Unit 9: Thermochemistry

The heat is on! In this unit, we’ll learn about the laws of thermodynamics and the energy changes that take place during chemical reactions.

- Understand the laws of thermodynamics and their applications in real world scenarios.
- Describe and classify energy changes during chemical reactions.
- Analyze calorimetry data and apply the formula $q = mc\Delta T$ to calculate heat, mass, temperature change, or specific heat capacity.

### TEKS standards

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<th>TEKS standards</th>
<th>Example phenomena</th>
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<td>CHEM.13A Explain everyday examples that illustrate the four laws of thermodynamics.</td>
<td><strong>How does a refrigerator work?</strong> Refrigerators use a cycle of compression and expansion of a chemical refrigerant (like Freon) to maintain a low temperature environment. First, low-pressure refrigerant gas enters the compressor, where it is mechanically compressed to a high temperature and pressure. Next, this high-temperature gas moves into the condenser on the outside of the refrigerator. As thermal energy transfers from the refrigerant gas to the air outside the refrigerator, the temperature of the refrigerant decreases, and it becomes a liquid. When this liquid refrigerant flows into the evaporator coils inside the refrigerator, thermal energy transfers from the air inside the refrigerator to the refrigerant. The temperature of the refrigerant increases, while the temperature of the air inside the refrigerator decreases, and the refrigerant evaporates to the gas phase. It then flows back to the compressor to begin the cycle again. Electrical energy is converted to mechanical energy and then thermal energy to maintain this cycle.</td>
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| CHEM.13B Investigate the process of heat transfer using calorimetry. | **Prompts for students to consider:**
  - How does each component in the refrigeration cycle (compressor, condenser, evaporator) participate in heat transfer?
  - How does the refrigeration cycle illustrate the first law of thermodynamics?
  - How does the transfer of thermal energy during the refrigeration cycle demonstrate the second law of thermodynamics?
  - How does a simple icebox work to keep food cold? What are some practical advantages of modern refrigerators over icebox coolers? |
| CHEM.13C Classify processes as exothermic or endothermic and represent energy changes that occur in chemical reactions using thermochemical equations or graphical analysis. | **CHEM.13D Perform calculations involving heat, mass, temperature change, and specific heat.** |
How does a thermometer determine temperature?
Thermometers rely on thermal equilibrium to determine the temperature of an object. For example, when a liquid expansion thermometer at room temperature is placed in a glass of ice water, thermal energy transfers from the liquid (such as mercury) in the thermometer to the lower temperature water in the glass. The loss of thermal energy causes the mercury to contract and take up less volume, so its level falls inside the thermometer tube. The scale shown on the thermometer relates the change in mercury height to a “degree” on the unit scale. Once the liquid in the thermometer reaches thermal equilibrium with the water, its temperature stops changing.

Prompts for students to consider:
- How can we explain the function of a liquid expansion thermometer using the laws of thermodynamics?
- Why does it take some time for a thermometer placed in contact with an object to read a stable temperature?
- Why isn’t water a practical choice for the liquid in a thermometer?
- If the body's internal temperature is 37 °C, why do our bodies feel hot when the air temperature is the same?
- If our bodies are constantly transferring thermal energy to our surroundings, how are we able to maintain a relatively constant internal temperature?

How are calories on food labels determined?
Calories are a measure of the energy content in food. One kilocalorie (often written as Calorie) is the equivalent of 4184 joules of energy. A bomb calorimeter is one tool used to determine the amount of calories in food. It works by burning a sample of food in a sealed container and measuring the temperature increase of water surrounding the container. The amount of thermal energy released from the food is determined, and this value is directly proportional to the energy content of the food. Food labels in the United States are required to list the energy content in Calories.

Prompts for students to consider:
- How does the function of a bomb calorimeter illustrate the first and second laws of thermodynamics?
- What happens to the thermal energy released when a sample of food burns in a bomb calorimeter?
- How is the change in water temperature used to determine the number of Calories in a food sample?
- Why do foods with sugars or oils have a significantly higher number of Calories?
Unit resources

- For the videos in this unit, use the Learning summary video notetaking guide.
- For the articles in this unit, use the Article notetaking guide.
- For the exercises in this unit, use the Blank workspace template.
- To record key terms and information, use the Vocabulary and notation notetaker.

Lesson overview

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<td>Lesson 1: Thermal energy and equilibrium</td>
<td>Identify everyday examples that demonstrate the zeroth law of thermodynamics and thermal equilibrium. Use the first law of thermodynamics to explain conservation of energy in everyday scenarios. Analyze common situations using the second law of thermodynamics to explain why thermal energy transfers from a system with a higher temperature to a system with a lower temperature. Relate the third law of thermodynamics to the properties and behavior of matter as its temperature approaches absolute zero. Apply the laws of thermodynamics to explain the operation of everyday devices.</td>
<td>• Encourage students to brainstorm everyday examples of systems reaching thermal equilibrium. To get started, you might ask students to consider what will happen if ice cubes are placed in a glass of tap water, and the glass is left out for several hours. • Have students draw and annotate diagrams to show the direction of thermal energy transfer in scenarios where objects at different temperatures come into contact. • Ask students to analyze common processes, like the operation of a car engine, where energy is converted from one form to another. Have students draw diagrams or flowcharts to trace the conversion of energy and explain how each process illustrates the first law of thermodynamics. • Use simple demonstrations to help students understand the concept of increasing entropy. For example, spray perfume in one corner of the room and notice how the scent disperses, place a drop of food coloring in water and see it spread out, or add powdered drink mix to water and watch it dissolve. • Leverage students’ understanding of particle motion and kinetic energy to explain how the transfer of thermal energy (the sum of the kinetic energy of all the particles in a system) occurs via transfer of kinetic energy when particles collide. • Relate the third law of thermodynamics to real-world applications like superconductivity. • Consider giving students a mini research activity where they select and analyze a scenario, process, or device using the laws of thermodynamics.</td>
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**Lesson 2: Energy changes in chemical reactions**

**TEKS standard:** CHEM.13C

- Classify an exothermic process as one that results in an overall release of energy by a system and an endothermic process as one that results in an overall absorption of energy by a system.

- Explain that during a chemical reaction, an input of energy is required to break bonds in the reactants, and energy is released when new bonds are formed in the products.

- Identify enthalpy as the total heat content of a system and enthalpy change ($\Delta H$) as the net change in heat content of a system.

- Interpret thermochemical equations and energy diagrams to determine the direction of heat flow and the magnitude of enthalpy changes in chemical reactions.

- Utilize quick demonstrations that allow students to experience exothermic and endothermic processes, such as dissolving calcium chloride in water or activating a hand warmer (exothermic) and dissolving ammonium chloride or an effervescent tablet in water (endothermic).

- To help students recognize that every exothermic process is paired with an endothermic process, ask them to analyze common scenarios by constructing diagrams in which they define the system, indicate the direction of heat flow, and define the process as exothermic or endothermic.

- Emphasize that enthalpy change for a reaction is a net change, taking into account the energy required to break bonds and the energy released when new bonds form. If more energy is required to break bonds than is released when new bonds form, the change will be positive, and the reaction will be endothermic. If more energy is released when bonds form compared to the energy required to break bonds, the change will be negative, and the reaction will be exothermic.

- Use energy diagrams to help students analyze and describe energy changes from reactants to products in familiar reactions like combustion or photosynthesis. Ask students to consider where the thermal energy released from an exothermic reaction goes and where the energy absorbed by an endothermic reaction comes from.

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**Lesson 3: Specific heat**

**TEKS standards:** CHEM.13B; 13D

- Define specific heat capacity as the energy required to change the temperature of a material by one degree Celsius per gram, and explain how this property relates to the behavior and applications of different materials.

- Apply the formula $q = mc\Delta T$ to calculate heat, mass, temperature change, or specific heat capacity.

- Explain the use of calorimetry to determine heat transfer between substances.

- Help students to understand specific heat capacity by exploring examples of common insulators and conductors. Ask students to consider, for example, why we use metals to make pots and materials like wood or plastic to make stirring spoons.

- Before introducing the equation $q = mc\Delta T$, ask students to brainstorm factors that will impact the amount of energy required to change the temperature of a given sample. Once students recognize the amount of temperature change, the size of the sample (mass), and the kind of substance (related to specific heat capacity) as key factors, the equation will make more sense conceptually.
Identify essential components of a calorimeter setup and explain their functions.

Analyze experimental data obtained from calorimetry experiments to draw conclusions about the specific heat capacities of substances.

- Emphasize that calorimetry relies on the principle of energy conservation, where the heat released or absorbed by a system is equal to the heat gained or lost by its surroundings.
- Have students create diagrams showing the calorimeter setup and the direction of thermal energy transfer in calorimetry experiments. Discuss how loss of heat to the surroundings can affect results when using a calorimeter.

**Best practices**

**COMMON MISCONCEPTIONS AND HOW TO ADDRESS THEM**

**“Heat and temperature are the same thing.”**

Since people often say that something “feels hot” or that one thing is hotter (or colder) than another when talking about relative temperatures, students may believe that heat and temperature are interchangeable.

**How to address this misconception**

Temperature is a measure of the average kinetic energy of the particles in a system, while heat refers to the transfer of thermal energy between systems due to a temperature difference. Thermal energy moves from a system with a higher temperature to a system with a lower temperature until the two systems reach thermal equilibrium. Explain that the sensation of “cold” is caused by the movement of heat from the surface of the body when it comes in contact with a system at lower temperature. Things “feel hot” when heat moves from a system at higher temperature to the body. To illustrate this concept, measure the temperature of a small metal object at room temperature, then invite students to hold the object in their hands. At first, students will report that it feels cold, despite the fact that it is at room temperature. Over time, as heat transfers from the hand to the object, and they reach thermal equilibrium, the object will no longer feel cold.

**“Bond formation is an endothermic process, and bond breaking is an exothermic process.”**

Students may believe that energy must be used to bond atoms together to form something new, resulting in an endothermic process. Students also may believe that when bonds are broken, the energy stored within the bonds is released, resulting in an exothermic process.

**How to address this misconception**

Energy diagrams can help students to visualize changes in energy during a chemical reaction. Emphasize that a minimum amount of energy is required to start a reaction (activation energy). The energy diagram shows an initial increase in energy to break bonds, even for an exothermic reaction like combustion of a hydrocarbon. Energy in the reaction system then decreases as new bonds form to make products that are more stable than the reactants. In combustion, more energy is released from bond formation than is consumed in bond breaking. Point out that the enthalpy change is represented in the energy diagram as the difference between the height of the reactants and the
products on the y-axis. If products are lower than reactants, then the enthalpy change is negative and the reaction is exothermic. The reverse is true for an endothermic reaction.

CLASSROOM ACTIVITIES

Investigate specific heat with a coffee cup calorimeter.
In this activity, students will use a simple calorimeter to determine the specific heat capacity of one or more metals.

Materials: Each group will need: metal sample(s) (e.g., copper, aluminum, iron), a balance, a Styrofoam cup, a beaker, a thermometer, water, tongs, and a hot plate. Exercise all necessary safety precautions.

☐ Obtain enough room-temperature water to cover the metal sample when placed inside the Styrofoam cup. Record the mass of the water and the mass of the metal sample separately.
☐ Add the room-temperature water to the Styrofoam cup, and record the initial water temperature.
☐ Prepare a hot water bath, and add the metal sample. Allow the metal sample to reach thermal equilibrium with the hot water, and record this temperature as the initial metal temperature.
☐ Quickly remove the metal from the hot water using a pair of tongs, and place it in the Styrofoam cup.
☐ Gently stir the water and metal, and record the mixture's temperature every 30 s until it begins to decrease. Record the peak temperature as the final temperature for the metal and the water.
☐ Use the collected data to determine the metal's specific heat capacity. Repeat for a different metal.

Analyze energy changes in chemical reactions.
In this activity, students will observe temperature changes during several chemical reactions and use their data to determine if each reaction is exothermic or endothermic.

Materials: Each group will need vinegar, baking soda, calcium chloride, water, a thermometer, metric measuring spoons, and several 50-mL beakers. Exercise all necessary safety precautions.

☐ For each reaction: record the initial temperature of the reactants, combine the reactants, monitor the temperature of the reaction mixture until it stops changing, then record the final temperature.
☐ For reaction 1, combine 20 mL of water and 5 mL of calcium chloride.
☐ For reaction 2, combine 20 mL of vinegar and 5 mL of baking soda.
☐ For reaction 3, combine 20 mL of water, 5 mL of baking soda, and 5 mL of calcium chloride.
☐ Analyze the results to determine if each reaction was endothermic or exothermic.

GENERAL CLASSROOM IMPLEMENTATION RESOURCES:

- Weekly Khan Academy Quick Planning Guide: Use this template to plan your week using Khan Academy.
- Using Khan Academy in the Classroom: Learn teaching techniques and strategies to support your students and save time with Khan Academy.
- Differentiation Strategies for the Classroom: Discover strategies to support the learning of all students.