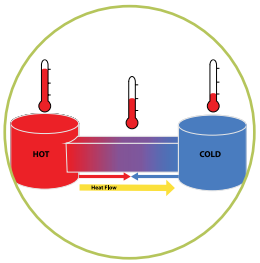
Developing a Computational Model for Heat Exchange

A Carolina Essentials™ Activity



Overview

This introductory activity encourages students to make connections between kinetic energy of particles, heat/thermal energy, heat transfer, and conservation of energy. Mass and temperature data are collected, and relationships between mass, energy transfer, and temperature changes are established. Students then graph data and find the equation of the line of best fit which leads to the development of a computational model for heat transfer.

Physical Science
Grades: 9–12

Phenomenon

You come into class and your chair seat is warm, warmer than the classroom itself. What do you need to know to explain this phenomenon?

Essential Question

How can the energy that flows into and out of a system be modeled mathematically?

Activity Objectives

1. Collect data to evaluate the transfer of thermal energy between cups of water with different temperatures.
2. Determine the mathematical relationship between energy transfer, mass, and change in temperature.

Next Generation Science Standards* (NGSS)

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 into and out of the system are known.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking • Create a computational model or simulation of a phenomenon, designed device, process, or system.	**PS3.B: Conservation of Energy and Energy Transfer** • 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. • Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.	**Systems and System Models** • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

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TIME REQUIREMENTS

PREP 30 min | **ACTIVITY** 30–60 min

Teacher Prep: 30 minutes

Student Activity: 30–60 min depending on the number of groups (data for a total of 30 trials should be recorded)

SAFETY REQUIREMENTS

MATERIALS

Heat Transfer Kit

4 beakers, 1,000 mL

2 beakers, 600 mL (optional—for stabilizing the cups)

Graduated cylinder, 100 mL

Warm water, 1,000–2,000 mL (50–70° C)

Cold water, 1,000–2,000 mL (5–15° C)

Hot plate

High/low temperature gloves

HELPFUL LINKS

It's Not the Heat, It's Thermochemistry

Food Calorimetry: How to Measure Calories in Food

Calorimetry: Measuring the Energy in Foods

REFERENCE KITS

First and Second Laws of Thermodynamics

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Teacher Preparation and Disposal

Prepare 1,000 mL beakers with warm and cold water. The warm water should be 50 to 70° C and the cold water 5 to 15° C. Students can add tap water to the warm and cold beaker water to alter initial temperatures.

Student Procedure

1. For stability, place the foam cups in beakers, if provided.
2. Label the cups “A” and “B.”
3. Add 75 mL of warm water to cup A and cover it quickly. Record the mass of water. (Remember that 1 mL of water weighs approximately 1 g.)
4. Add 75 mL of cold water to cup B and cover it quickly. Record the mass of water.
5. Insert the aluminum bar into both cups. Make certain the bar is submerged in the water in both cups.
6. Insert the thermometers into the water in both cups and record the initial temperatures for both.
7. Wait until the temperature of the water in both cups is the same, and record the final temperature for both cups.
8. Repeat the process with more warm water in cup A than cold water in cup B. Record the mass, initial temperature, and final temperature for both cups.
9. Repeat the process a third time, with more cold water in cup B than warm water in cup A. Record the mass, initial temperature, and final temperature for both cups.
10. Place your data on the class data table.

Teacher Preparation and Tips

The beakers add stability for the cups but are not necessary.

All groups should get similar results for this trial.

If water spills, student must remeasure the water and start over.

The aluminum bar and the thermometers must be submerged in the water.

Students are not asked to record time, but it is an interesting side observation and discussion to consider.

You may wish to assign the volumes of water students use to prevent a clustering of points on the graph.

There should be a minimum of 30 points graphed. There will be one cluster of points since all students do the 75 mL warm and 75 mL cool.

Data and Observations

Student data will vary with the amount of water and initial temperatures. In every case, the warmer water should cool (-ΔT), and the cooler water should warm (+ΔT).

Energy Transfer Data

Trial	**Cup A** Mass of Water (g)	**Cup A** Initial Temperature (°C)	**Cup A** Final Temperature (°C)	**Cup B** Mass of Water (g)	**Cup B** Initial Temperature (°C)	**Cup B** Final Temperature (°C)
1						
2						
3						
4						

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Energy Transfer Class Data

Trial	**Cup A** Mass of Water (g)	**Cup A** Initial Temperature (°C)	**Cup A** Final Temperature (°C)	**Cup B** Mass of Water (g)	**Cup B** Initial Temperature (°C)	**Cup B** Final Temperature (°C)
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Energy Transfer Class Data

Trial	**Cup A** Mass of Water (g)	**Cup A** Initial Temperature (°C)	**Cup A** Final Temperature (°C)	**Cup B** Mass of Water (g)	**Cup B** Initial Temperature (°C)	**Cup B** Final Temperature (°C)
30						
31						
32						
33						

Record all calculations in a table.

1. Using the **class data table,** calculate the change in temperature **(ΔT)** for cups A and B. **ΔT** is calculated $T_{final} - T_{initial}$. One cup will have a **−ΔT**.

   Be certain there are at least 30 data points in the class data table. Actual student data will vary.

2. Using class data and the **ΔT** calculations from above, calculate the ratio of $\Delta T_A : \Delta T_B$ for every trial. Record the ratio as a decimal number rounded to the tenths place.

   Actual student data will vary.

3. Using class data, calculate the ratio of $Mass_A$: $Mass_B$ for every trial. Round to the tenths place.

   Actual student data will vary.

4. Graph the ratio of masses to the ratio of temperature change.

5. Draw the line of best fit and calculate the slope of the line.

   The line of best fit should be a straight line with an origin of 0,0.

6. The line should go through 0,0. Determine the equation for the line. Remember that you graphed **ratios**.

   Use the format Y = mX + b

   $Y = \Delta T_A / \Delta T_B$

   $X = M_A / M_B$

   Slope = ~1

   b = 0

   $-\Delta T_A/\Delta T_B = 1(M_A/M_B) + 0$ or $-\Delta T_A/\Delta T_B = M_A/M_B$

7. Rewrite and interpret the equation of the line so data from cup A is on one side of the equal sign and data from cup B is on the other side. Remember that you graphed ratios. This is the mathematical model.

   $-\Delta T_A/M_A = \Delta T_B / M_B$

   This equation shows that the ratio of a positive change in temperature to mass is equal to the negative ratio of temperature to mass. This demonstrates the Law of Conservation of Energy by showing that thermal energy gained by substance B (+ΔT), equals thermal energy lost (-ΔT) by substance A.

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Analysis and Discussion

1. How is temperature related to kinetic energy?

   Kinetic energy and temperature are directly related. As kinetic energy of particles increases, temperature increases. The inverse is also true.

2. Use your data to explain how the aluminum bar transfers energy between cups.

   The particles in the higher temperature substance in cup A have more kinetic energy than the particles in the aluminum bar. As the particles collide with the bar, they transfer energy to the bar. Since the particles in substance A are transferring thermal kinetic energy to the bar, substance A cools off.

   Thermal kinetic energy is transferred through collisions between particles in the bar, which makes the temperature of the bar greater than the temperature of the substance in cup B. As particles in substance B collide with the bar, the thermal kinetic energy from the bar is transferred to substance B. This process continues until the Al bar and the substance in both cups A and B, obtain the same temperature, (reach thermal equilibrium).

3. Use your data to explain how the equation in item 7 above relates to the law of conservation of energy.

   Thermal kinetic energy is conserved. The energy "lost" from the substance in cup A was "gained" by the substance in cup B (heat gained = heat lost).

4. How would the mathematical model change if the substances in cups A and B were not the same?

   If the substances in cups A and B were not the same, the slope of the line would probably not be 1. One substance may require more heat energy to change its temperature by 1° C than the other substance. This is the concept of heat capacity. The slope of the line would reflect the ratio of heat capacities of the substances being used.

5. Use the law of conservation of energy and heat transfer to explain the warm seat from the phenomenon.

   The student who sat in the chair before I did transferred some thermal kinetic energy to the cooler chair. Thermal energy travels from warmer to cooler regions, so the chair warmed up until the person and the chair were the same temperature. When I sat down, the chair seat was warmer than I was, so thermal kinetic energy was transferred from the chair to me until the temperatures were the same.

TEACHER NOTES

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