STUDENT ACTIVITY GUIDE

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

The challenge

If you've ever been to the beach on a sunny day in the middle of summer, you've probably experienced how hot the sand feels on your bare feet, even though the water temperature feels cool. Maybe you've had a similar experience walking on the hot concrete of a pool deck on your way to a refreshing swim.

Even though the same sunlight is shining on the water and the sand or concrete, the temperature of the water doesn't rise as much. What causes this difference? What factors affect how much the temperature of a substance changes when a given amount of thermal energy is transferred into or out of it? In this activity, you'll investigate those factors and use your knowledge to develop an explanation.

By the end of this activity, I will be able to…

- collect and analyze data to understand and develop models explaining how heat transfers when two components of different temperatures are combined within a closed system
- collect and analyze 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
- calculate the specific heat capacity of a substance based on heat transfer data
- make predictions about the effects of specific heat capacity on the temperature change of a substance when heat is transferred to or from the substance

Setting the stage

We often say that something in our environment “feels hot” or “feels cold.” These sensations are due to thermal energy transfer between our bodies and our surroundings. In order to understand this process and others related to it, we need to keep in mind some key concepts.

First of all, we should remember that a **system** is a group of components that interests us in a particular scenario. Everything outside the system is designated as the **surroundings**. When considering thermal energy transfer, it is important to define clearly what the system is, so that we can notice if energy is moving into or out of the system.

The **Law of Conservation of Energy** tells us that 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 ______________________________ the energy gained/lost by its surroundings.

When we think about quantifying something in terms of how “hot” or “cold” it is, we often think about its temperature. **Temperature** is a measure of the average (circle one) **kinetic/potential** energy of the particles in a system. This kind of energy is related to the ______________________________ of the particles.

- As particles move faster, their kinetic energy (circle one) **increases/decreases**, and temperature (circle one) **increases/decreases**.
- As particles move more slowly, their kinetic energy (circle one) **increases/decreases**, and temperature (circle one) **increases/decreases**.

Temperature can be measured using a ______________________________ with a scale in units of degrees Celsius.

Thermal energy is the *sum* of the kinetic energy of *all* the particles in a system in units of joules. The thermal energy in a system depends not only on the average kinetic energy of the particles (temperature), but also on the number of particles present. Therefore, a bucket of water at 25 °C will have (circle one) **more/less/the same** thermal energy compared to a swimming pool of water at 25 °C.

Heat is the amount of thermal energy transferred when two systems of *different temperatures* come in contact with each other. A system cannot *have* heat. Systems *transfer* heat when they come into contact with other systems and there is a temperature difference. Components within a system can also transfer heat if they are initially at different ____________________________ when they come into contact.

The direction of heat transfer is always from a component with (circle one) **lower/higher** temperature to a component with (circle one) **lower/higher** temperature. Heat transfer continues until the components reach the same temperature, meaning that the average kinetic energy of the particles is the same in both components. When a system reaches this point where temperature remains constant, we say it is at **thermal equilibrium**. Particles continue to move around and collide, but kinetic energy, on average, is now evenly distributed among the particles, so no net transfer of thermal energy will occur.

Consider a scenario where two components at different temperatures come into contact within a system. Component A has a temperature of 25 °C when it comes into contact with component B, which has a temperature of 150 °C. What do you expect will happen?

Heat will transfer (circle one) **to/from** component A (circle one) **to/from** component B.

As heat transfer occurs:

- the temperature of component A will ____________________________ and
- the temperature of component B will ____________________________ until
- the temperature of component A is ____________________________ the temperature of component B.

The amount of heat transferred when components of different temperatures come in contact depends on several factors, which you will investigate in this activity. The heat transferred to or from a particular component can be calculated using the equation:

$$q = mc\Delta T$$

In this equation, q is the amount of heat transferred (in joules), m is the mass of the component (in grams), c is the specific heat capacity of the component (in J/g °C), and ΔT is the final temperature minus the initial temperature of the component (in °C).

Specific heat capacity is a characteristic property of a substance that represents the amount of thermal energy required to change the temperature of the substance per unit mass.

The sign of q tells us the direction in which heat transfer occurs with respect to our system or a specific component within the system. A negative value of q indicates thermal energy (circle one) **entering/leaving** the component. A positive value of q indicates thermal energy (circle one) **entering/leaving** the component.

Now that you've reviewed some key concepts, let's investigate thermal energy transfer and develop an explanation for why sand on a beach feels so hot, even when the water feels cool.

Let's get started!

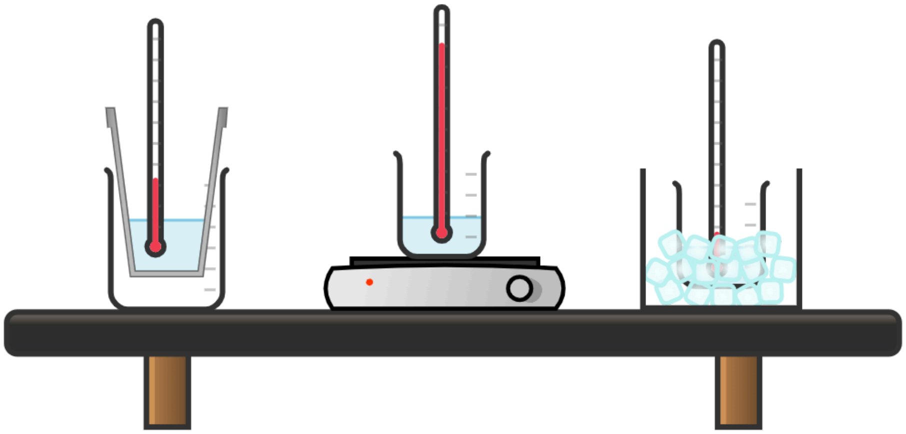
Materials

- Lab notebook or other paper for recording experimental data and responses to *Follow-up questions* (optional, not necessary if completing digitally)
- water
- ice
- 25 g copper (wire, nails, or shot)
- 25 g lead (wire, fishing weights, or shot)
- 25 g glass (marbles or beads)
- 1 Styrofoam cup (Styrofoam is a registered trademark, but any polystyrene foam cup will work)
- 2 beakers-250 mL (or other similar sized heat-resistant containers)
- 1 beaker-500 mL (or other similar sized heat-resistant container)
- 3 extra-large test tubes
- tape/marker for labeling test tubes

- 1 test tube holder
- 1 balance (or kitchen scale)
- 1 weighboat (or small container for measuring mass on the balance)
- 2 thermometers
- 1 hotplate
- 1 heat-resistant mitt
- 1 insulated pad
- 1 strainer

Investigation (Part 1): Heat transfer between water samples

In this experiment, you will combine water samples at different temperatures and observe how heat transfers between the components of a system. The diagram below shows water at room temperature in a Styrofoam cup, water being heated on a hotplate, and water in an ice bath.



Experimental procedure:

1. Place a Styrofoam cup on the balance and zero it. Add water to the cup until the mass reads ~25 g. Record the mass of the water in the cup to the nearest tenth of a gram in the data table below.
    - ***Tip:*** Since the density of water is 1 g/mL, it will take approximately 25 mL of water to reach 25 g on the balance.

2. Place the Styrofoam cup inside a medium-sized (250-400 mL) beaker or similar container to prevent it from getting knocked over. Use a thermometer to measure the temperature of the water, and record it in the data table below (initial temperature of water in cup). Leave the thermometer in the cup while you move on to the next steps.
    - ***Tip:*** It may take some time for the water, thermometer, and surroundings to reach thermal equilibrium. After placing the thermometer in the water, wait a few minutes before recording the temperature. Make sure the thermometer is giving a constant reading before recording the value.

3. Place a 250 mL beaker on the balance and zero it. Add water to the beaker until the mass reads ~25 g. Record the mass of the water to the nearest tenth of a gram in the data table below (mass of water heated/cooled).

4. Put the beaker on a hotplate and place a thermometer in the water. Carefully heat the beaker until the water boils and its temperature reaches ~100 °C. Record the temperature of the water to the nearest tenth of a degree in the data table below (initial temperature of water heated/cooled).
    - ***Caution:*** Do not look directly down into the beaker or hold your hand over the beaker while heating the water. Steam coming off the surface may cause burns.

5. Remove the thermometer from the beaker, and turn off the hotplate. One team member should prepare to read the thermometer in the Styrofoam cup, while another team member should get a heat-resistant mitt and insulated pad.
    - ***Caution:*** Hot glassware looks the same as cool glassware. Do not touch the beaker with your bare hands. Always use the heat-resistant mitt.
    - ***Caution:*** Hot glassware may crack if placed directly on a cool surface. Always place hot glassware on an insulated pad when removing it from the hotplate.

6. When everyone is ready, use the heat-resistant mitt to carefully pour the heated water into the Styrofoam cup. Gently stir the water with the thermometer 2-3 times, then watch carefully to see when the temperature stops rising—this will be the thermal equilibrium temperature. Record this value in the data table below as the final

temperature of all water in the cup.

- ***Tip:*** Be sure to keep a close eye on the thermometer as soon as the heated water is added to the cup. The change may occur very quickly, and you want to make sure you don't miss it!

7. When you are done observing and recording the thermal equilibrium temperature for trial #1, carefully pour the water from the cup into the sink, and wipe up any spills. Repeat steps 1-6, but this time, in step 4, heat the water to only ~50 °C. Be sure to record all mass and temperature measurements in the data table below.

8. When you are done observing and recording the thermal equilibrium temperature for trial #2, carefully pour the water from the cup into the sink, and wipe up any spills.

9. To begin trial #3, set up an ice bath by filling a 500 mL beaker halfway with ice and water. Then, repeat steps 1-3. Be sure to record all mass and temperature measurements in the data table below.

10. Once you have massed 25 g of water in the 250 mL beaker, gently place the beaker into the ice bath. Put a thermometer in the beaker and monitor the temperature until it reaches ~0 °C. Record the temperature of the water to the nearest tenth of a degree in the data table below (initial temperature of water heated/cooled).
    - ***Tip:*** The temperature of the water may not reach 0 °C. It is okay to proceed if the temperature is a few degrees above zero. Just make sure you record the actual value from the thermometer in the data table.

11. Remove the thermometer from the beaker. When one team member is prepared to read the thermometer in the Styrofoam cup, carefully remove the beaker from the ice bath, and pour the cooled water into the Styrofoam cup. Gently stir the water with the thermometer 2-3 times, then watch carefully to see when the temperature stops falling—this will be the thermal equilibrium temperature. Record this value in the data table below as the final temperature of all water in the cup.

12. When you are done observing and recording the thermal equilibrium temperature for trial #3, carefully pour the water from the cup into the sink, and wipe up any spills.

Let's make a prediction!

For trial #4, you will heat ~50 g of water to ~100 °C and add it to ~25 g of room temperature water in a Styrofoam cup. How do you predict the thermal equilibrium temperature will compare to trial #1, where you used ~25 g of water at ~100°C? Explain your reasoning.

13. Once you have made your predictions, repeat steps 1-6, but this time, in step 3, measure ~50 g of water in the beaker. Be sure to record all mass and temperature measurements in the data table below.
14. When you are done observing and recording the thermal equilibrium temperature for trial #4, carefully pour the water from the cup into the sink, and wipe up any spills.

Trial #	**1**	**2**	**3**	**4**
Mass of water in cup (g)				
$T_{initial}$ of water in cup (°C)				
Mass of water heated/cooled (g)				
$T_{initial}$ of water heated/cooled (°C)				
T_{final} of all water in cup (°C)				

Follow-up questions (Part 1)

1. If we consider the system to be the water originally in the Styrofoam cup and the water added to the Styrofoam cup, sketch two different models to show how heat transfers between the components in the system when:
    a. water from the hotplate is added
    b. water from the ice bath is added

   Use arrows to show the direction of heat transfer in each scenario.

2. Use your experimental data as evidence to support the models you sketched above.

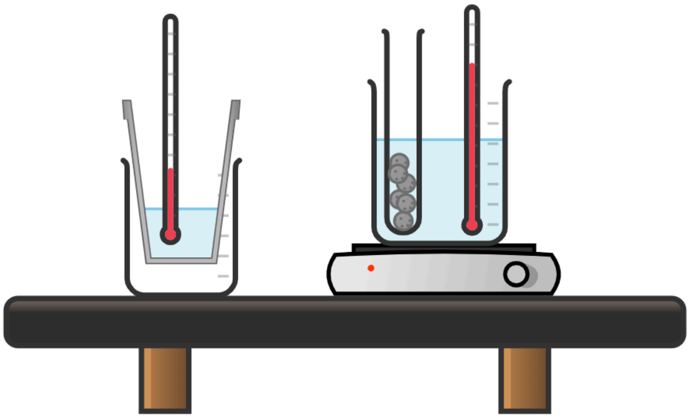
3. What effect did increasing the mass of the heated water have on the amount of heat transferred within the system? Use your experimental data as evidence to support your claim.

4. In addition to mass, what other variable affected the amount of heat transferred within the system? Use your experimental data as evidence to support your claim.

5. You measured the thermal equilibrium temperature of the system when the temperature stopped going up (hot water added) or when it stopped going down (cold water added). What would you expect to happen to the temperature of the system, in either case, if you left the cup of water sitting out on the table for an hour after you finished the experiment? Explain your reasoning with words and diagrams.

Investigation (Part 2): Heat transfer between water and other materials

In this experiment, you will heat different materials to ~100 ° C and observe how heat transfers when each one is added to room temperature water. The diagram below shows water at room temperature in a Styrofoam cup and another material in a test tube being heated in a water bath on a hotplate.



Experimental procedure:

1. Prepare a hot water bath by filling a 500 mL beaker about three-quarters of the way full with water, placing it on a hotplate, and turning on the hotplate to high.
2. Label three extra-large test tubes #1-3.
3. Using a balance and a weightboat, measure ~25 g of copper (Cu) and transfer it to extra-large test tube #1. Record the mass of the copper to the nearest tenth of a gram in the data table below.
4. Repeat step 3 for lead (test tube #2) and glass (test tube #3). Be sure to record the mass of each material to the nearest tenth of a gram in the data table below.
5. Carefully place all three test tubes in the hot water bath so that the materials are fully

submerged. If the water in the beaker does not completely cover all of the materials in the test tubes, carefully add more water to the bath, and continue heating.

6. As in Part 1, place a Styrofoam cup on the balance and zero it. Add water to the cup until the mass reads ~25 g. Record the mass of the water in the cup to the nearest tenth of a gram in the data table below.
7. Place the Styrofoam cup inside a medium-sized (250-400 mL) beaker or similar container to prevent it from getting knocked over. Use a thermometer to measure the temperature of the water, and record it in the data table below (initial temperature of water in cup). Leave the thermometer in the cup while you move on to the next steps.
    - ***Tip:*** It may take some time for the water, thermometer, and surroundings to reach thermal equilibrium. After placing the thermometer in the water, wait a few minutes before recording the temperature. Make sure the thermometer is giving a constant reading before recording the value.
8. When the water in the hot water bath begins to boil, place a thermometer in the bath. Since the test tubes and their contents should be in thermal equilibrium with the water bath, we can record the temperature of the bath as the initial temperature of the materials. Record the water bath temperature to the nearest tenth of a degree in the data table below as the **initial temperature of the copper sample**.
9. One team member should prepare to read the thermometer in the Styrofoam cup, while another team member should get a test tube holder and/or a heat-resistant mitt. When everyone is ready, use the test tube holder (or a heat-resistant mitt) to carefully grasp test tube #1, remove it from the hot water bath, and pour the heated copper into the Styrofoam cup. Gently stir the water with the thermometer 2-3 times, then watch carefully to see when the temperature stops rising—this will be the thermal equilibrium temperature. Record this value in the data table below as the final temperature of the water and material in the cup.
10. When you are done observing and recording the thermal equilibrium temperature for trial #1, carefully pour the water and copper mixture through a strainer over the sink. Transfer the copper to a paper towel to dry, and wipe up any spills.

11. Carry out steps 6-10 using lead (Pb) from test tube #2. Be sure to record all mass and temperature measurements in the data table below.

12. When you are done observing and recording the thermal equilibrium temperature for trial #2, carefully pour the water and lead mixture through a strainer over the sink. Transfer the lead to a paper towel to dry, and wipe up any spills.

13. Carry out steps 6-10 using glass from test tube #3. Be sure to record all mass and temperature measurements in the data table below.

14. When you are done observing and recording the thermal equilibrium temperature for trial #3, carefully pour the water and glass mixture through a strainer over the sink. Transfer the glass to a paper towel to dry, and wipe up any spills.

Trial #	**1**	**2**	**3**
Material	**copper**	**lead**	**glass**
Mass of material (g)			
$T_{initial}$ of material (°C)			
Mass of water in cup (g)			
$T_{initial}$ of water in cup (°C)			
T_{final} of water and material in cup (°C)			

Follow-up questions (Part 2)

1. If we consider the system to be the water originally in the Styrofoam cup and the material added to the water in the cup, sketch a model to show how heat transfers between the components in the system.

2. What variables were kept constant for all three trials in Part 2?

3. Fill in the table below by calculating the change in temperature of each material and the change in temperature of the water in the Styrofoam cup for each trial. List the 4 substances (the three materials and water) in order from the largest change in temperature to the smallest change in temperature.

Trial #	Material	(T_{final} - $T_{initial}$) for material	(T_{final} - $T_{initial}$) for water in cup
1			
2			
3			

Order from ***largest to smallest*** change in temperature:

4. Each substance has a characteristic specific heat capacity. Based on your temperature data and the table of accepted specific heat capacity values below, 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? Use evidence from your experiment to support your claim.

Substance	**Specific heat capacity (J/g °C)**
water (H_2O)	4.184
copper (Cu)	0.384
lead (Pb)	0.127
iron (Fe)	0.449
aluminum (Al)	0.897
glass	0.840
PET plastic	1.030

5. The accepted specific heat capacity values for iron and aluminum are listed in the table above. Imagine that you carried out the same experiment as in Part 2 using these two metals. Refer to your response for question #3—where would you place iron and aluminum in the order from largest to smallest change in temperature? Explain your reasoning.

6. Use your experimental data, the specific heat capacity of water (4.184 J/g °C), and the equation $q = mc\Delta T$ to calculate the amount of heat transferred to the water in the Styrofoam cup when the heated copper was added in trial #1.

7. Does the heat transferred to water (q) have a positive or negative sign? Explain what the sign tells you.

8. Based on your answers above, how much heat was transferred from the copper to the water? Will this q value for copper have a positive or negative sign? Explain your reasoning.

9. Use your experimental data, the q value from question #8, and the equation $q = mc\Delta T$ to calculate the specific heat capacity of copper.

10. Compare the experimental value you calculated for the specific heat capacity of copper to the accepted value given in the table above. Is your value close to the accepted value? What are some sources of error in the design of the experiment that might cause your value to be different from the accepted value?

11. Taking into account the sources of error that you identified above and what you know about effective experimental design, what are some changes you would make to the

procedure and setup in Part 2? What would you do to improve the accuracy of your experimental value for the specific heat capacity of copper?

Keep creating!

We've seen that the specific heat capacity of a material has an impact on the degree to which its temperature changes when a given amount of heat is transferred per unit mass. Use your understanding of this relationship and your model of heat transfer to create a pamphlet you could hand out at the beach. The pamphlet should address the following questions:

- Why does the sand feel so much hotter than the water, even though both are experiencing the same solar radiation on a sunny summer day?
- When your feet come in contact with the sand, what happens, in terms of thermal energy transfer, to cause it to "feel hot?"
- When your feet come in contact with the water, what happens in terms of thermal energy transfer, to cause it to "feel cool?"

Make your pamphlet colorful, engaging, and informative. Brainstorm and research other natural phenomena related to specific heat capacity and/or examples where the specific heat capacity of a material is utilized to address an engineering challenge. Include at least one of these in your pamphlet.

More creative activities!

Below are some ideas for how you can use your creativity and your understanding of heat transfer and specific heat capacity to generate new ideas and solutions.

- In this investigation, you used a Styrofoam cup to carry out each heat transfer experiment in order to limit the "loss" of thermal energy from the system to the surroundings. Styrofoam (or any polystyrene foam) is considered an "insulator," meaning it does not allow thermal energy to transfer readily through the material.

Styrofoam cups are typically used to keep coffee or tea from decreasing in temperature. At the same time, items that need to remain at low temperatures are often packed in Styrofoam containers for shipping. Do some research to learn more about foam insulation, and create a model showing how it works both to keep some things “hot” and to keep other things “cold.”

- The ocean plays an essential role in regulating Earth’s climate by absorbing solar radiation, storing it, and distributing it around the planet. Do some research to learn more about how water’s specific heat capacity allows the ocean to act as a “heat sink,” to moderate regional temperatures, and to slow global warming. Design an interactive exhibit for a science center that can teach other people about what you learned.
- Different building materials, such as brick, concrete, steel, or glass, have different levels of thermal conductivity. Thermal conductivity is a measure of the rate at which materials conduct thermal energy, and it is important in determining the amount of energy needed to maintain comfortable environmental conditions inside a building. Do some research to learn more about thermal conductivity in building materials, then use your knowledge to design an energy efficient building. Create a short slide show or brochure to pitch your design. Be sure to explain how you chose your materials and how they will contribute to the building’s energy efficiency.