

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.

Enduring Understanding	Essential Knowledge	Learning Objective
<p>5.A Two systems with different temperatures that are in thermal contact will exchange energy. The quantity of thermal energy transferred from one system to another is called heat.</p>	<p>5.A.1: Temperature is a measure of the average kinetic energy of atoms and molecules.</p>	<p>5.1 The student is able to create or use graphical representations in order to connect the dependence of potential energy to the distance between atoms and factors, such as bond order (for covalent interactions) and polarity (for intermolecular interactions), which influence the interaction strength. [See SP 1.1, 1.4, 7.2, connects to Big Idea 2; AND note that this learning objective connects to Essential knowledge components of 5.A-5.E]</p> <p>5.2 The student is able to relate temperature to the motions of particles, either via particulate representations, such as drawings of particles with arrows indicating velocities, and/or via representations of average kinetic energy and distribution of kinetic energies of the particles, such as plots of the Maxwell-Boltzmann distribution. [See SP 1.1, 1.4, 7.1]</p>
	<p>5.A.2: The process of kinetic energy transfer at the particulate scale is referred to in this course as heat transfer, and the spontaneous direction of the transfer is always from a hot to a cold body.</p>	<p>5.3 The student can generate explanations or make predictions about the transfer of thermal energy between systems based on this transfer being due to a kinetic energy transfer between systems arising from molecular collisions. [See SP 7.1]</p>
	<p>5.B Energy is neither created nor destroyed, but only transformed from one form to another.</p>	
	<p>5.B.1: Energy is transferred between systems either through heat transfer or through one system doing work on the other system.</p>	<p>5.4 The student is able to use conservation of energy to relate the magnitudes of the energy changes occurring in two or more interacting systems, including identification of the systems, the type (heat versus work), or the direction of energy flow. [See SP 1.4, 2.2, connects to Essential knowledge 5.B.1, 5.B.2]</p>
	<p>5.B.2: When two systems are in contact with each other and are otherwise isolated, the energy that comes out of one system is equal to the energy that goes into the other system. The combined energy of the two systems remains fixed. Energy transfer can occur through either heat exchange or work.</p>	<p>5.5 The student is able to use conservation of energy to relate the magnitudes of the energy changes when two nonreacting substances are mixed or brought into contact with one another. [See SP 2.2, connects to Essential knowledge 5.B.1, 5.B.2]</p>
	<p>5.B.3: Chemical systems undergo three main processes that change their energy: heating/ cooling, phase transitions, and chemical reactions.</p>	<p>5.6 The student is able to use calculations or estimations to relate energy changes associated with heating/cooling a substance to the heat capacity, relate energy changes associated with a phase transition to the enthalpy of fusion/vaporization, relate energy changes associated with a chemical reaction to the enthalpy of the reaction, and relate energy changes to $P\Delta V$ work. [See SP 2.2, 2.3]</p>
	<p>5.B.4: Calorimetry is an experimental technique that is used to measure the change in energy of a chemical system.</p>	<p>5.7 The student is able to design and/or interpret the results of an experiment in which calorimetry is used to determine the change in enthalpy of a chemical process (heating/cooling, phase transition, or chemical reaction) at constant pressure. [See SP 4.2, 5.1]</p>
<p>5.C Breaking bonds requires energy, and making bonds releases energy.</p>		
	<p>5.C.1: Potential energy is associated with a particular geometric arrangement of atoms or ions and the electrostatic interactions between them.</p>	<p>5.8 The student is able to draw qualitative and quantitative connections between the reaction enthalpy and the energies involved in the breaking and formation of chemical bonds. [See SP 2.3, 7.1, 7.2]</p>
	<p>5.C.2: The net energy change during a reaction is the sum of the energy required to break the bonds in the reactant molecules and the energy released in forming the bonds of the product molecules. The net change in energy may be positive for endothermic reactions where energy is required, or negative for exothermic reactions where energy is released.</p>	

Big Idea 5: The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter.

Enduring Understanding	Essential Knowledge	Learning Objective
5.D Electrostatic forces exist between molecules as well as between atoms or ions, and breaking the resultant intermolecular interactions requires energy.	5.D.1: Potential energy is associated with the interaction of molecules; as molecules draw near each other, they experience an attractive force.	5.9 The student is able to make claims and/or predictions regarding relative magnitudes of the forces acting within collections of interacting molecules based on the distribution of electrons within the molecules and the types of intermolecular forces through which the molecules interact. [See SP 6.4]
	5.D.2: At the particulate scale, chemical processes can be distinguished from physical processes because chemical bonds can be distinguished from intermolecular interactions.	5.10 The student can support the claim about whether a process is a chemical or physical change (or may be classified as both) based on whether the process involves changes in intramolecular versus intermolecular interactions. [See SP 5.1]
	5.D.3: Noncovalent and intermolecular interactions play important roles in many biological and polymer systems.	5.11 The student is able to identify the noncovalent interactions within and between large molecules, and/or connect the shape and function of the large molecule to the presence and magnitude of these interactions. [See SP 7.2]
5.E Chemical or physical processes are driven by a decrease in enthalpy or an increase in entropy, or both.	5.E.1: Entropy is a measure of the dispersal of matter and energy.	5.12 The student is able to use representations and models to predict the sign and relative magnitude of the entropy change associated with chemical or physical processes. [See SP 1.4]
	5.E.2: Some physical or chemical processes involve <i>both</i> a decrease in the internal energy of the components ($\Delta H^\circ < 0$) under consideration <i>and</i> an increase in the entropy of those components ($\Delta S^\circ > 0$). These processes are necessarily "thermodynamically favored" ($\Delta G^\circ < 0$).	5.13 The student is able to predict whether or not a physical or chemical process is thermodynamically favored by determination of (either quantitatively or qualitatively) the signs of both ΔH° and ΔS° , and calculation or estimation of ΔG° when needed. [See SP 2.2, 2.3, 6.4; connects to 5.E.3]
	5.E.3: If a chemical or physical process is not driven by <i>both</i> entropy and enthalpy changes, then the Gibbs free energy change can be used to determine whether the process is thermodynamically favored.	5.14 The student is able to determine whether a chemical or physical process is thermodynamically favorable by calculating the change in standard Gibbs free energy. [See SP 2.2; connects to 5.E.2]
	5.E.4: External sources of energy can be used to drive change in cases where the Gibbs free energy change is positive.	5.15 The student is able to explain how the application of external energy sources or the coupling of favorable with unfavorable reactions can be used to cause processes that are not thermodynamically favorable to become favorable. [See SP 6.2]
		5.16 The student can use LeChatelier's principle to make qualitative predictions for systems in which coupled reactions that share a common intermediate drive formation of a product. [See SP 6.4; connects to 6.B.1]
	5.17 The student can make quantitative predictions for systems involving coupled reactions that share a common intermediate, based on the equilibrium constant for the combined reaction. [See SP 6.4; connects to 6.A.2]	
5.E.5: A thermodynamically favored process may not occur due to kinetic constraints (kinetic vs. thermodynamic control).	5.18 The student can explain why a thermodynamically favored chemical reaction may not produce large amounts of product (based on consideration of both initial conditions and kinetic effects), or why a thermodynamically unfavored chemical reaction can produce large amounts of product for certain sets of initial conditions. [See SP 1.3, 7.2; connects to 6.D.1]	