AP CHEMISTRY

UNIT 6

Thermochemistry

7–9%
AP EXAM WEIGHTING

~10–11
CLASS PERIODS

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Thermochemistry

ESSENTIAL QUESTIONS

- Why is energy released when liquid water becomes an ice cube?
- Why does your skin feel cold when water evaporates off of it?
- How does a thermal energy transfer affect temperature, states of matter, and chemical bonds?
- How can energy changes be tracked and measured when energy can't be seen?
- Why do combustion reactions that form carbon dioxide release 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. Thermochemistry 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.

SUGGESTED SKILL

Argumentation

6.D

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

TOPIC 6.1

Endothermic and Exothermic Processes

Required Course Content

LEARNING OBJECTIVE

6.1.A

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

ESSENTIAL KNOWLEDGE

6.1.A.1

Temperature changes in a system indicate energy changes.

6.1.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.

6.1.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.

6.1.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

LEARNING OBJECTIVE	ESSENTIAL KNOWLEDGE
6.2.A Represent a chemical or physical transformation with an energy diagram.	6.2.A.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

LEARNING OBJECTIVE

6.3.A

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

ESSENTIAL KNOWLEDGE

6.3.A.1

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

6.3.A.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.”

6.3.A.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

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?**
- The Exam > **2021 Chief Reader Report**

Required Course Content

LEARNING OBJECTIVE

6.4.A

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

6.4.A.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.

6.4.A.2

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

6.4.A.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.

6.4.A.4

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

6.4.A.5

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

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LEARNING OBJECTIVE

6.4.A

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

6.4.A.6

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

6.4.A.7

In calorimetry experiments involving dissolution, temperature changes of the mixture within the calorimeter can be used to determine the direction of energy flow. If the temperature of the mixture increases, thermal energy is released by the dissolution process (exothermic). If the temperature of the mixture decreases, thermal energy is absorbed by the dissolution process (endothermic).

TOPIC 6.5

Energy of Phase Changes

Required Course Content

LEARNING OBJECTIVE

6.5.A

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

6.5.A.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.

6.5.A.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 enthalpy of condensation of a substance is equal to the negative of its molar enthalpy of vaporization. Similarly, the molar enthalpy of fusion can be used to calculate the energy absorbed when melting a substance and the energy released when freezing a substance.

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?**
- The Exam > **2022 Chief Reader Report**

SUGGESTED SKILL

Model Analysis

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

- AP Chemistry Lab Manual > **Investigation 12: The Hand Warmer Challenge: Where Does the Heat Come From?**
- The Exam > **2021 Chief Reader Report**

TOPIC 6.6
Introduction to Enthalpy of Reaction

Required Course Content

LEARNING OBJECTIVE

6.6.A

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

6.6.A.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.

6.6.A.2

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 as the reactants convert to products in an exothermic reaction. Thermal energy is transferred from the surroundings as the reactants convert to products in an endothermic reaction.

6.6.A.3

The chemical potential energy of the products of a reaction is different from that of the reactants because of the breaking and forming of bonds. The energy difference results in a change in the kinetic energy of the particles, which manifests as a temperature change.

Exclusion Statement: *The technical distinctions between enthalpy and internal energy will not be assessed on the AP Exam. Most reactions studied at the AP level are carried out at constant pressure, where the enthalpy change of the process is equal to the heat (and by extension, the energy) of reaction.*

TOPIC 6.7
Bond Enthalpies

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).

Required Course Content

LEARNING OBJECTIVE

6.7.A

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

ESSENTIAL KNOWLEDGE

6.7.A.1

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

6.7.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).

TOPIC 6.8

Enthalpy of Formation

Required Course Content

LEARNING OBJECTIVE

6.8.A

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

ESSENTIAL KNOWLEDGE

6.8.A.1

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

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

TOPIC 6.9
Hess's Law

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

- The Exam > **2023 Chief Reader Report**

Required Course Content

LEARNING OBJECTIVE

6.9.A

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

ESSENTIAL KNOWLEDGE

6.9.A.1

Many processes can be broken down into a series of steps. Each step in the series has its own energy change.

LEARNING OBJECTIVE

6.9.B

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

ESSENTIAL KNOWLEDGE

6.9.B.1

Because total energy is conserved (first law of thermodynamics), and each individual reaction in a sequence transfers thermal energy to or from the surroundings, the net thermal energy transferred in the sequence will be equal to the sum of the thermal energy transfers in each of the steps. These thermal energy transfers are the result of potential energy changes among the species in the reaction sequence; thus, at constant pressure, the enthalpy change of the overall process is equal to the sum of the enthalpy changes of the individual steps.

6.9.B.2

The following are essential principles of Hess's law:

i. When a reaction is reversed, the enthalpy change stays constant in magnitude but becomes reversed in mathematical sign.

ii. When a reaction is multiplied by a factor *c*, the enthalpy change is multiplied by the same factor *c*.

iii. 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 change of the overall reaction.

Exclusion Statement: *The concept of state functions will not be assessed on the AP Exam.*