AP CHEMISTRY

UNIT 6

Thermodynamics

7–9%
AP EXAM WEIGHTING

~10–11
CLASS PERIODS

Remember to go to **AP Classroom** to assign students the online **Personal Progress Check** for this unit.

Whether assigned as homework or completed in class, the **Personal Progress Check** provides each student with immediate feedback related to this unit's topics and skills.

Personal Progress Check 6

Multiple-choice: ~20 questions
Free-response: 2 questions

- Short-answer
- Short-answer

UNIT 6

7–9% AP EXAM WEIGHTING | **~10–11** CLASS PERIODS

Thermodynamics

BIG IDEA 4
Energy ENE

- Why is energy released when water becomes an ice cube?
- How are chemical transformations that require bonds to break and form influenced by energy?

Developing Understanding

The laws of thermodynamics describe the essential role of energy and explain and predict the direction of changes in matter. The availability or disposition of energy plays a role in virtually all observed chemical processes. Thermodynamics provides tools for understanding this key role, particularly the conservation of energy, including energy transfer in the forms of heat and work. Chemical bonding is central to chemistry. A key concept to know is that the breaking of a chemical bond inherently requires an energy input, and because bond formation is the reverse process, it will release energy. In subsequent units, the application of thermodynamics will determine the favorability of a reaction occurring.

Building the Science Practices

5.F 6.D 6.E

The ability to link atomic- and particulate-level phenomena and models to macroscopic phenomena is central to the study of chemistry. In previous units, students used representations, equations, and reasoning to demonstrate this ability. In Unit 6, students will develop justifications for claims made about the direction of thermal energy transfer of a system in relation to its surroundings when a temperature change, physical change, or a chemical reaction occurs. Students will construct representations of energy using appropriate diagrams with arrows showing the direction of energy transfer between the system and the surroundings. They will continue to develop their explanations of chemical phenomena by explaining how the change in energy of a system is balanced by transfer of energy by either heat or work into or out of the system.

Preparing for the AP Exam

On the AP Exam, students must be able to translate between a balanced chemical reaction and a calculation involving the energies of bonds broken and bonds formed within the reaction. In addition, students will be required to analyze calorimetry data and apply mathematical routines to calculate or estimate the heat transferred and the overall enthalpy of a reaction. In a question that asks students to apply mathematical routines to estimate or calculate the overall enthalpy of a reaction, students often struggle to determine the number of bonds that were broken and made in the reaction. Teachers can ensure that students are able to identify the bonds broken and formed in the reaction and use the enthalpies for such to determine the overall enthalpy for the reaction, in addition to their ability to represent a chemical reaction with its associated equation.

UNIT AT A GLANCE

Enduring Understanding	Topic	Suggested Skill	Class Periods ~10–11 CLASS PERIODS
ENE-2	**6.1 Endothermic and Exothermic Processes**	6.D Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.	
	6.2 Energy Diagrams	3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.	
	6.3 Heat Transfer and Thermal Equilibrium	6.E Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.	
	6.4 Heat Capacity and Calorimetry	2.D Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate.	
	6.5 Energy of Phase Changes	1.B Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties.	
	6.6 Introduction to Enthalpy of Reaction	4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.	
ENE-3	**6.7 Bond Enthalpies**	5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).	
	6.8 Enthalpy of Formation	5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).	
	6.9 Hess's Law	5.A Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).	

Go to **AP Classroom** to assign the **Personal Progress Check** for Unit 6.
Review the results in class to identify and address any student misunderstandings.

SAMPLE INSTRUCTIONAL ACTIVITIES

The sample activities on this page are optional and are offered to provide possible ways to incorporate various instructional approaches into the classroom. Teachers do not need to use these activities or instructional approaches and are free to alter or edit them. The examples below were developed in partnership with teachers from the AP community to share ways that they approach teaching some of the topics in this unit. Please refer to the Instructional Approaches section beginning on p. 197 for more examples of activities and strategies.

Activity	Topic	Sample Activity
1	6.1 6.2	**Think-Pair-Share** Have student pairs generate a list of exothermic and endothermic processes that occur in their everyday life. Have them share their lists with other pairs to determine if they have correctly identified these common processes in terms of endo- or exothermicity.
2	6.3	**Demo with Q&A** After working a few practice problems in groups with the $q = mC\Delta T$ equation, demonstrate that heating 40 g of copper pellets to 80°C and placing them into 40 g of 20°C water does not result in 50°C as a final temperature. Have students reason why and then record the final temperature of the copper/water mixture. Then have them calculate the specific heat capacity of copper and compare it to published values. As a class discussion, account for deviations from the expected results.
3	6.4	**Process Oriented Guided Inquiry Learning (POGIL)** Have students wet one finger with water and keep one finger dry then wave them in the air to see which feels cooler. Have them respond to a series of guided questions about the energy transfers involved in the evaporation process. Next, two beakers are heated side by side on a hot plate. Heating a beaker with 100 g of water on the same hot plate alongside a beaker with 100 g of 1-propanol results in very different changes in temperature. Through guided inquiry, students derive the concept of specific heat. As a class, compare whether the two liquids have been treated "fairly," and the concept of molar heat capacity is established and compared to specific heat capacity.
4	6.7 6.8	**Think-Pair-Share** Have pairs of students examine tables of average bond enthalpy and establish patterns with regard to bond order, atomic radius, and bond length. Similar patterns are examined for the standard enthalpies of formation. Have student pairs work through several practice problems using bond energies and enthalpies of formation to determine the enthalpy of a chemical reaction and compare their calculations.
5	6.9	**Post-Lab Discussion** Have students apply Hess's law by reacting magnesium metal and magnesium oxide with hydrochloric acid to determine the enthalpy change of the following reaction: $Mg + O_2 \rightarrow MgO$. Then have them evaluate their results and discuss sources of error.

SUGGESTED SKILL

Argumentation

6.D

Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.

AVAILABLE RESOURCES

- Classroom Resource > **Quantitative Skills in the AP Sciences**

TOPIC 6.1
Endothermic and Exothermic Processes

Required Course Content

ENDURING UNDERSTANDING

ENE-2

Changes in a substance's properties or change into a different substance requires an exchange of energy.

LEARNING OBJECTIVE

ENE-2.A

Explain the relationship between experimental observations and energy changes associated with a chemical or physical transformation.

ESSENTIAL KNOWLEDGE

ENE-2.A.1

Temperature changes in a system indicate energy changes.

ENE-2.A.2

Energy changes in a system can be described as endothermic and exothermic processes such as the heating or cooling of a substance, phase changes, or chemical transformations.

ENE-2.A.3

When a chemical reaction occurs, the energy of the system either decreases (exothermic reaction), increases (endothermic reaction), or remains the same. For exothermic reactions, the energy lost by the reacting species (system) is gained by the surroundings, as heat transfer from or work done by the system. Likewise, for endothermic reactions, the system gains energy from the surroundings by heat transfer to or work done on the system.

ENE-2.A.4

The formation of a solution may be an exothermic or endothermic process, depending on the relative strengths of intermolecular/interparticle interactions before and after the dissolution process.

TOPIC 6.2
Energy Diagrams

SUGGESTED SKILL

Representing Data and Phenomena

3.A

Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.

Required Course Content

ENDURING UNDERSTANDING

ENE-2

Changes in a substance's properties or change into a different substance requires an exchange of energy.

LEARNING OBJECTIVE

ENE-2.B

Represent a chemical or physical transformation with an energy diagram.

ESSENTIAL KNOWLEDGE

ENE-2.B.1

A physical or chemical process can be described with an energy diagram that shows the endothermic or exothermic nature of that process.

SUGGESTED SKILL

Argumentation

6.E

Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.

TOPIC 6.3
Heat Transfer and Thermal Equilibrium

Required Course Content

ENDURING UNDERSTANDING

ENE-2

Changes in a substance's properties or change into a different substance requires an exchange of energy.

LEARNING OBJECTIVE

ENE-2.C

Explain the relationship between the transfer of thermal energy and molecular collisions.

ESSENTIAL KNOWLEDGE

ENE-2.C.1

The particles in a warmer body have a greater average kinetic energy than those in a cooler body.

ENE-2.C.2

Collisions between particles in thermal contact can result in the transfer of energy. This process is called "heat transfer," "heat exchange," or "transfer of energy as heat."

ENE-2.C.3

Eventually, thermal equilibrium is reached as the particles continue to collide. At thermal equilibrium, the average kinetic energy of both bodies is the same, and hence, their temperatures are the same.

TOPIC 6.4
Heat Capacity and Calorimetry

Required Course Content

ENDURING UNDERSTANDING

ENE-2

Changes in a substance's properties or change into a different substance requires an exchange of energy.

LEARNING OBJECTIVE

ENE-2.D

Calculate the heat q absorbed or released by a system undergoing heating/cooling based on the amount of the substance, the heat capacity, and the change in temperature.

ESSENTIAL KNOWLEDGE

ENE-2.D.1

The heating of a cool body by a warmer body is an important form of energy transfer between two systems. The amount of heat transferred between two bodies may be quantified by the heat transfer equation:

EQN: $q = mc\Delta T$.

Calorimetry experiments are used to measure the transfer of heat.

ENE-2.D.2

The first law of thermodynamics states that energy is conserved in chemical and physical processes.

ENE-2.D.3

The transfer of a given amount of thermal energy will not produce the same temperature change in equal masses of matter with differing specific heat capacities.

ENE-2.D.4

Heating a system increases the energy of the system, while cooling a system decreases the energy of the system.

ENE-2.D.5

The specific heat capacity of a substance and the molar heat capacity are both used in energy calculations.

continued on next page

SUGGESTED SKILL

Question and Method

2.D

Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate.

AVAILABLE RESOURCES

- AP Chemistry Lab Manual > **Investigation 12: The Hand Warmer Challenge: Where Does the Heat Come From?**

LEARNING OBJECTIVE

ENE-2.D

Calculate the heat q absorbed or released by a system undergoing heating/cooling based on the amount of the substance, the heat capacity, and the change in temperature.

ESSENTIAL KNOWLEDGE

ENE-2.D.6

Chemical systems change their energy through three main processes: heating/cooling, phase transitions, and chemical reactions.

TOPIC 6.5
Energy of Phase Changes

Required Course Content

ENDURING UNDERSTANDING

ENE-2

Changes in a substance's properties or change into a different substance requires an exchange of energy.

LEARNING OBJECTIVE

ENE-2.E

Explain changes in the heat *q* absorbed or released by a system undergoing a phase transition based on the amount of the substance in moles and the molar enthalpy of the phase transition.

ESSENTIAL KNOWLEDGE

ENE-2.E.1

Energy must be transferred to a system to cause a substance to melt (or boil). The energy of the system therefore increases as the system undergoes a solid-to-liquid (or liquid-to-gas) phase transition. Likewise, a system releases energy when it freezes (or condenses). The energy of the system decreases as the system undergoes a liquid-to-solid (or gas-to-liquid) phase transition. The temperature of a pure substance remains constant during a phase change.

ENE-2.E.2

The energy absorbed during a phase change is equal to the energy released during a complementary phase change in the opposite direction. For example, the molar heat of condensation of a substance is equal to the negative of its molar heat of vaporization.

SUGGESTED SKILL

Models and Representations

1.B

Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic-level properties.

AVAILABLE RESOURCES

- AP Chemistry Lab Manual > **Investigation 12: The Hand Warmer Challenge: Where Does the Heat Come From?**

SUGGESTED SKILL

Model Analysis

4.C

Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.

AVAILABLE RESOURCES

- AP Chemistry Lab Manual > **Investigation 12: The Hand Warmer Challenge: Where Does the Heat Come From?**

TOPIC 6.6
Introduction to Enthalpy of Reaction

Required Course Content

ENDURING UNDERSTANDING

ENE-2

Changes in a substance's properties or change into a different substance requires an exchange of energy.

LEARNING OBJECTIVE

ENE-2.F

Calculate the heat q absorbed or released by a system undergoing a chemical reaction in relationship to the amount of the reacting substance in moles and the molar enthalpy of reaction.

ESSENTIAL KNOWLEDGE

ENE-2.F.1

The enthalpy change of a reaction gives the amount of heat energy released (for negative values) or absorbed (for positive values) by a chemical reaction at constant pressure.

X THE TECHNICAL DISTINCTIONS BETWEEN ENTHALPY AND INTERNAL ENERGY WILL NOT BE ASSESSED ON THE AP EXAM.

***Rationale**: These distinctions are beyond the scope of the AP Chemistry course. Most reactions studied at the AP level are carried out at constant pressure. Under these conditions the enthalpy change of the process is equal to the heat (and by extension, the energy) of reaction. For example, in the AP Chemistry course the terms "bond energy" and "bond enthalpy" are often used interchangeably.*

TOPIC 6.7
Bond Enthalpies

Required Course Content

ENDURING UNDERSTANDING

ENE-3

The energy exchanged in a chemical transformation is required to break and form bonds.

LEARNING OBJECTIVE

ENE-3.A

Calculate the enthalpy change of a reaction based on the average bond energies of bonds broken and formed in the reaction.

ESSENTIAL KNOWLEDGE

ENE-3.A.1

During a chemical reaction, bonds are broken and/or formed, and these events change the potential energy of the system.

ENE-3.A.2

The average energy required to break all of the bonds in the reactant molecules can be estimated by adding up the average bond energies of all the bonds in the reactant molecules. Likewise, the average energy released in forming the bonds in the product molecules can be estimated. If the energy released is greater than the energy required, the reaction is exothermic. If the energy required is greater than the energy released, the reaction is endothermic.

SUGGESTED SKILL

Mathematical Routines

5.F

Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).

AVAILABLE RESOURCES

- Classroom Resource > **Quantitative Skills in the AP Sciences**

SUGGESTED SKILL

Mathematical Routines

5.F

Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).

AVAILABLE RESOURCES

- Classroom Resource > **Quantitative Skills in the AP Sciences**

TOPIC 6.8
Enthalpy of Formation

Required Course Content

ENDURING UNDERSTANDING

ENE-3

The energy exchanged in a chemical transformation is required to break and form bonds.

LEARNING OBJECTIVE

ENE-3.B

Calculate the enthalpy change for a chemical or physical process based on the standard enthalpies of formation.

ESSENTIAL KNOWLEDGE

ENE-3.B.1

Tables of standard enthalpies of formation can be used to calculate the standard enthalpies of reactions.

EQN: $\Delta H^\circ_{\text{reaction}} = \Sigma \Delta H_f^\circ{}_{\text{products}} - \Sigma \Delta H_f^\circ{}_{\text{reactants}}$

TOPIC 6.9
Hess's Law

Required Course Content

ENDURING UNDERSTANDING

ENE-3

The energy exchanged in a chemical transformation is required to break and form bonds.

LEARNING OBJECTIVE

ENE-3.C

Represent a chemical or physical process as a sequence of steps.

ESSENTIAL KNOWLEDGE

ENE-3.C.1

Although the concept of "state function" is not required for the course, two principles of Hess's law should be understood. First, when a reaction is reversed, the enthalpy change stays constant in magnitude but becomes reversed in mathematical sign. Second, when two (or more) reactions are added to obtain an overall reaction, the individual enthalpy changes of each reaction are added to obtain the net enthalpy of the overall reaction.

ENE-3.D

Explain the relationship between the enthalpy of a chemical or physical process and the sum of the enthalpies of the individual steps.

ENE-3.D.1

When the products of a reaction are at a different temperature than their surroundings, they exchange energy with the surroundings to reach thermal equilibrium. Thermal energy is transferred to the surroundings from the products of an exothermic reaction. Thermal energy is transferred from the surroundings to the products of an endothermic reaction.

SUGGESTED SKILL

Mathematical Routines

5.A

Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).

AVAILABLE RESOURCES

- Classroom Resource > **Quantitative Skills in the AP Sciences**