# Unit 4: Energy, Rates, and Equilibrium

## Chapter 12: Thermochemistry

### Lesson 3: Enthalpy Changes and Hess's Law

### 1. Big Idea:

Energy changes in chemical reactions can be calculated and manipulated using thermochemical equations and Hess’s Law.

### 2. Essential Questions:

- **How do we calculate the enthalpy change for a reaction using Hess’s Law?**

**Answer:** Hess’s Law states that the total enthalpy change for a reaction is the same, no matter the pathway taken. By breaking a reaction into smaller steps with known enthalpy changes, we can add these values to calculate the overall enthalpy change.

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### 3.1 Phenomenon-Based Learning:

**Unit Phenomenon:**

The Thermodynamics House: Can You Solve the Puzzles and Escape?

**Chapter Phenomenon:**

The second floor of the escape house is devoted to studying the energy involved in chemical reactions. How does energy transfer occur during chemical processes, how much energy is absorbed or released, and how these values can be calculated and manipulated for your escape?

**Lesson Phenomenon:**

**"The Pathway to Escape"**

You have now reached the second to last room of the escape house! Your challenge for this room is to find missing enthalpy values based on provided enthalpy values for each reaction step displayed on interactive screens around the room. Each correct calculation helps piece together clues leading you closer to unlocking your final exit.

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### 4. Vocabulary:

- **Enthalpy:** The heat content of a system at constant pressure. It is represented as ΔH and is measured in kilojoules (kJ).

- **Hess's Law:** A principle stating that the total enthalpy change for a reaction is the same regardless of the pathway taken, as long as the initial and final states are the same.

- **Standard Enthalpy of Combustion:** The enthalpy change when one mole of a substance is completely burned in oxygen under standard conditions.

- **Standard Enthalpy of Formation:** The enthalpy change when one mole of a compound is formed from its elements in their standard states under standard conditions.

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### 5. SMART Objectives:

- Write thermochemical equations.

- Calculate the enthalpy change for a reaction to classify it as endothermic or exothermic.

- Apply Hess's Law to predict the enthalpy change for a multi-step reaction.

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### 6. Engage (Ignite):

**Phenomenon-Related Question:**

Imagine you are trapped in a high-tech escape house. The only way to unlock the door is to calculate the energy changes for a series of chemical reactions. Can you figure out how much energy is absorbed or released in each reaction?

**Hands-On Experiment:**

**Title:** Investigating Endothermic and Exothermic Reactions

**Materials Needed:**

- Baking soda (sodium bicarbonate)

- Vinegar (acetic acid)

- Calcium chloride (available in de-icing products or as a drying agent)

- Water

- Two small plastic cups

- Thermometer

**Procedure:**

1. In the first cup, mix one tablespoon of baking soda with 50 mL of vinegar. Observe the reaction and measure the temperature before and after the reaction.

2. In the second cup, dissolve one tablespoon of calcium chloride in 50 mL of water. Observe the reaction and measure the temperature before and after the reaction.

3. Record your observations and temperature changes for both reactions.

**Follow-Up Questions:**

1. Which reaction caused the temperature to increase?

**Answer:** The calcium chloride and water reaction caused the temperature to increase, indicating it is exothermic.

2. Which reaction caused the temperature to decrease?

**Answer:** The baking soda and vinegar reaction caused the temperature to decrease, indicating it is endothermic.

3. How can you classify a reaction as endothermic or exothermic based on temperature change?

**Answer:** If the temperature increases, the reaction is exothermic (releases heat). If the temperature decreases, the reaction is endothermic (absorbs heat).

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### 7. Pre-Explore (Direct Instruction):

**Background Information:**

Chemical reactions involve energy changes. Some reactions release energy into the surroundings (exothermic), while others absorb energy from the surroundings (endothermic). Enthalpy (ΔH) is a measure of this energy change at constant pressure.

Hess's Law helps us calculate the enthalpy change for reactions that occur in multiple steps. By knowing the enthalpy changes for individual steps, we can add them together to find the overall enthalpy change.

**Interactive Notes:**

- Discuss the concept of enthalpy (ΔH) and how it relates to energy changes in reactions.

- Explain how to write thermochemical equations, including the enthalpy change as part of the equation.

- Introduce Hess’s Law with a simple example: Combining two or more reactions to calculate the enthalpy change for a target reaction.

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### 8. Evaluate (Progress Check) - Pre-Explore:

**Scaffolded Questions:**

1. What does a negative ΔH value indicate about a reaction?

**Answer:** A negative ΔH value indicates an exothermic reaction, where energy is released.

2. What is the purpose of Hess’s Law?

**Answer:** Hess’s Law allows us to calculate the enthalpy change for a reaction by using known enthalpy changes of other reactions.

3. Why is it important to include the enthalpy change in a thermochemical equation?

**Answer:** Including the enthalpy change shows how much energy is absorbed or released during the reaction.

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### 9. Explain (Lightbulb):

**Core Concept:**

### # What is Enthalpy?

Enthalpy (ΔH) is the heat content of a system at constant pressure. It tells us how much energy is absorbed or released during a chemical reaction.

- **Exothermic Reactions:** Release heat. ΔH is negative. Example: Combustion of methane (CH₄ + 2O₂ → CO₂ + 2H₂O, ΔH = -890 kJ).

- **Endothermic Reactions:** Absorb heat. ΔH is positive. Example: Melting ice (H₂O(s) → H₂O(l), ΔH = +6 kJ/mol).

### # Thermochemical Equations

A thermochemical equation includes the enthalpy change (ΔH) along with the balanced chemical equation. For example:

\[ \text{H₂(g) + ½O₂(g) → H₂O(l), ΔH = -286 \, \text{kJ}} \]

### # Hess's Law

Hess’s Law states that the total enthalpy change for a reaction is the same, no matter how the reaction occurs. This means we can add or subtract enthalpy changes for individual steps to find the overall enthalpy change.

**Example Problem 1:**

Given the following reactions:

1. C(s) + O₂(g) → CO₂(g), ΔH = -393 kJ

2. CO₂(g) → CO(g) + ½O₂(g), ΔH = +283 kJ

Find the enthalpy change for the reaction:

C(s) + ½O₂(g) → CO(g).

**Solution:**

Add the two reactions:

\[ \text{C(s) + O₂(g) → CO₂(g), ΔH = -393 kJ} \]

\[ \text{CO₂(g) → CO(g) + ½O₂(g), ΔH = +283 kJ} \]

\[ \text{C(s) + ½O₂(g) → CO(g), ΔH = -393 + 283 = -110 kJ} \]

**Progress Check Question:**

Given the reactions:

1. N₂(g) + 3H₂(g) → 2NH₃(g), ΔH = -92 kJ

2. H₂(g) → 2H(g), ΔH = +436 kJ

Find the enthalpy change for the reaction:

N₂(g) + 6H(g) → 2NH₃(g).

**Answer:**

\[ \text{N₂(g) + 3H₂(g) → 2NH₃(g), ΔH = -92 kJ} \]

\[ \text{H₂(g) → 2H(g), ΔH = +436 kJ (multiplied by 3)} \]

\[ \text{N₂(g) + 6H(g) → 2NH₃(g), ΔH = -92 + (3 × 436) = +1216 kJ} \]

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### Real-World Connection:

Hess’s Law is used in designing energy-efficient processes, such as in fuel production or battery design. For example, calculating the energy changes in hydrogen fuel cells helps engineers optimize their performance.

### Topic: Understanding Chemical Reactions

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### 10. Evaluate (Progress Check)

### # Scaffolded Questions:

1. **What is a chemical reaction?**

- **Answer:** A chemical reaction is a process where one or more substances (reactants) are changed into new substances (products) with different properties.

2. **How does the Law of Conservation of Mass apply to chemical reactions?**

- **Answer:** The Law of Conservation of Mass states that matter cannot be created or destroyed in a chemical reaction. This means the mass of the reactants must equal the mass of the products.

3. **Explain why balancing chemical equations is important. What would happen if the equation is not balanced?**

- **Answer:** Balancing chemical equations ensures that the Law of Conservation of Mass is followed. If an equation is not balanced, it would imply that atoms are being lost or created, which is not possible. Balancing shows the correct proportions of reactants and products.

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### 11. Elaborate (Power Up)

### # Mini-Tasks:

1. **Write a balanced chemical equation for the reaction between hydrogen gas (H₂) and oxygen gas (O₂) to form water (H₂O). Explain your steps.**

- **Answer:** The balanced equation is:

\[ 2H₂ + O₂ → 2H₂O \]

Steps:

- Count the number of hydrogen and oxygen atoms on both sides.

- Adjust coefficients to ensure there are the same number of each type of atom on both sides.

2. **Imagine you are a scientist trying to create a new compound. What factors would you consider to ensure the reaction is safe and efficient?**

- **Answer:** Factors include:

- The reactivity of the substances involved.

- The energy required (activation energy).

- Possible by-products or waste.

- Safety measures for handling reactants and products.

3. **Why do some reactions release energy (exothermic), while others absorb energy (endothermic)? Provide examples of each.**

- **Answer:**

- Exothermic reactions release energy because the energy required to break bonds in reactants is less than the energy released when new bonds form (e.g., combustion of methane).

- Endothermic reactions absorb energy because breaking bonds requires more energy than is released when new bonds form (e.g., photosynthesis).

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### 12. Final Evaluation

### # Debate Question:

**Should scientists prioritize creating synthetic chemicals if they can replace natural resources? Why or why not?**

- **Arguments For:** Synthetic chemicals can reduce the strain on natural resources, provide more affordable alternatives, and be designed for specific purposes.

- **Arguments Against:** Synthetic chemicals can have unknown environmental impacts, may not be biodegradable, and could harm ecosystems.

### # Assessment Questions:

**Multiple-Choice Questions:**

1. **What is the correct definition of a chemical reaction?**

a) A physical change in matter

b) A process where substances are mixed but not changed

c) A process where substances are changed into new substances

d) A process that only happens in living organisms

- **Correct Answer:** c) A process where substances are changed into new substances

- **Explanation:** Chemical reactions involve the transformation of reactants into products with new properties.

2. **Which of the following is an example of an exothermic reaction?**

a) Melting ice

b) Boiling water

c) Burning wood

d) Photosynthesis

- **Correct Answer:** c) Burning wood

- **Explanation:** Burning wood releases heat and light, making it an exothermic reaction.

3. **What does the coefficient in a chemical equation represent?**

a) The number of atoms in a molecule

b) The number of molecules or moles of a substance

c) The type of chemical bond

d) The speed of the reaction

- **Correct Answer:** b) The number of molecules or moles of a substance

- **Explanation:** Coefficients indicate how many molecules or moles of each substance are involved in the reaction.

4. **Why is it important to balance chemical equations?**

a) To make the reaction faster

b) To follow the Law of Conservation of Mass

c) To change the reactants into products

d) To create more reactants

- **Correct Answer:** b) To follow the Law of Conservation of Mass

- **Explanation:** Balancing ensures that the mass of reactants equals the mass of products.

**Long-Answer Questions:**

1. **Explain the difference between reactants and products in a chemical reaction. Provide an example.**

- **Answer:** Reactants are the starting substances in a chemical reaction, while products are the new substances formed. For example, in the reaction \[ 2H₂ + O₂ → 2H₂O \], hydrogen (H₂) and oxygen (O₂) are reactants, and water (H₂O) is the product.

2. **Describe the steps to balance the equation: \[ CH₄ + O₂ → CO₂ + H₂O \].**

- **Answer:**

- Step 1: Count the atoms of each element on both sides.

- Step 2: Adjust coefficients to balance carbon (C), hydrogen (H), and oxygen (O).

- Balanced equation: \[ CH₄ + 2O₂ → CO₂ + 2H₂O \].

3. **Why is energy involved in chemical reactions? Discuss the role of activation energy.**

- **Answer:** Energy is needed to break bonds in reactants and form new bonds in products. Activation energy is the minimum energy required to start a reaction. Without it, the reaction would not occur.

4. **How can you identify if a reaction is exothermic or endothermic? Provide real-life examples.**

- **Answer:**

- Measure temperature changes: If the surroundings heat up, it’s exothermic (e.g., combustion). If the surroundings cool down, it’s endothermic (e.g., melting ice).

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### 13. Extend (Beyond the Lesson)

### # Additional Tasks and Challenges:

1. **Research Task:** Investigate how chemical reactions are used in industries like medicine, agriculture, or energy production. Write a short report on one application.

- **Example Answer:** In medicine, chemical reactions are used to create antibiotics like penicillin, which help fight bacterial infections.

2. **Real-World Problem:** Imagine you are designing a chemical reaction to reduce air pollution. What factors would you consider, and how would you test your solution?

- **Example Answer:** Factors include the type of pollutants, the reaction’s efficiency, and its environmental impact. Testing could involve small-scale experiments and monitoring emissions.

3. **Spaced Practice Activity:**

- Week 1: Balance 5 simple chemical equations.

- Week 2: Identify whether given reactions are exothermic or endothermic.

- Week 3: Write a paragraph explaining the importance of chemical reactions in daily life.

By revisiting these concepts over time, students will strengthen their understanding and ability to apply knowledge to new situations.