# Unit: Unit 4: Energy, Rates, and Equilibrium

## Chapter: Chapter 12: Thermochemistry

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

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### 1. Big Idea:

The total enthalpy change of a chemical reaction depends only on the initial and final states, not the pathway taken, which allows us to calculate unknown enthalpy changes using Hess's Law.

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### 2. Essential Questions:

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

- **Answer:** Hess’s Law states that the total enthalpy change of a reaction is the sum of the enthalpy changes of its individual steps. By rearranging and combining known thermochemical equations, the enthalpy change for a reaction can be determined even if it occurs in multiple steps.

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### 3. Phenomenon-Based Learning:

**Unit Phenomenon:**

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

You and your classmates find yourselves trapped in a 2-story high-tech laboratory escape house. To unlock the final door and escape the house, you must solve a series of puzzles presented to you in each room. The puzzles explore how energy flows through chemical reactions and how these reactions behave under different conditions.

**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 (H):** The heat content of a system at constant pressure. It reflects the energy stored in chemical bonds and released or absorbed during a reaction.

- **Hess's Law:** A principle stating that the enthalpy change for a reaction is the same, no matter how many steps the reaction is divided into.

- **Standard Enthalpy of Combustion (ΔH°c):** The enthalpy change when one mole of a substance burns completely in oxygen under standard conditions.

- **Standard Enthalpy of Formation (ΔH°f):** 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 to represent chemical reactions.

- Calculate the enthalpy change for a reaction and 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):

Imagine being in the second-to-last room of the Thermodynamics Escape House. On the walls, there are screens showing chemical reactions and their enthalpy changes. Some values are missing, and your task is to calculate them to unlock the next door.

**Interactive Activity:**

Display this scenario using an AI-based tool like ChatGPT or an interactive simulation. Ask the AI:

- "What happens to the energy in a reaction when we break it into smaller steps?"

- "Can we predict the energy change for a reaction without directly measuring it?"

Encourage learners to type these questions into the AI tool and explore its explanations. Then, ask them to share one thing they learned or a question they still have.

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

**Background Information:**

Chemical reactions involve energy changes, which can be measured as enthalpy changes (ΔH). These changes tell us if a reaction absorbs energy (endothermic) or releases it (exothermic). Hess's Law helps us calculate enthalpy changes for complex reactions by breaking them into smaller steps with known enthalpy values.

**Interactive Elements:**

- Show a simple reaction like the combustion of methane:

CH₄ + 2O₂ → CO₂ + 2H₂O (ΔH = -890 kJ).

Discuss how this reaction releases energy and is exothermic.

- Pose a Progress Check question: \*If we know the enthalpy changes for smaller reactions, how can we use them to calculate the total enthalpy change for a larger reaction?\*

- Facilitate a peer discussion: \*Why do you think the pathway doesn’t affect the total energy change?\*

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### 8. Explore:

**Quick Lab Activity: Hess's Law in Action**

**Objective:** Use Hess's Law to calculate the enthalpy change for a reaction.

**Materials:**

- Index cards with thermochemical equations and enthalpy changes (pre-prepared).

- Calculator.

- Worksheet for recording calculations.

**Instructions:**

1. Divide into small groups. Each group receives index cards with the following equations:

- C(s) + O₂(g) → CO₂(g) (ΔH = -393.5 kJ)

- H₂(g) + ½O₂(g) → H₂O(l) (ΔH = -285.8 kJ)

- CH₄(g) + 2O₂(g) → CO₂(g) + 2H₂O(l) (ΔH = ?)

2. Rearrange and combine the given equations to match the overall reaction:

CH₄(g) + 2O₂(g) → CO₂(g) + 2H₂O(l).

3. Use Hess's Law to calculate the enthalpy change for the overall reaction.

4. Record the steps and calculations on the worksheet.

5. Discuss the results as a group: \*Was the total enthalpy change the same regardless of the pathway? Why or why not?\*

**Expected Outcome:**

The calculated enthalpy change for CH₄ combustion should match the known value (-890 kJ), demonstrating Hess's Law.

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This lesson plan ties the concepts of enthalpy and Hess’s Law to an engaging escape room scenario, making the learning experience both interactive and memorable.

### 9. Explain (Lightbulb Moment)

### # \*\*Derive the Concept of Enthalpy in Connection to Thermochemical Equations\*\*

Enthalpy is a measure of the total energy in a system, including both its internal energy and the energy required to make space for it (pressure-volume work). In chemical reactions, we focus on the change in enthalpy (\( \Delta H \)), which tells us how much heat is absorbed or released. For example, when you burn wood in a fireplace, heat is released into the surroundings, making it an exothermic reaction. On the other hand, boiling water absorbs heat, making it an endothermic process.

Imagine you're in the escape house and need to determine whether a reaction releases heat (helping to warm the room) or absorbs it (cooling the room). This is where understanding enthalpy changes becomes crucial. A thermochemical equation shows the relationship between the reactants, products, and the enthalpy change. For example:

\[

\text{CH}\_4 + 2\text{O}\_2 \rightarrow \text{CO}\_2 + 2\text{H}\_2\text{O} \quad \Delta H = -890 \, \text{kJ}

\]

Here, \( \Delta H = -890 \, \text{kJ} \) means 890 kJ of energy is released when methane (\( \text{CH}\_4 \)) burns in oxygen. A diagram showing energy flow (with arrows pointing out for exothermic reactions and in for endothermic ones) can help learners visualize these processes.

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### # \*\*Write Thermochemical Equations\*\*

Thermochemical equations are chemical equations that include the enthalpy change (\( \Delta H \)). They help us understand how much energy is involved in a reaction. For example:

\[

\text{N}\_2 + 3\text{H}\_2 \rightarrow 2\text{NH}\_3 \quad \Delta H = -92 \, \text{kJ}

\]

This equation shows that 92 kJ of energy is released when nitrogen reacts with hydrogen to form ammonia. Thermochemical equations are important because they allow scientists to predict energy changes in real-world processes like combustion engines or industrial synthesis.

**Solved Example:**

Write the thermochemical equation for the combustion of hydrogen gas:

\[

2\text{H}\_2 + \text{O}\_2 \rightarrow 2\text{H}\_2\text{O} \quad \Delta H = -572 \, \text{kJ}

\]

**Progress Check:**

Write the thermochemical equation for the combustion of propane (\( \text{C}\_3\text{H}\_8 \)) if \( \Delta H = -2,220 \, \text{kJ} \).

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### # \*\*Calculate the Enthalpy Change for a Reaction to Classify it as Endothermic or Exothermic\*\*

To classify a reaction, calculate \( \Delta H \) using the formula:

\[

\Delta H = \sum \Delta H\_{\text{products}} - \sum \Delta H\_{\text{reactants}}

\]

If \( \Delta H \) is negative, the reaction is exothermic (releases heat). If \( \Delta H \) is positive, the reaction is endothermic (absorbs heat).

**Example:**

For the reaction:

\[

\text{C} + \text{O}\_2 \rightarrow \text{CO}\_2

\]

Given:

\[

\Delta H\_{\text{CO}\_2} = -393.5 \, \text{kJ/mol}, \quad \Delta H\_{\text{C}} = 0, \quad \Delta H\_{\text{O}\_2} = 0

\]

\[

\Delta H = (-393.5) - (0 + 0) = -393.5 \, \text{kJ/mol}

\]

This reaction is exothermic because \( \Delta H \) is negative.

**Practice Question:**

Classify the reaction \( \text{2H}\_2\text{O} \rightarrow 2\text{H}\_2 + \text{O}\_2 \) if \( \Delta H = +483.6 \, \text{kJ} \).

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### # \*\*Define Hess's Law\*\*

Hess's Law states that the total enthalpy change for a reaction is the same, no matter how many steps it takes. This means you can add up the enthalpy changes of individual steps to find the overall \( \Delta H \).

Think of it like climbing stairs: whether you take one big step or several small ones, the total height you climb is the same. For example, in the escape house, you might need to combine clues from different rooms to calculate the total energy change.

**Visual Aid:** Use a flowchart showing a reaction broken into multiple steps, with \( \Delta H \) values for each step adding up to the total.

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### # \*\*Apply Hess's Law to Predict the Enthalpy Change for a Multi-Step Reaction\*\*

**Example:**

Given:

1. \( \text{C} + \text{O}\_2 \rightarrow \text{CO}\_2 \quad \Delta H = -393.5 \, \text{kJ} \)

2. \( \text{CO}\_2 \rightarrow \text{CO} + \frac{1}{2}\text{O}\_2 \quad \Delta H = +283.0 \, \text{kJ} \)

Find \( \Delta H \) for:

\[

\text{C} + \frac{1}{2}\text{O}\_2 \rightarrow \text{CO}

\]

**Solution:**

Add the equations:

\[

\text{C} + \text{O}\_2 \rightarrow \text{CO}\_2 \quad (\Delta H = -393.5 \, \text{kJ})

\]

\[

\text{CO}\_2 \rightarrow \text{CO} + \frac{1}{2}\text{O}\_2 \quad (\Delta H = +283.0 \, \text{kJ})

\]

\[

\text{C} + \frac{1}{2}\text{O}\_2 \rightarrow \text{CO} \quad (\Delta H = -110.5 \, \text{kJ})

\]

**Practice Question:**

Use Hess's Law to find \( \Delta H \) for:

\[

\text{N}\_2 + 3\text{H}\_2 \rightarrow 2\text{NH}\_3

\]

Given:

1. \( \text{N}\_2 + \text{O}\_2 \rightarrow 2\text{NO} \quad \Delta H = +180.5 \, \text{kJ} \)

2. \( 2\text{NO} + 3\text{H}\_2 \rightarrow 2\text{NH}\_3 + \text{O}\_2 \quad \Delta H = -1170.5 \, \text{kJ} \)

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### 10. Elaborate (Power Up)

**Activity: Escape Room Puzzle Challenge**

Design a puzzle where learners must calculate \( \Delta H \) for a multi-step reaction to unlock a virtual door. Provide clues for each step's enthalpy change, and let students use Hess's Law to piece them together.

**Mini-Project:**

Ask students to research and design a model showing how exothermic and endothermic reactions are used in real life (e.g., hand warmers or ice packs). Have them present their findings to the class.

**Critical Thinking Question:**

If you could design a chemical reaction to heat or cool a room in the escape house, which type would you choose and why?

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### 11. Evaluate (Progress Check and Quiz)

**Sample Quiz Questions:**

1. Write the thermochemical equation for the combustion of ethanol (\( \text{C}\_2\text{H}\_5\text{OH} \)) if \( \Delta H = -1,367 \, \text{kJ} \).

2. Classify the reaction \( \text{H}\_2 + \text{Cl}\_2 \rightarrow 2\text{HCl} \quad \Delta H = -184.6 \, \text{kJ} \) as endothermic or exothermic.

3. (ACT-Style MCQ) Given the following reactions:

- \( \text{A} \rightarrow \text{B} \quad \Delta H = +50 \, \text{kJ} \)

- \( \text{B} \rightarrow \text{C} \quad \Delta H = -30 \, \text{kJ} \)

What is \( \Delta H \) for \( \text{A} \rightarrow \text{C} \)?

a) +20 kJ

b) -20 kJ

c) +80 kJ

d) -80 kJ

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### 12. Extend (Beyond the Lesson)

**Real-World Problem-Solving:**

Challenge students to design a portable device that uses an exothermic reaction to keep food warm or an endothermic reaction to cool drinks.

**Spaced Practice:**

Revisit Hess's Law in future lessons by connecting it to topics like Gibbs free energy or reaction spontaneity.

**Future Connection:**

Introduce the concept of entropy in the next lesson, tying it to energy changes and the escape house puzzles.