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 using Hess's Law, which states that the total enthalpy change depends only on the initial and final states, not the pathway taken.

Hess’s Law states that the total enthalpy change for a reaction is the sum of the enthalpy changes of individual steps. This principle simplifies the calculation of enthalpy changes for complex reactions, enabling scientists to determine energy changes using simpler, measurable reactions.

### 2. Essential Questions:

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

**Answer:** By rearranging and combining thermochemical equations so that the overall reaction matches the target reaction, we can sum the enthalpy changes of the individual steps to find the total enthalpy change.

### 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.

### 4. Vocabulary:

- **Enthalpy:**  a measure of the total energy of a system, including internal energy and energy required to make room for it by displacing its surroundings

- **Hess's Law:** a principle stating that the total enthalpy change of a reaction is the same, no matter the number of steps or pathway taken, as long as the initial and final states are the same

- **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) t**he enthalpy change when one mole of a compound is formed from its elements in their standard states under standard conditions.

### 5. SMART Objectives:

By the end of the lesson, learners will be able to:

- 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.

### 6. Engage (Ignite):

Consider you are in the escape house, and the screen in front of you displays the following clue:

"**The total energy change for this reaction is hidden in the steps. Determination of heat transfer by dissolution of salt into water using calorimetry?”**

You see three chemical equations with their enthalpy changes, but one value is missing. To unlock the next door, you must calculate the missing enthalpy using the other equations.

Ask yourself:

- Can energy be "recycled" in a reaction?

- How can knowing the energy of one reaction help you predict the energy of another?

**Interactive Activity:**

Use an AI-powered tool like ChatGPT to ask questions about energy changes in chemical reactions.

* What are some real-world applications of energy changes in reactions?
* How can understanding energy transfer help in designing chemical processes?

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

To solve the challenge, it’s important to understand how energy flows in chemical reactions. Revisit the idea of exothermic and endothermic reactions from earlier grades:

- **Exothermic reactions** release energy (e.g., combustion of wood).

- **Endothermic reactions** absorb energy (e.g., melting ice).

**Example:**

Think about rechargeable batteries used in smartphones. When a battery discharges, it releases energy (exothermic process), allowing the phone to operate. When the battery is recharged, energy is absorbed (endothermic process), storing energy for future use. These examples demonstrate how energy flow impacts everyday technology.

**Interactive Element:**

Look at the following reactions:

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

2. CO(g) + ½O₂(g) → CO₂(g) ΔH = -283.0 kJ

What is the enthalpy change for the reaction:

C(s) + ½O₂(g) → CO(g)?

### Scaffolded Questions:

1. What does a negative ΔH value mean?

**Answer:** It means the reaction is exothermic and releases energy.

2. Why is it important to include ΔH in a thermochemical equation?

**Answer:** It shows how much energy is absorbed or released during the reaction.

3. How can Hess's Law simplify calculations for complex reactions?

**Answer:** It allows us to calculate the overall enthalpy change by adding or subtracting enthalpy changes of individual steps.

### 8. Explore:

**Quick Lab Activity:**

Title: **Exploring Energy Changes in Reactions**

**Objective:** Investigate energy changes during chemical reactions using index cards and calorimetry to reinforce the concept of energy flow.

**Materials:**

- Index cards with chemical equations and enthalpy changes written on them

- Beakers, water, and a stirring rod

- Worksheet for recording calculations

- Salt (e.g., table salt)

- Thermometer

- Worksheet for recording calculations

**Procedure:**

1. Arrange the index cards on a table. Each card represents a step in a chemical reaction, including the equation and its enthalpy change.
2. Dissolve a measured amount of salt (e.g., 5 g) in 100 mL of water in a beaker. Record the initial and final temperatures.
3. Calculate the energy change during the dissolution process using q=m⋅c⋅ΔTq = m \cdot c \cdot \Delta Tq=m⋅c⋅ΔT, where mmm is the mass of water, ccc is the specific heat capacity of water (4.18 J/g°C), and ΔT\Delta TΔT is the temperature change.
4. Return to the index cards. Rearrange and combine the equations to calculate the enthalpy change for the target reaction:  
   C(s)+½O2(g)→CO(g)C(s) + ½ O\_2(g) → CO(g)C(s)+½O2​(g)→CO(g).  
   Remember to reverse or multiply equations as needed, adjusting enthalpy values accordingly.
5. Record your calculations and verify your results using the worksheet.

**Example Data:**

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

- CO(g) + ½O₂(g) → CO₂(g) ΔH = -283.0 kJ

**Expected Outcome:**

The enthalpy change for the target reaction is ΔH = -110.5 kJ.

**Reflection Question:**

How does this activity show that Hess's Law works?

This structured plan ensures learners connect the phenomenon to the lesson content while engaging in hands-on exploration of Hess’s Law and enthalpy changes.

### 9. Explain (Lightbulb Moment)

In the escape house, each step in solving the puzzle mirrors the steps of a chemical reaction. Calculating the missing enthalpy values in the puzzle demonstrates how energy changes depend on the beginning and ending states of reactions, just like using Hess’s Law to calculate enthalpy changes for multi-step reactions.

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

Enthalpy, symbolized as H, represents the total heat content of a system. It helps understand energy transfer during chemical reactions. Think of it as a reaction's "energy bank account," where energy is either deposited (absorbed) or withdrawn (released). The change in enthalpy (ΔH\Delta HΔH) indicates how much energy is involved.

**Example:**  
When fuel burns in a car engine, heat is released (exothermic). However, when plants undergo photosynthesis, they absorb sunlight's energy (endothermic)..

**Visualizing Energy Changes in Reactions**

Imagine a graph where the energy levels of reactants and products are plotted:

* **Exothermic Reactions (ΔH<0\Delta H < 0ΔH<0):**  
  When the products have less energy than the reactants, the reaction releases energy. This is depicted as a **downward slope** on the graph, indicating a release of heat to the surroundings.
* **Endothermic Reactions (ΔH>0\Delta H > 0ΔH>0):**  
  When the products have more energy than the reactants, the reaction absorbs energy. This is shown as an **upward slope** on the graph, reflecting an energy gain from the surroundings.

**Suggested Visual**: A bar graph comparing the energy of reactants and products for exothermic and endothermic reactions.

### Write Thermochemical Equations

Thermochemical equations are chemical equations that include the enthalpy change (ΔH) of the reaction. They show not only the substances involved but also whether energy is absorbed or released.

For example:

CH4 ​+ 2O2​ → CO2 ​+ 2H2​O ΔH = −890kJ

This equation tells us that burning methane releases 890 kJ of energy.

**Solved Example**:

Write the thermochemical equation for the reaction where 2 mol of hydrogen gas reacts with 1 mol of oxygen gas to form water, releasing 572 kJ of energy.

2H2 ​+ O2 ​→ 2H2​O ΔH = −572kJ

**Progress Check**:

Write the thermochemical equation for the reaction where 1 mol of nitrogen gas reacts with 3 mol of hydrogen gas to form ammonia, releasing 92 kJ of energy.

### Calculate the Enthalpy Change to Classify Reactions

To classify a reaction as endothermic or exothermic, calculate the enthalpy change (ΔH) using the formula:

ΔH=Energy of Products−Energy of Reactants

- If ( ΔH > 0 ), the reaction is **endothermic** (absorbs energy).

- If (ΔH < 0 ), the reaction is **exothermic** (releases energy).

**Real-Life Examples**:

- **Exothermic**: Combustion of gasoline in a car engine.

- **Endothermic**: Melting ice cubes on a hot day.

**Solved Problem**:

In a reaction, the reactants have an energy of 200 kJ, and the products have an energy of 150 kJ. Calculate ΔH and classify the reaction.

ΔH=150kJ−200kJ=−50kJ

This is an **exothermic** reaction.

**Practice Question**:

A reaction has reactants with 300 kJ of energy and products with 400 kJ of energy. Calculate ΔH and classify the reaction.

### Define Hess's Law

Hess’s Law states that the total enthalpy change for a reaction is the same, no matter how many steps the reaction takes. This means we can add up the enthalpy changes of individual steps to find the total ΔH.

**Example**:

Consider the energy involved in assembling a jigsaw puzzle. Whether you complete the puzzle by adding one piece at a time or several sections together, the final picture remains the same. Similarly, in chemical reactions, the total energy change depends on the reactants and products, not the sequence of steps..

**Suggested Visual:**  Illustrate two reaction pathways—one direct and one multi-step—showing that the total ΔH\Delta HΔH remains the same regardless of the pathway.

**Follow-Up Question**: Why is Hess’s Law useful for reactions that are hard to measure directly?

### Apply Hess's Law to Multi-Step Reactions

To apply Hess’s Law, follow these steps:

1. Write the equations for each step of the reaction.

2. Adjust the equations so they match the overall reaction (reverse or multiply if necessary).

3. Add up the ΔH values of each step.

**Solved Problem**:

Given the reactions:

1. C+O2​→CO2​ΔH=−393kJ

2. CO2​→CO+21​O2​ΔH=+283kJ

Find ΔH for the reaction:

C+ 1/ 2 ​O2​→CO

**Solution**:

Add the two equations:

C+O2​+CO2​→CO2​+CO+21​O2​

Cancel common terms:

C+21​O2​→CO

Add

ΔH=−393kJ+283kJ=−110kJ

**Practice Problem**:

Use Hess’s Law to find ΔH for the reaction:

N2​+3H2​→2NH3​

Given:

1. N2​+O2​→2NOΔH=+180kJ

2. 2NO+3H2​→2NH3​+H2​OΔH=−250kJ

**Scaffolded Questions to Confirm Understanding:**

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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### 10. Elaborate (Power Up)

**Extended Activity**: Design a mini-project where students create a "Reaction Energy Map" for a multi-step reaction. They will:

- Research a real-world process (e.g., photosynthesis or combustion).

- Break it into steps and calculate ΔH for each step using Hess’s Law.

- Present their findings using diagrams and graphs.

**Critical Thinking Question**: How can understanding enthalpy changes help engineers design more energy-efficient processes?

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

### 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.

### ACT-Type Questions:

**Paragraph:**  
Energy changes in chemical reactions are a fundamental aspect of thermochemistry. Exothermic reactions, such as combustion, release energy, while endothermic reactions, like photosynthesis, absorb energy. Hess's Law allows scientists to calculate the total enthalpy change for reactions, even those that are difficult to measure directly. This principle is widely used in designing industrial processes, such as the synthesis of ammonia in the Haber process, which is vital for producing fertilizers.

**MCQs Based on the Paragraph:**

1. Which of the following is an example of an exothermic reaction?  
   a) Photosynthesis  
   b) Melting ice  
   c) Combustion of methane  
   d) Boiling water  
   **Correct Answer:** c) Combustion of methane
2. How does Hess's Law simplify enthalpy calculations?  
   a) By eliminating the need for balancing equations  
   b) By considering only the intermediate steps of a reaction  
   c) By allowing the addition of enthalpy changes for individual steps  
   d) By focusing only on exothermic reactions  
   **Correct Answer:** c) By allowing the addition of enthalpy changes for individual steps
3. The Haber process is primarily used for:  
   a) Producing synthetic fuels  
   b) Manufacturing fertilizers  
   c) Generating renewable energy  
   d) Synthesizing plastics  
   **Correct Answer:** b) Manufacturing fertilizers

**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).

### 12. Extend (Beyond the Lesson)

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.