Unit 4: Energy, Rates, and Equilibrium

## Chapter 12: Thermochemistry

# Lesson 3: Enthalpy Changes and Hess's Law

### 1. Big Idea:

The enthalpy change of a chemical reaction can be calculated even if the reaction occurs in multiple steps by using Hess's Law, which states that the total enthalpy change depends only on the initial and final states, not the path taken.

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### 2. Essential Questions:

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

Hess’s Law allows us to calculate the enthalpy change of a reaction by adding the enthalpy changes of individual steps, as long as the steps add up to the overall reaction.

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### 3. Phenomenon-Based Learning:

**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**: a measure of the heat energy stored in a system under constant pressure

- **Hess's Law**: a principle stating that the total enthalpy change of a reaction is the same, no matter the route taken

- **standard enthalpy of combustion**: the enthalpy change when one mole of a substance burns completely in oxygen under standard conditions

- **standard enthalpy of formation**: the enthalpy change when one mole of a compound is formed from its elements 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):

Consider being locked in a high-tech escape room. The only way to unlock the exit is by solving a series of puzzles. In this room, you are given a set of screens showing different chemical reactions. Some reactions are incomplete, and you must calculate missing enthalpy values to move forward. The screens display clues like this:

- Reaction A → B: ΔH = -200 kJ

- Reaction B → C: ΔH = +150 kJ

- Reaction A → C: ΔH = ?

The challenge is to use what you know about energy transfer in reactions to find the missing value.

Here’s a twist: What if these reactions didn’t happen in just one step but multiple? Can you still calculate the total energy change? Use an AI tool to brainstorm questions like: “Why is energy conserved even when reactions take different paths?” or “How do scientists measure energy in chemical reactions?” Write your questions and share your thoughts with a partner.

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

When a chemical reaction occurs, energy is either absorbed or released. This energy is called enthalpy. Reactions with a negative enthalpy change release energy (exothermic), while those with a positive enthalpy change absorb energy (endothermic).

Even if a reaction occurs in multiple steps, the total enthalpy change remains the same. This is the basis of Hess’s Law. For example, if you know the enthalpy changes of smaller steps in a reaction process, you can add them up to find the total enthalpy change of the overall reaction. This is like finding the total distance of a road trip by adding up the distances between stops.

**Example:**

- Reaction 1: H₂ + ½O₂ → H₂O ΔH = -241.8 kJ

- Reaction 2: 2H₂O → 2H₂ + O₂ ΔH = +483.6 kJ

Adding these reactions together gives:

H₂ + ½O₂ → 2H₂ + O₂

Total ΔH = (-241.8) + (+483.6) = +241.8 kJ

Interactive Task: Work with a partner to take notes on how Hess’s Law is similar to solving a puzzle. Discuss why the enthalpy change of a reaction depends only on the start and end points, not the steps in between.

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

1. What is enthalpy, and how is it measured?

**Answer:** Enthalpy is a measure of the heat energy stored in a system under constant pressure. It is measured in kilojoules (kJ).

2. What does Hess’s Law tell us about the pathway of a reaction?

**Answer:** Hess’s Law states that the total enthalpy change of a reaction depends only on the initial and final states, not the path taken.

3. How can we classify a reaction as endothermic or exothermic based on enthalpy change?

**Answer:** If the enthalpy change is negative, the reaction is exothermic (releases heat). If it is positive, the reaction is endothermic (absorbs heat).

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### 8. Explore (Pathfinder):

**Quick Lab Activity:**

**Objective:** Use Hess’s Law to determine the enthalpy change of a reaction.

**Materials:**

- Index cards with reaction equations and enthalpy changes written on them (e.g., H₂ + O₂ → H₂O, ΔH = -286 kJ)

- Calculator

- Blank paper

**Instructions:**

1. Arrange the provided reaction equations and enthalpy values in the order they occur.

2. Write the overall reaction by combining the steps into one equation.

3. Add the enthalpy values for each step to calculate the total enthalpy change.

4. Compare your result with the enthalpy change written on a separate index card labeled “Overall Reaction.”

**Example Setup:**

- Reaction 1: C(graphite) + O₂ → CO₂ ΔH = -393.5 kJ

- Reaction 2: CO₂ → CO + ½O₂ ΔH = +283.0 kJ

- Overall Reaction: C(graphite) + ½O₂ → CO

**Expected Calculation:**

ΔH = (-393.5) + (+283.0) = -110.5 kJ

**Follow-Up:** Discuss with your group why the enthalpy change of the overall reaction is independent of the number of steps. Write down your observations and share them with the class.

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### 9. Explain (Lightbulb Moment):

Let’s connect what you learned about **enthalpy changes** and **Hess’s Law** in Lesson 3 with the exciting escape house adventure in the **Unit Phenomenon**: \*The Thermodynamics House: Can You Solve the Puzzles and Escape?\* Picture yourself standing in the second-to-last room of the escape house. The room is buzzing with energy! Interactive screens flash with chemical reaction equations and enthalpy values. Your task is to calculate the missing enthalpy changes using what you know. Each correct calculation unlocks a piece of the puzzle to help you escape. But how do you solve these puzzles? By understanding **enthalpy**, **thermochemical equations**, and **Hess's Law**!

These concepts help us understand how energy moves during chemical reactions. With them, we can predict whether a reaction absorbs energy (endothermic) or releases it (exothermic). Hess’s Law is like a map—it allows you to calculate the total energy change for a complex reaction, even if it happens in multiple steps. Let’s dive in and learn how these ideas work!

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### Core Concepts of the Lesson

### # 1. What Is Enthalpy?

Enthalpy (\(H\)) is a measure of the total energy in a chemical system. During chemical reactions, bonds break and form, and energy is either absorbed or released. This change in energy is called the **enthalpy change** (\(\Delta H\)).

- If a reaction absorbs energy (e.g., melting ice), it’s **endothermic** (\(\Delta H > 0\)).

- If a reaction releases energy (e.g., burning wood), it’s **exothermic** (\(\Delta H < 0\)).

Real-Life Connection: Have you ever seen an instant ice pack? When you crack it, the chemicals inside absorb heat, making it cold. That’s an **endothermic reaction**!

**Visual Suggestion**: Include a diagram showing energy flow in endothermic and exothermic reactions. Use arrows to indicate heat moving in or out of the system.

**Question**: Think about cooking an egg. Is it an endothermic or exothermic process?

**Answer**: It’s endothermic because heat is absorbed to cook the egg!

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### # 2. Writing Thermochemical Equations

A **thermochemical equation** shows the energy change along with the chemical reaction. 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}

\]

This equation tells us that burning methane releases 890 kJ of energy, making it exothermic.

**Solved Example**: Write the thermochemical equation for the combustion of hydrogen, given that \(\Delta H = -286 \, \text{kJ}\).

\[

2\text{H}\_2 + \text{O}\_2 \rightarrow 2\text{H}\_2\text{O} \quad \Delta H = -286 \, \text{kJ}

\]

**Progress Check**: Write the thermochemical equation for the decomposition of calcium carbonate (\(\text{CaCO}\_3 \rightarrow \text{CaO} + \text{CO}\_2\)) where \(\Delta H = +178 \, \text{kJ}\).

**Answer**: \(\text{CaCO}\_3 \rightarrow \text{CaO} + \text{CO}\_2 \quad \Delta H = +178 \, \text{kJ}\)

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### # 3. Classifying Reactions as Endothermic or Exothermic

To classify a reaction, calculate its enthalpy change (\(\Delta H\)):

**Step-by-Step Process**:

1. Identify the enthalpy values for the reactants and products.

2. Subtract the total enthalpy of the reactants from the total enthalpy of the products:

\[

\Delta H = \text{(Total enthalpy of products)} - \text{(Total enthalpy of reactants)}

\]

3. Interpret the result:

- If \(\Delta H > 0\), the reaction is endothermic.

- If \(\Delta H < 0\), the reaction is exothermic.

**Example**:

\[

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

\]

Since \(\Delta H < 0\), this reaction is exothermic.

**Practice Question**: Is the decomposition of water (\(2\text{H}\_2\text{O} \rightarrow 2\text{H}\_2 + \text{O}\_2\)) endothermic or exothermic, if \(\Delta H = +572 \, \text{kJ}\)?

**Answer**: Endothermic (\(\Delta H > 0\))

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### # 4. What Is Hess’s Law?

Hess’s Law states: **The total enthalpy change for a reaction is the same, no matter the pathway taken**. This means we can add the enthalpy changes of individual steps in a reaction to find the total \(\Delta H\).

**Real-Life Analogy**: Imagine you’re climbing a mountain. Whether you take a direct route or a winding path, your total elevation gain is the same.

**Visual Suggestion**: Show a diagram of two different reaction pathways leading to the same products, with \(\Delta H\) values labeled for each step.

**Question**: Why is Hess’s Law useful for calculating enthalpy changes?

**Answer**: It lets us calculate \(\Delta H\) for reactions that are hard to measure directly by breaking them into simpler steps.

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### # 5. Applying Hess’s Law to Multi-Step Reactions

Let’s use Hess’s Law to calculate \(\Delta H\) for this reaction:

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

\]

We’re given two related reactions:

1. \(\text{C} + \frac{1}{2}\text{O}\_2 \rightarrow \text{CO} \quad \Delta H = -110 \, \text{kJ}\)

2. \(\text{CO} + \frac{1}{2}\text{O}\_2 \rightarrow \text{CO}\_2 \quad \Delta H = -283 \, \text{kJ}\)

**Step-by-Step Solution**:

1. Add the two equations:

\[

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

\]

The intermediate (\(\text{CO}\)) cancels out, leaving:

\[

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

\]

2. Add the enthalpy changes:

\[

\Delta H = -110 \, \text{kJ} + (-283 \, \text{kJ}) = -393 \, \text{kJ}

\]

Thus, \(\Delta H = -393 \, \text{kJ}\).

**Practice Problem**: Use Hess’s Law to calculate \(\Delta H\) for the reaction \(\text{N}\_2 + 2\text{O}\_2 \rightarrow 2\text{NO}\_2\), given:

1. \(\text{N}\_2 + \text{O}\_2 \rightarrow 2\text{NO} \quad \Delta H = +180 \, \text{kJ}\)

2. \(2\text{NO} + \text{O}\_2 \rightarrow 2\text{NO}\_2 \quad \Delta H = -112 \, \text{kJ}\)

**Answer**: \(+68 \, \text{kJ}\)

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### 10. Elaborate (Power Up):

### # Extended Activity: Design an Experiment

Challenge learners to create a mini-lab experiment to measure the enthalpy change of a reaction, such as dissolving salt in water.

**Instructions**:

1. Measure the initial temperature of water.

2. Add a known amount of salt and stir.

3. Measure the final temperature.

4. Use this data to calculate \(\Delta H\).

**Expected Outcome**: Learners will observe whether the reaction is endothermic (temperature decreases) or exothermic (temperature increases).

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

### # Quiz Questions:

1. Write the thermochemical equation for the combustion of propane (\(\text{C}\_3\text{H}\_8\)), given \(\Delta H = -2219 \, \text{kJ}\).

2. Classify the reaction \(\text{H}\_2 + \text{Cl}\_2 \rightarrow 2\text{HCl} \quad \Delta H = -184 \, \text{kJ}\) as endothermic or exothermic.

3. Apply Hess’s Law to calculate \(\Delta H\) for:

\[

\text{C}\_2\text{H}\_4 + \text{H}\_2 \rightarrow \text{C}\_2\text{H}\_6

\]

Given:

- \(\text{C}\_2\text{H}\_4 + 3\text{O}\_2 \rightarrow 2\text{CO}\_2 + 2\text{H}\_2\text{O} \quad \Delta H = -1411 \, \text{kJ}\)

- \(\text{C}\_2\text{H}\_6 + 3.5\text{O}\_2 \rightarrow 2\text{CO}\_2 + 3\text{H}\_2\text{O} \quad \Delta H = -1560 \, \text{kJ}\)

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### 12. Extend (Beyond the Lesson):

### # Real-World Application:

Research how thermodynamics is used in designing energy-efficient homes. Ask students to create a model showing how chemical reactions (e.g., combustion of fuels) are used to heat homes.

### # Connecting to Future Topics:

Introduce the concept of Gibbs free energy, which combines enthalpy and entropy, to predict whether a reaction is spontaneous.

By mastering these concepts, learners will not only escape the Thermodynamics House but also unlock a deeper understanding of the energy driving chemical reactions!