Khan Academy

High School Chemistry

Unit 7: Thermochemistry

Overview

In this unit, students will explore how thermal energy is transferred between components of systems and how energy is conserved in these processes.

Lesson 1: Students will explore the relationships between thermal energy, temperature, and heat and learn about conservation of energy. Based on these concepts, students will **develop and use models** to predict the direction of heat transfer and explain how a system reaches thermal equilibrium.

Lesson 2: Students will learn about factors that affect the amount of thermal energy transferred, including specific heat capacity. **Using mathematics and computational thinking**, students will be able to analyze scenarios and solve for different variables in the equation $q = mc\Delta T$.

Lesson 3: Hands-on science activity (see below)

Lesson 4: Students will apply their understanding of specific heat capacity and thermal energy transfer to the practice of calorimetry.

Hands-on science activity

Why does sand at the beach feel hot, even when the water feels cool?

Students will **carry out an investigation** and **analyze and interpret data** to draw conclusions about the relationship between the specific heat capacity of a substance and the degree to which its temperature changes when a given amount of heat is transferred per unit mass. Click here for links to the activity.

Standards

Performance expectations: **HS-PS3-1 | HS-PS3-2 | HS-PS3-4**

Disciplinary core ideas: **HS-PS3.A.2 | HS-PS3.A.3 | HS-PS3.A.4 | HS-PS3.B.1 | HS-PS3.B.2 | HS-PS3.B.3**

Science and engineering practices:

- Developing and using models
- Planning and carrying out investigations
- Using mathematics and computational thinking
- Analyzing and interpreting data

Crosscutting concepts:

- Energy and matter
- Systems and system models
- Stability and change
- Cause and effect

Click here to read the full standards.

Essential questions

- How can the laws of thermodynamics be used to explain thermal energy transfer and conservation of energy in real-world scenarios?
- What is the relationship between the specific heat capacity of a substance and the degree to which its temperature changes when a given amount of heat is transferred per unit mass?
- How can we use calorimetry to learn about a system?

Lesson notes

Lesson 1: Thermal energy and equilibrium

PEs: HS-PS3-2
DCIs: HS-PS3.A.2, HS-PS3.A.3, HS-PS3.A.4

Resources

Video	Exercise
2	2

Objectives	Teaching tips
• Understand how **thermal energy**, **temperature**, and **heat** are related, and use these terms appropriately to describe energy transfer scenarios. • Define a **system** and predict the direction of thermal energy transfer when systems at different temperatures come into contact with each other. • Identify everyday examples that demonstrate systems reaching **thermal equilibrium** (second law of thermodynamics). • Analyze energy changes in scenarios, processes, or devices using the first and second laws of thermodynamics.	• Encourage students to brainstorm everyday examples of systems reaching thermal equilibrium. Begin by asking students 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 and transfer of energy. • Have students explore the transfer and transformation of energy within a system using the PhET Energy Forms and Changes simulation. • 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 observe 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. • Ask students to consider how a refrigerator stays cold inside. (*See the "Related phenomena" section below for more information.*)

Lesson 2: Specific heat capacity

PEs: HS-PS3-4
DCIs: HS-PS3.A.2, HS-PS3.A.2, HS-PS3.B.2

Resources

Video	Exercise
1	1

Objectives	Teaching tips
• Define **specific heat capacity** 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.	• 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.

- Consider common kitchen examples, such as boiling a large pot of water for pasta or a small kettle of water for tea, baking with a glass dish or a metal cookie sheet, or allowing coffee to cool to the desired temperature for drinking.
- 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.

- Implement the hands-on activity "*Why does sand at the beach feel hot, even when the water feels cool?*" in order to give students experience observing heat transfer events and applying their understanding of specific heat capacity and the relationships represented by $q = mc\Delta T$ (see Lesson 3).

Lesson 3: Hands-on science activity
Why does sand at the beach feel hot, even when the water feels cool?

PEs: HS-PS3-4
DCIs: HS-PS3.A.2, HS-PS3.B.1, HS-PS3.B.2

Resources

Activity: 1

Description	Links
Students will **carry out an investigation** and **analyze and interpret data** to draw conclusions about the relationship between the specific heat capacity of a substance and the degree to which its temperature changes when a given amount of heat is transferred per unit mass.	• Full activity overview (**Khan Academy article**) • Student activity guide (**Doc** | **PDF**) • Teacher guide (**Doc** | **PDF**)

Lesson 4: Calorimetry

PEs: HS-PS3-1, HS-PS3-4
DCIs: HS-PS3.B.1, HS-PS3.B.2, HS-PS3.B.3

Resources

Video: 2
Exercise: 2

Objectives	Teaching tips
• Explain the use of **calorimetry** to determine heat transfer between substances. • 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. • Ask students to consider how calories on food labels are determined. (*See the "Related phenomena" section below for more information.*)

Related phenomena

Example phenomenon

How does a refrigerator stay cold inside?

Store refrigerator with food

Background information

Refrigerators use a cycle of compression and expansion of a chemical refrigerant 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.

Exploring this phenomenon helps students develop and master the following understandings:

- [ ] Energy cannot be created or destroyed. It can move from one component to another within a system or be transferred between a system and its surroundings. It can also change forms.
- [ ] Temperature is a measure of the average kinetic energy of the particles in a system. It increases as the particles move faster and decreases as the particles move more slowly.
- [ ] Heat transfers from a component with higher temperature to a component with lower temperature until the components reach thermal equilibrium.

Tips for implementing phenomenon-based learning

- Ideas to encourage student engagement:
  - Give students a simple diagram of a refrigerator with the compressor, condenser, and evaporator labeled. Discuss the steps in the compression cycle, and ask students to annotate the diagram, indicating the direction of thermal energy transfer and the effect on temperature in each step.
  - Ask students to create a flowchart accounting for all energy transfers and transformations in the compression cycle, starting with electrical energy coming from the wall socket and ending with thermal energy moving from the air inside the refrigerator to the liquid refrigerant in the evaporator coils.
  - Leverage students' understanding of intermolecular forces and phase changes from Unit 6. Ask them to draw particle diagrams showing changes in particle motion and arrangement as the refrigerant changes from gas to liquid and vice versa during the cycle. Have students indicate the direction of thermal energy transfer in each case.

- Sample prompts to elicit student ideas and encourage discussion:
  - How does the refrigeration cycle illustrate the law of conservation of energy? Where does the energy come from and where does it go?
  - How does each component in the refrigeration cycle (compressor, condenser, evaporator) participate in thermal energy transfer?
  - What energy changes occur when a substance changes phase from liquid to gas or vice versa?
  - How does a simple icebox cooler, like one you might take to a picnic, work to keep food cold? What are some practical advantages of modern refrigerators over icebox coolers?

Example phenomenon

How are calories on food labels determined?

Nutrition facts with calories listed on packaged foods

Background information

Calories are a measure of the energy content in food. One kilocalorie (often written as **C**alorie) is the equivalent of 4184 joules of energy. A calorimeter is a tool used to determine the energy released or absorbed during a chemical reaction, and it can be used to find the energy content in a sample of food.

When a food sample is burned in a calorimeter, the energy released is transferred to a known mass of water, and the temperature increase of the water is measured. The amount of energy absorbed by the water can be calculated using the specific heat capacity, mass, and change in temperature of the water. Since energy is conserved, this value is equivalent to the energy released by the burning food. Dividing the energy released by the mass of the sample provides the energy content per gram of that food. Food labels in the United States are required to list the energy content in Calories.

Exploring this phenomenon helps students develop and master the following understandings:

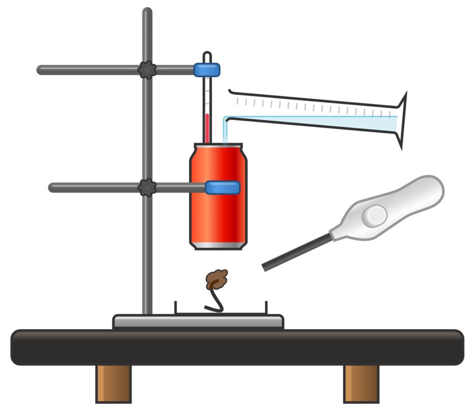
- [ ] Energy cannot be created or destroyed, but it can move from one component to another within a system or be transferred between a system and its surroundings. This means that energy lost/gained by a system must be equal to the energy gained/lost by its surroundings.
- [ ] Specific heat capacity is a characteristic property of a substance that represents the amount of thermal energy required to change the temperature of one gram of the substance by one degree Celsius.
- [ ] The amount of heat transferred when components of different temperatures come in contact can be calculated using the equation $q = mc\Delta T$.

Tips for implementing phenomenon-based learning

- Ideas to encourage student engagement:
  - Set up a simple demonstration, like the one shown in the diagram below, to allow students to observe a calorimeter in action. Collect data as a class, and ask students to determine the energy content per gram of one or more foods. Afterwards, have students compare the Calories/gram

that they found experimentally to the values on the food packaging.

- To carry out this demonstration:
  - Measure and record the mass of a piece of food, such as a cheese puff or marshmallow.
  - Make a stand for the food sample by unbending a paperclip and securing the food to the end. Place this set up in a small metal or Pyrex dish.
  - Add 100 g of water to a soda can, and suspend the can above the food sample with a thermometer in the water. Record the initial temperature of the water.
  - Light the food sample and allow it to burn completely. Monitor and record the highest temperature reached by the water in the can.



  - Students can use the equation $q = mc\Delta T$ to determine the energy absorbed by the water (q). This must be equal in magnitude to the energy released by the food sample. Use 1 cal/g°C as the specific heat capacity of water or have students convert the energy from joules to calories. They will also need to convert to kilocalories and divide by the mass of the food sample in order to compare their energy content values to the **C**alories on food labels.
  - If the energy content values calculated by students are significantly different from those on the food labels, this offers a good opportunity to discuss sources of error in the experimental design. For example, the food sample may not burn completely, and some thermal energy from the burning sample is “lost” to the surrounding air and the can.

- Sample prompts to elicit student ideas and encourage discussion:
  - How does the function of a calorimeter depend on the conservation of energy?
  - What happens to the thermal energy released when a sample of food burns in a calorimeter?
  - How do we know that energy is released by the food when it burns?
  - What is the role of the water in a calorimeter?

Common student misconceptions

Possible misconception: *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.

Critical concepts

- Temperature is a measure of the average kinetic energy of the particles in a system.
- Thermal energy is the *total* kinetic energy of *all* the particles in a system.
- 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.

How to address this misconception

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.

Possible misconception: *When energy transfers out of a system, it disappears.*

We often focus on energy changes occurring within a system and ignore energy that leaves as heat, light, or sound. This may lead students to believe that energy somehow "disappears" once it is no longer inside the system.

Critical concepts

- Conservation of energy means that the total change of energy in any system is always equal to the energy transferred into or out of the system.
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- The transfer of thermal energy can be observed by measuring changes in temperature.

How to address this misconception

Provide students with opportunities to observe energy transferring out of a system, and ask them to account for what happens to it. For example, boil water in a closed container, then remove the lid to open the system. Place a thermometer in the water and another in the air directly above the container. Ask students to observe what happens to the temperature inside the system (the water/container) and outside the system (the air and everything outside the container) over time. Have students explore the PhET Energy Forms and Changes simulation and discuss what they notice about energy leaving the system.

Unit resources

Student resources

- PhET Energy Forms and Changes: Use this simulation for a virtual investigation of the transfer and transformation of energy within a system.
- Article and video note taking template (Doc | PDF): Use this printable template for structured note taking on the articles and videos in this unit.
- Graph paper template (Doc | PDF): Use this printable template for manual graphing exercises.

Classroom implementation resources

- Weekly Khan Academy quick planning guide (Doc | PDF): Use this template to easily plan your week.
- Using Khan Academy in the classroom (Doc | PDF): Learn about teaching strategies and structures to support your students in their learning with Khan Academy.
- Differentiation strategies for the classroom (Doc | PDF): Read about strategies to support the learning of all students.
- Using phenomena with the NGSS: Learn more about how to incorporate phenomena into NGSS-aligned lessons.
- Hands-on science activities from Khan Academy: Choose from Khan Academy's collection of high-quality, ready-to-use, and free hands-on science activities. Each one is engaging, three-dimensional, phenomenon-based, and simple to implement.

NGSS standards reference guide

Performance expectations

- **HS-PS3-1:** Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
- **HS-PS3-2:** Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative position of particles (objects).
- **HS-PS3-4:** Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

Disciplinary core ideas

- **HS-PS3.A.2:** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms.
- **HS-PS3.A.3:** At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- **HS-PS3.A.4:** These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.
- **HS-PS3.B.1:** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.
- **HS-PS3.B.2:** Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- **HS-PS3.B.3:** Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior.

Science and engineering practices (SEPs)

- **Developing and using models**: Students progress to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed worlds.
- **Using mathematics and computational thinking:** Students progress to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and

logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions.

- **Planning and carrying out investigations:** Students progress to include investigations that provide evidence for and test conceptual, mathematical, physical, and empirical models.
- **Analyzing and interpreting data:** Students progress to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

Crosscutting concepts (CCCs) and their implementation

Crosscutting concept	Unit implementation
Systems and system models: Defining the system under study—specifying its boundaries and making explicitly a model of that system—provides tools for understanding and testing ideas that are applicable throughout science and engineering.	Students define systems in order to study thermal energy transfer within and between systems.
Energy and matter (Flows, cycles, and conservation): Tracking fluxes of energy and matter into, out of, and within systems helps one understand the systems' possibilities and limitations.	Students predict, observe, and quantify thermal energy transfer into, out of, and within systems.
Stability and change: For natural and built systems alike, conditions of stability and determinants of rates of change or evolution of a system are critical elements of study.	Students observe and analyze changes as systems reach thermal equilibrium.
Cause and effect (Mechanism and explanation): Events have causes, sometimes simple, sometimes multifaceted. A major activity of science is investigating and explaining causal relationships and the mechanisms by which they are mediated. Such mechanisms can then be tested across given contexts and used to predict and explain events in new contexts.	Students explain how the transfer of thermal energy occurs via the mechanism of particle collisions.