS3-4),(HS-PS3-5)</p> <p><b>WHST.11-12.8</b> Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation. (HS-PS3-4),(HS-PS3-5)</p> <p><b>WHST.9-12.9</b> Draw evidence from informational texts to support analysis, reflection, and research. (HS-PS3-4),(HS-PS3-5)</p> <p><b>SL.11-12.5</b> Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. (HS-PS3-1),(HS-PS3-2),(HS-PS3-5)</p> <p><b>Mathematics -</b></p> <p><b>MP.2</b> Reason abstractly and quantitatively. (HS-PS3-1),(HS-PS3-2),(HS-PS3-3),(HS-PS3-4),(HS-PS3-5)</p> <p><b>MP.4</b> Model with mathematics. (HS-PS3-1),(HS-PS3-2),(HS-PS3-3),(HS-PS3-4),(HS-PS3-5)</p> <p><b>HSN.Q.A.1</b> Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-PS3-1),(HS-PS3-3)</p> <p><b>HSN.Q.A.2</b> Define appropriate quantities for the purpose of descriptive modeling. (HS-PS3-1),(HS-PS3-3)</p> <p><b>HSN.Q.A.3</b> Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-PS3-1),(HS-PS3-3)</p>		

\* The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.

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## Chemistry: Engineering Design

(Engineering, technology, and science core disciplinary ideas are integrated into grade level science performance expectations.)

Students will:

AL.Chem.8 - Refine the design of a given chemical system to illustrate how LeChâtelier's principle affects a dynamic chemical equilibrium when subjected to an outside stress (e.g., heating and cooling a saturated sugar-water solution).\*

Students who demonstrate understanding can:

- HS-ETS1-1** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
- HS-ETS1-2** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
- HS-ETS1-3** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
- HS-ETS1-4** Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

**Chemistry: Engineering Design**

(Engineering, technology, and science core disciplinary ideas are integrated into grade level science performance expectations.)

The performance expectations were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p><b><u>Asking Questions and Defining Problems</u></b> Asking questions and defining problems in 9–12 builds on K–8 experiences and progresses to formulating, refining, and evaluating empirically testable questions and design problems using models and simulations.</p> <ul style="list-style-type: none"> <li>Analyze complex real-world problems by specifying criteria and constraints for successful solutions. (HS-ETS1-1)</li> </ul> <p><b><u>Using Mathematics and Computational Thinking</u></b> Mathematical and computational thinking in 9–12 builds on K–8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.</p> <ul style="list-style-type: none"> <li>Use mathematical models and/or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems. (HS-ETS1-4)</li> </ul> <p><b><u>Constructing Explanations and Designing Solutions</u></b> Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles and theories.</p> <ul style="list-style-type: none"> <li>Design a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-2)</li> <li>Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-ETS1-3)</li> </ul>	<p><b><u>ETS1.A: Defining and Delimiting Engineering Problems</u></b></p> <ul style="list-style-type: none"> <li>Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1)</li> <li>Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1)</li> </ul> <p><b><u>ETS1.B: Developing Possible Solutions</u></b></p> <ul style="list-style-type: none"> <li>When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (HS-ETS1-3)</li> <li>Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs. (HS-ETS1-4)</li> </ul> <p><b><u>ETS1.C: Optimizing the Design Solution</u></b></p> <ul style="list-style-type: none"> <li>Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2)</li> </ul>	<p><b><u>Systems and System Models</u></b></p> <ul style="list-style-type: none"> <li>Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, and information flows—within and between systems at different scales. (HS-ETS1-4)</li> </ul> <p>-----</p> <p><i>Connections to Engineering, Technology, and Applications of Science</i></p> <p><b><u>Influence of Science, Engineering, and Technology on Society and the Natural World</u></b></p> <ul style="list-style-type: none"> <li>New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-1) (HS-ETS1-3)</li> </ul>

**Chemistry: Engineering Design**

(Engineering, technology, and science core disciplinary ideas are integrated into grade level science performance expectations.)

<p><i>Connections to HS-ETS1.A: Defining and Delimiting Engineering Problems include:</i>  <b>Physical Science:</b> <u>HS-PS2-3, HS-PS3-3</u>  <i>Connections to HS-ETS1.B: Developing Possible Solutions Problems include:</i>  <b>Earth and Space Science:</b> <u>HS-ESS3-2, HS-ESS3-4</u> <b>Life Science:</b> <u>HS-LS2-7, HS-LS4-6</u>  <i>Connections to MS-ETS1.C: Optimizing the Design Solution include:</i>  <b>Physical Science:</b> <u>HS-PS1-6, HS-PS2-3</u></p>	
<p><i>Articulation of DCIs across grade-levels:</i>  <u><b>MS.ETS1.A</b></u> (HS-ETS1-1),(HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4); <u><b>MS.ETS1.B</b></u> (HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4); <u><b>MS.ETS1.C</b></u> (HS-ETS1-2),(HS-ETS1-4)</p>	
<p><i>Common Core State Standards Connections:</i>  <i>ELA/Literacy -</i>  <u><b>RST.11-12.7</b></u> Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-ETS1-1),(HS-ETS1-3)  <u><b>RST.11-12.8</b></u> Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-ETS1-1),(HS-ETS1-3)  <u><b>RST.11-12.9</b></u> Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible. (HS-ETS1-1),(HS-ETS1-3)  <i>Mathematics -</i>  <u><b>MP.2</b></u> Reason abstractly and quantitatively. (HS-ETS1-1),(HS-ETS1-3),(HS-ETS1-4)  <u><b>MP.4</b></u> Model with mathematics. (HS-ETS1-1),(HS-ETS1-2),(HS-ETS1-3),(HS-ETS1-4)</p>	

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