Lab Handout

Lab 15. Thermal Energy and Specific Heat

Which Material Has the Greatest Specific Heat?

Introduction

Scientists are able to identify unknown substances based on their chemical and physical properties. A substance is a type of matter with a specific composition and specific properties. One physical property of a substance is the amount of energy it will absorb per unit of mass. This property is called specific heat (s). Specific heat is the amount of energy, measured in joules, that is needed to raise the temperature of 1 gram of the substance 1 degree Celsius. Scientists often need to know the specific heat of different substances when they attempt to track how energy moves into, out of, and within a system.

Chemists use a technique called calorimetry to determine the specific heat of a substance. Calorimetry, or the measurement of heat transfer, is based on the law of conservation of energy. This law states that energy is not created nor destroyed; it is only converted from one form to another. This fundamental law serves as the foundation for all the research that is done in the field of thermodynamics, which is the study of heat, temperature, and heat transfer. Heat is defined as the total kinetic energy of all the atoms or molecules that make up a substance. Temperature, in contrast, is defined as a measure of the average kinetic energy of the atoms or molecules that make up a substance.

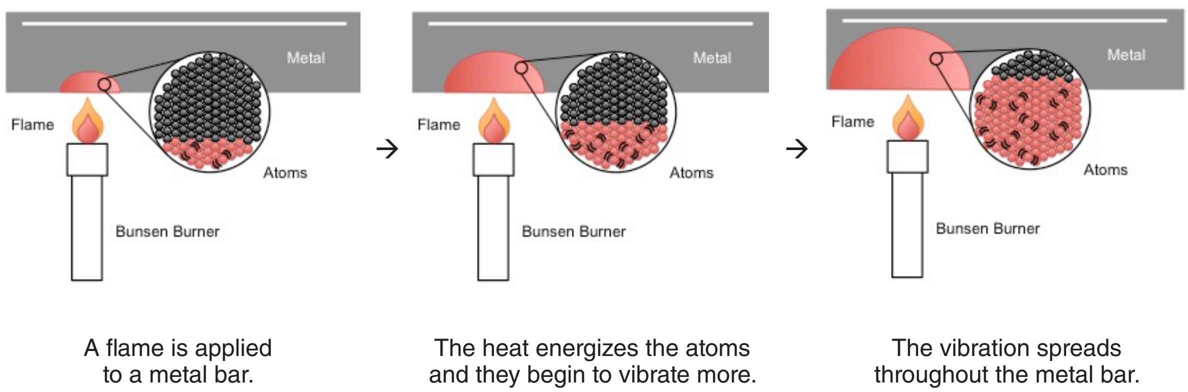
Heat, or thermal energy, can be transferred through a substance and between two different objects. Scientists call this process conduction (see Figure L15.1). The transfer of heat energy through the process of conduction can be explained by thinking of the heat from a source causing the atoms of a substance to vibrate faster, which means they have greater kinetic energy. These atoms then cause the atoms next to them to vibrate faster by bumping into them, which means that the kinetic energy of the neighboring atoms increases as well. Over time, kinetic energy is transferred from one atom to the next. As more atoms in the substance gain kinetic energy over time, the temperature of the substance increases. This process is also how heat energy is able to transfer between two different objects that are in contact with each other.

The amount of heat (q) transferred to an object depends on three factors. The first is the mass (m) of the object. The second factor is the specific heat (s) value of object. This is important because an object will consist of a specific type of substance, and each type of substance has a unique specific heat value. The third factor is the resulting temperature change (ΔT). The mathematical relationship between these three factors and the amount of heat transferred to an object is

$$q = m \times s \times \Delta T$$

FIGURE L15.1

Thermal energy can transfer through a substance or from one substance to another by conduction.



The materials that people use to build a new structure or to manufacture commercial goods have a wide range of specific heat values. Take concrete and wood as an example. Both of these materials can be used to build benches in parks or at bus stops for people to use. Wood, however, has a much higher specific heat than concrete. It therefore takes more heat energy to increase the temperature of a 10 kg piece of wood than it does to increase the temperature of a 10 kg piece of concrete. The piece of concrete, as a result, will get hotter faster than the piece of wood when it is exposed to the same amount of heat energy. This issue could be a potential problem in cities that tend to be hot and sunny most of the year. Engineers and manufacturers therefore need to know how to look up or determine the specific heat value of a potential building or manufacturing material before they decide to use it. In this investigation, you will have an opportunity to learn how to determine the specific heat value of a material using the process of calorimetry.

Your Task

Use what you know about heat, temperature, the conservation of energy, and defining systems to design and carry out an investigation to determine the specific heat values of several different materials.

The guiding question of this investigation is, **Which material has the greatest specific heat?**

Materials

You may use any of the following materials during your investigation:

Samples
- Aluminum (Al)
- Copper (Cu)
- Tin (Sn)
- Zinc (Zn)
- Glass
- Plastic
- Wood

Consumables
- Water (in squirt bottle)

Equipment
- Graduated cylinder (100 ml)
- 2 Beakers (each 250 ml)
- 2 Polystyrene cups
- Ring clamp and support stand
- Thermometer or temperature probe
- Hot plate
- Electronic or triple beam balance
- Tongs
- Stirring rod
- Safety glasses or goggles
- Chemical-resistant apron
- Nonlatex gloves

Safety Precautions

Follow all normal lab safety rules. In addition, take the following safety precautions:

1. Wear sanitized indirectly vented chemical-splash goggles and chemical-resistant nonlatex gloves and aprons during lab setup, hands-on activity, and takedown.
2. Use caution when working with hot plates, because they can burn skin and cause fires.
3. Hot plates also need to be kept away from water and other liquids.
4. Use only GFCI-protected electrical receptacles for hot plates.
5. Clean up any spilled liquid immediately to avoid a slip or fall hazard.
6. Handle all glassware with care.
7. Handle glass thermometers with care. They are fragile and can break, causing a sharp hazard that can cut or puncture skin.
8. Wash hands with soap and water after completing the lab activity.

Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

To calculate the specific heat of a material, you will need to determine how much energy the material is able to transfer to a sample of water using a calorimeter. A calorimeter is used to prevent heat loss to the surroundings (see Figure L15.2). The heat gained by the water in a calorimeter is therefore equal in magnitude (but opposite in sign) to the heat lost by the material:

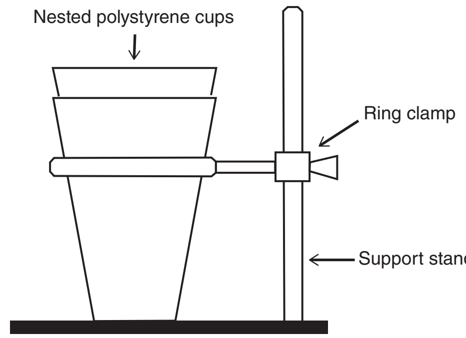
$$q_{water} = -q_{material}$$

The amount of heat gained by the water is calculated using the mass of water used, the specific heat of water (4.18 J/g•°C), and the difference between the final and initial temperature of the water in the calorimeter. The amount of water used for calorimetry varies, but most people use between 10 and 50 ml because water has such a high specific heat. The equation for calculating the amount of heat gained by the water is

$$q_{\text{water}} = m_{\text{water}} \times s_{\text{water}} \times \Delta T_{\text{water}}$$

FIGURE L15.2

A basic calorimeter



The amount of heat lost by a material once it is added to the water is calculated using the mass of the material, the specific heat of that material, and the difference between the material's final temperature and its initial temperature. The final temperature of the material is assumed to be the same as the final temperature of the water in the cup. The initial temperature of the material will be 100°C. To ensure that the initial temperature of the material will be 100°C before you add it to the water in the calorimeter, you can place the material in a boiling-water bath for 10–15 minutes. The equation for calculating the amount of heat lost by a metal is

$$-q_{metal} = m_{\text{material}} \times s_{\text{material}} \times \Delta T_{material}$$

Now that you understand the basics of calorimetry, you must determine what data you need to collect, how you will collect it, and how you will analyze it in order to answer the guiding question.

To determine *what data you will need to collect,* think about the following questions:

- How will you know how much thermal energy has been transferred from a material to the water in a calorimeter?
- What information do you need to calculate the specific heat of material once you know how much thermal energy has been transferred from a material to the water in a calorimeter?

To determine *how you will collect your data,* think about the following questions:

- What equipment will you need to collect the data you need?
- How will you make sure that your data are of high quality (i.e., how will you reduce error)?
- How will you keep track of the data you collect?
- How will you organize your data?

To determine *how you will analyze your data,* think about the following questions:

- What type of calculations will you need to make?
- What type of graph could you create to help make sense of your data?

Connections to Crosscutting Concepts, the Nature of Science, and the Nature of Scientific Inquiry

As you work through your investigation, be sure to think about

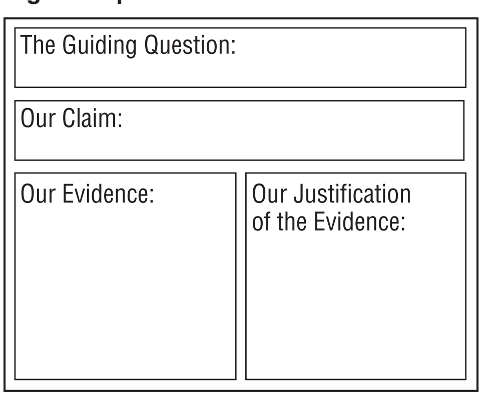
- the importance of defining a system under study;
- how scientists often need track how energy moves into, out of, and within a system;
- the difference between observations and inferences in science; and
- how scientists use different methods to answer different types of questions.

Initial Argument

Once your group has finished collecting and analyzing your data, your group will need to develop an initial argument. Your initial argument needs to include a *claim*, *evidence* to support your claim, and a *justification* of the evidence. The claim is your group's answer to the guiding question. The evidence is an analysis and interpretation of your data. Finally, the justification of the evidence is why your group thinks the evidence matters. The justification of the evidence is important because scientists can use different kinds of evidence to support their claims. Your group will create your initial argument on a whiteboard. Your whiteboard should include all the information shown in Figure L15.3.

FIGURE L15.3

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One member of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the arguments developed by their classmates. This is similar to how scientists present their arguments to other scientists at conferences. If you are responsible for critiquing your classmates' arguments, your goal is to look for mistakes so these mistakes can be fixed and they can make their argument better. The argumentation session is also a good time to think about ways you can make your initial argument better. Scientists must share and critique arguments like this to develop new ideas.

To critique an argument, you might need more information than what is included on the whiteboard. You will therefore need to ask the presenter lots of questions. Here are some good questions to ask:

- How did you collect your data? Why did you use that method? Why did you collect those data?
- What did you do to make sure the data you collected are reliable? What did you do to decrease measurement error?
- How did your group analyze the data? Why did you decide to do it that way? Did you check your calculations?
- Is that the only way to interpret the results of your analysis? How do you know that your interpretation of your analysis is appropriate?
- Why did your group decide to present your evidence in that way?
- What other claims did your group discuss before you decided on that one? Why did your group abandon those alternative ideas?
- How confident are you that your claim is valid? What could you do to increase your confidence?

Once the argumentation session is complete, you will have a chance to meet with your group and revise your initial argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the most acceptable and valid answer to the research question!

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections. Each section should provide an answer to the following questions:

1. What question were you trying to answer and why?
2. What did you do to answer your question and why?
3. What is your argument?

Your report should answer these questions in two pages or less. This report must be typed, and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable and valid!