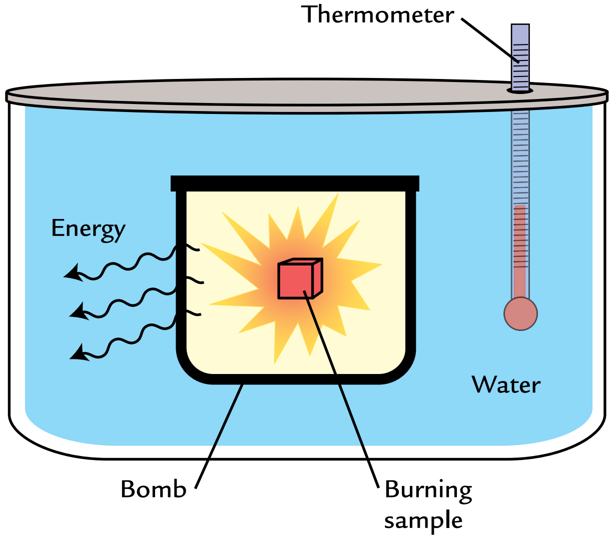
63 Measuring Calories

Scientists use a device called a **calorimeter**, as shown below, to measure the amount of chemical potential energy there is in all sorts of materials. To determine the chemical energy of a material, scientists first measure the mass of a sample of the material. Then they place the sample in a sealed container called a bomb. They put the bomb in a well-insulated container filled with a known volume of water. An electrical spark from inside the bomb starts the sample burning. The water in the container absorbs the energy released by the burned sample. A thermometer measures the change in the temperature of the water. The potential energy of the original material is equal to the thermal energy transferred to the water.

In this activity, you will use a simple calorimeter to measure the amount of stored energy in a nut. When you eat a nut, or any other food, the potential chemical energy in it is released and used by your body. A calorimeter can determine the amount of stored energy in the nut, measured in calories. A **calorie** is the energy unit you explored in Activity 62, "Quantifying Energy"—it is the energy required to raise the temperature of one gram of water by 1°C. When describing the energy available in food, such as with the nut, the unit Calorie is used. A **Calorie**, with a capital C, is 1,000 calories.

CHALLENGE **How many Calories are in a nut?**



A CALORIMETER

MATERIALS

For each group of four students

- 1 wire coat hanger, wrapped with aluminum foil
- 1 aluminum beverage can
- 1 nut
- 1 SEPUP fuel holder
- 1 50-mL graduated container
- 1 glass thermometer
- wooden matches or lighter
- 1 cup of water
- tongs or potholder

For each student

- 1 pair of safety goggles
- 1 Student Sheet 53.1, "Anticipation Guide: Ideas About Energy," from Activity 53, "Home Energy Use"

SAFETY

Be sure to wear safety goggles during this investigation. Long hair must be tied back, and loose sleeves rolled up. If anything besides the nut starts to burn, inform your teacher immediately. **Be especially careful not to get clothing or your hair near the flame.** Make sure to keep a cup of water close by the experiment as a fire-safety precaution.

Notify your teacher if you are allergic to nuts.

The can may become quite hot. Carefully follow all instructions from your teacher.

PROCEDURE

1. Carefully place the nut on the fuel holder.
2. Pour 100 mL of water into the can.
3. Set up your calorimeter with the can hanging from the bent coat hangar as shown on the next page. Position the bottom of the can so it will be in the flame of the burning nut, but not so low that it will put out the flame.

THE CALORIMETER APPARATUS.

4. Just before lighting the nut, record the starting temperature of the water.
5. Light the nut. When it begins to burn, slide it under the can, and let it burn completely. If you think the nut stopped burning before all its energy was transformed, ask your teacher for advice on relighting it.
6. As soon as the nut stops burning, use the thermometer to stir the water gently inside the can, and record its final temperature.
7. Calculate the change in the water temperature, and record it in your science notebook.
8. Calculate, in calories, the amount of heat energy the water gained, by using this formula:

$$\textbf{energy released (calories)} = \begin{array}{c}\textbf{temperature change}\\ \textbf{of water (°C)}\end{array} \times \begin{array}{c}\textbf{mass of}\\ \textbf{water (g)}\end{array}$$

Hint: 1 mL of water weighs 1 gram.

9. There are 1,000 calories in 1 Calorie. Determine how many Calories were in the nut, and record it in your science notebook.

ANALYSIS

1. How many Calories were in your nut? Show your calculation.
2. Explain, in terms of energy transfer and transformation, what caused the temperature of the water to change.
3. Was all of the energy from the burning nut transferred to the water? If not, explain what happened to the energy that was not transferred to the water.
4. How would you improve the design of this calorimeter so that it would work better?
   - **a.** Draw a detailed, labeled diagram of your improved calorimeter. Be sure that you could build it yourself, if you had the materials.
   - **b.** Explain why your design is better than the one you used.
5. If you burned a puffed cheese snack of the same size as the nut, would you get the same result? Why or why not?

6. A curious student wanted to know if the calorimeter would work with different amounts of water. The table below shows the results from her burning three nuts of the same type and mass, but using varied amounts of water in the can. Explain from the table below whether the calorimeter measured the energy in the nut properly when used with each amount of water.

EXTENSION

With your teacher's permission, measure the temperature change caused by burning a marshmallow or a puffed cheese snack.

Nut Experiment Data

Experiment	Mass of Water (g)	Temperature Change (°C)
Nut 1	200	19
Nut 2	100	39
Nut 3	50	77

Food nutrition labels are required to show information about the energy in the food, measured in Calories.

Measuring Calories

63

2-3
40- to 50-minute sessions

ACTIVITY OVERVIEW

In this activity, students use water in a calorimeter to capture the energy released from a burning nut. The calorie and Calorie are formally introduced, and students become familiar with the potential energy of various foods and materials. They then apply their understanding of heat transfer to analyzing and improving the design of the calorimeter used in their nut burning experiment.

KEY CONCEPTS AND PROCESS SKILLS

(with correlation to NSE 5–8 Content Standards)

1. Energy is associated with heat, light, electricity, mechanical motion, sound, nuclei, and the nature of a chemical. (PhysSci: 3)
2. Energy is transferred in many ways. (PhysSci: 3)
3. Heat moves in predictable ways. (PhysSci: 3)
4. One way to gather data is through observations. Accurate and complete observations are important to making conclusions about the natural world. (Inquiry: 1)
5. Students use appropriate tools and techniques to gather, analyze, and interpret data. (Inquiry: 1)

KEY VOCABULARY

calorimeter

calorie

Calorie

endothermic

exothermic

MATERIALS AND ADVANCE PREPARATION

For the teacher

	1	Scoring Guide: Analyzing Data (AD)
	1	Transparency 63.1, "Sample Energy Values"
	1	250-mL bottle of luminol solution
	1	250-mL bottle of luminol activator
	1	50-mL graduated cylinder
*	2	100-mL beakers, or other small identical containers
*	1	250-mL beaker, or other larger container
*	1	overhead projector

For each group of four students

	1	SEPUP fuel holder
	1	50-mL graduated cylinder
	1	glass thermometer
*	1	nut, removed from shell
*	1	wire coat hanger, wrapped with aluminum foil
*	1	aluminum beverage can
*	1	cup of water
*		wooden matches or a log lighter
*		tongs or potholder
*		ring stand (optional)
*		clamp (optional)

For each student

	1	pair of safety goggles
	1	Student Sheet 53.1, "Anticipation Guide: Ideas About Energy," from Activity 53, "Home Energy Use"
	1	Scoring Guide: Analyzing Data (AD) (optional)

**Not supplied in kit*

Refer to the photo in the Student Book to make the calorimeters from coat hangers and aluminum foil. First, bend the hangers to make a stand to hold an aluminum soda can. It is not necessary to disassemble the coat hanger, just bend its two "arms" toward each other so that the hanger forms a pyramid. Bend the end of the hook part downward so that it forms a "u" to hold the can. Stretch the hangers to a height tall enough that they will hold a soda can about an inch above the nut. The nut should be set on a nut holder as shown in the Student Book. A ring stand and clamp can be substituted for the wire hanger stands, but are not included in the kit. Once the stand is set up, wrap aluminum foil around the base and backside of the coat-hanger device to make a shield that helps reflect the heat back to the can. These can easily be stored by stacking them in a row.

You may want to experiment ahead of time with lighting a nut. Getting good technique in advance will help you help students who are having trouble with ignition. Wooden matches or log lighters work well. Paper matches do not stay burning long enough to ignite the nut. Make sure to provide each group with a cup of water as a fire safety precaution.

If you have 100 mL graduated cylinders, you may want to replace the 50-mL cylinders provided in the kit so that it is easier to measure the water at the end of the experiment.

Review the demonstrations in the Teaching Suggestions and set up the materials you will need.

Masters for Scoring Guides are in Teacher Resources III: Assessment.

SAFETY

If any students have allergies to nuts, they should be excused from participating in this activity and should not remain in the room. Alternatively, you can have students determine the calories in a mini-marshmallow, puffed cheese snack, or potato chip.

Students should use safety eyewear during this investigation. Make sure those with long hair have tied it back. Students need to be especially careful not to get their clothing or hair near the flame.

Be sure you have adequate ventilation. Some classrooms have smoke detectors that will be set off during this experiment. If this is the case, find another location where students can do the experiments safely. There are several tools you can have on hand to extinguish unwanted flames, including the cup of water provided to each group. If you have metal bowls that can cover the SEPUP nut holder, demonstrate their use, and place several of these around the classroom. Be sure you know your school's policy on the use of fire extinguishers and how to handle a fire if one gets beyond the control of these simple steps.

TEACHING SUMMARY

Getting Started

1. Demonstrate chemical reactions that result in energy transformations.
2. Introduce the calorimetry experiment.

Doing the Activity

3. Students conduct the calorimetry experiment on a nut.

Follow-Up

4. (AD ASSESSMENT) Students calculate the energy released from the nut.
5. (LITERACY) Students revisit the Anticipation Guide from an earlier activity.

REFERENCES

U.S. Dept. of Agriculture, Agricultural Research Service. (2007). Nutrient Data Laboratory. Retrieved May, 2007, from www.nal.usda.gov/fnic/foodcomp/search.

Environmental Software and Services, Air Pollution and Environmental Impact Assessment. (2007). *Caloric Values.* Retrieved May, 2007, from www.ess.co.at/AIR-EIA/calories.html.

TEACHING SUGGESTIONS

GETTING STARTED

1. Demonstrate chemical reactions that result in energy transformations.

Demonstrate a chemical reaction that produces light. Using a graduated cylinder, add 5 mL of luminol solution to 15 mL of luminol-activator. As these two chemicals interact, light is released. For best results, make the classroom as dark as possible. Students may be familiar with light sticks, which involve a similar reaction.

Teacher's Note: The ratio of luminol solution to luminol activator determines the intensity and the duration of the blue light produced. The 1:3 ratio suggested here produces a relatively bright light of short duration. Using more luminol solution and less activator produces a dimmer blue light of longer duration.

Ask students, ***Where did the light energy come from?*** Listen to their suggestions, which are likely to refer to their observations that something happened that released energy when the substances combined. The initial energy came from potential energy in the two reactants. Explain that the release of energy (in this case, light) is a sign of a chemical change or interaction in the graduated cylinder.

Contrast this interaction with the melted ice in Activity 62, "Quantifying Energy." Although energy was transferred in that activity, it was a physical instead of a chemical change because ice and liquid water are the same chemical, H_2O. Tell the class that chemical reactions and changes result in specific kinds of energy transformations. In a chemical reaction, new substances with different properties and molecular structures form, and energy is released or absorbed during the reaction. A reaction that absorbs energy is called **endothermic**, and a reaction that releases energy is called **exothermic**. When many common substances react with oxygen and are oxidized, they release some of their stored chemical potential energy in the form of heat and light. Oxidation of food is called respiration; oxidation of fuels is called combustion (or burning), oxidation of metal is called rusting. In this activity, students will burn a nut and measure the energy released from the exothermic reaction.

Have students suggest other chemical changes that release energy, and list them on the board. They may not come up with very many at this point, but save their list and add to it as they think of more examples as the do the activity. Other examples they may think of are the reactions in fireworks, combustion of fuels, or cellular respiration.

2. Introduce the calorimetry experiment.

Hold up a nut. Ask if the nut has any potential energy (other than its gravitational potential energy from being held up in the air). Students may indicate that because it is food, it has energy available for people. They should be able to identify that the nut has potential chemical energy. Ask, ***How can we release and measure this stored energy from the nut?*** The answer is to burn it and measure the energy released. The types of energy that are released when the nut is burned are thermal, light, and a small amount of sound.

Some students may observe that the reaction requires energy because you need a match to get it started. However, once students see how long the nut burns, they should be convinced that the reaction releases far more energy than is needed to get it started. That makes the reaction overall exothermic, not endothermic. You may also wish to use the analogy of a ball that is sitting along a cliff, but not quite at the edge. It will take a little energy to get the ball to the edge of the cliff, but then far more energy will be released as the ball falls to the bottom of the cliff. The overall result is a release of energy, as in burning the nut. The ball, due to its position, has potential gravitational energy, and the nut, due to its molecular structure, has chemical energy that can be released.

Have students read the introduction, and review with them the basic principals of the **calorimeter** as they look at the diagram of the calorimeter in the Student Book. Introduce the term **calorie** as the amount of heat energy required to raise one gram of water 1°C. Make sure they understand that they had experience with that unit of measurement in Activity 62, “Quantifying Energy,” albeit without using the term. Let students know that in this activity, by burning a nut they will calculate the energy released in the same manner they calculated energy from melting ice in the last activity.

Introduce the term **Calorie** with a capital C as equivalent to 1,000 calories. Point out that dieticians adopted it because the calorie is such a small amount of energy. For example, a can of soda contains about 150 Calories, which is much easier to write and calculate with than is 150,000 calories. Scientists refer to Calories only in the context of food analysis. In all other situations, 1,000 calories is called a kilocalorie. Emphasize to students that when they read the side of a food package to see how many Calories per serving are in it, it is identifying exactly how much potential energy is in it. This measurement is often determined using a calorimeter. Calories can come in many types of chemicals; fats, proteins, and carbohydrates are the most common. Our bodies use the chemical process called respiration to release the potential energy in food. This energy keeps our heart beating, our lungs breathing, our muscles moving us around, our nerves reacting, and our brains thinking.

■ DOING THE ACTIVITY

3. Students conduct the calorimetry experiment on a nut.

Before students begin the Procedure, review the safety issues related to this activity, adding any of your personal or school-safety policies for fire. Review the safety note in the Student Book, and see that students have properly secured any bulky clothes, loose sleeves and shirt cuffs, and long hair. Warn them that the aluminum can will become quite hot during the experiment. They must use the tongs or potholders provided to handle the cans safely.

Distribute the calorimetry apparatus, and show students how to set it up properly. Discuss the purpose of each part of the apparatus. Discuss the function of the foil. Students may be able to deduce that the foil helps minimize the escape of energy to the surrounding environment for a more efficient transfer of energy from the nut to the water.

Have students conduct the activity as described in the Procedure. Some students will have trouble getting the nut to stay lit, or will need to relight a nut that extinguishes before it is completely burned. Tips to get the nut to light include:

- Have a thin edge or point of the nut pointing down.
- Hold the match to the thinnest part of the nut.
- Make sure there are no drafts blowing on the match.
- Hold the match below the nut so the top of the flame completely touches it.

■ FOLLOW-UP

4. (AD Assessment) Students calculate the energy released from the nut.

Temperature change results will vary. Students' measurements are typically in the 35–45˚C range, giving a 3.5–4.5 Calorie range, significantly lower than accepted value of 5.5 Calories. Students' values tend to be lower because much of the chemical energy stored in the nut is not transferred to the water. Ask students, ***What can account for the lower value in your result?*** Students often attribute the “heat loss” to energy transfer from the flame to the air or foil instead of the can, or enegy transfer from the can to the air. They might also point out nuts that did not burn completely.

When reviewing the Analysis Questions, you may want to ask students to briefly present their designs from Analysis Question 4 to the class. If you plan to let students design and build their own calorimeters as an extension to the question, be sure to examine them carefully for any safety problems before students try them.

✓Analysis Question 5 asks students to show understanding of one of the basic ideas of calorimetry. Calorimetry only makes sense if students know that different materials have different amounts of potential energy. Display Transparency 63.1, "Sample Energy Values," to emphasize this point. Students may notice that the caloric values for some food items are lower than they might expect. For example, spaghetti is 1.6 Calories/gram when the standard carbohydrate value is about 4 Calories/gram. Likewise, the nuts in the experiment are lower in Calories than the pure fat value of about 9 Calories/gram. This is because the water and fiber that make up a significant portion of many foods we eat are not metabolized and are not counted in caloric value

Analysis Question 6 is designed to be assessed using the ANALYZING DATA (AD) Scoring Guide. The question provides students an opportunity to apply the calorimetry equation from the last two activities to some lab results generated elsewhere. If appropriate, give each student a copy of the AD Scoring Guide. Let students know how you will give them feedback on their work. For more information on the SEPUP Assessment System and Scoring Guides, see Teacher Resources III: Assessment.

5. **(LITERACY) Students revisit the Anticipation Guide from an earlier activity.**

Conclude the activity by revisiting Questions 6–7 on Student Sheet 53.1, "Anticipation Guide: Ideas About Energy." Have students complete the After column for those two questions. Correct responses are shown below.

■ EXTENSION

The caloric content of other snack items will vary depending on the size. Students' results should be lower than these ideal numbers, due to energy loss during heating.

SUGGESTED ANSWERS TO QUESTIONS

1. *How many Calories were in your nut? Show your calculation.*

   Energy released (calories) = temperature change of water (°C) x mass of water (grams)

   = 40°C x 100 g

   = 4,000 calories

   = 4 Calories

2. *Explain, in terms of energy transfer and transformation, what caused the temperature of the water to change.*

   The temperature change was caused by the combustion of the nut, which transformed chemical potential energy into released thermal energy. The process of heating transferred the energy to the water and raised its temperature.

3. *Was all of the energy from the burning nut transferred to the water? If not, explain what happened to the energy that was not transferred to the water.*

   During heating, some of the energy was not transferred to the water and was released into the air and into the soda can. The aluminum foil helped minimize the losses to the environment, but they were still significant.

4. *How would you improve the design of this calorimeter so that it would work better?*

   a. *Draw a detailed, labeled diagram of your improved calorimeter. Be sure that you could build it yourself, if you had the materials.*

   b. *Explain why your design is better than the one you used.*

Answers to Student Sheet 53.1, "Anticipation Guide: Ideas About Energy."

__–__ 6. *Metals are poor conductors of thermal energy and electricity.*

This is false because, by definition, conductors easily transfer thermal energy. Students may also know this is false from the hands-on investigations in this unit.

In upcoming activities students will learn that most materials that are good conductors of heat are also good conductors of electricity.

__–__ 7. *Energy cannot be quantified.*

This is false because energy is measured in many units including the calorie, the joule, and the BTU.

Answers will vary, but should focus on reducing the energy loss to the environment. Some diagrams may resemble the calorimeter diagram in the student book, but be more specific about materials. Materials on the outside of the calorimeter should be as insulating as possible.

5. *If you burned a puffed cheese snack of the same size as the nut, would you get the same result? Why or why not?*

No, the result would not be the same. Each material or food has a different potential energy per mass and will release different amounts of energy when burned. If students have completed the Extension, they may cite the actual energy of the cheese snack for comparison.

6. *(AD ASSESSMENT) A curious student wanted to know if the calorimeter would work using different amounts of water. The table below shows the results from her burning three nuts of the same type and mass, but using varied amounts of water in the can. Explain from the table below if the calorimeter measured the energy in the nut properly when used with different amounts of water.*

Experiment	***Mass of water (g)***	***Temperature change (°C)***
Nut 1	*200*	*19*
Nut 2	*100*	*39*
Nut 3	*50*	*77*

Level 3 Response:

Yes, the calorimeter measured the energy in the nuts properly. When the energy lost for each nut is calculated using the formula used in this activity, the energy amounts of the nuts were 3,800 calories, 3,900 calories, and 3,850 calories, which is approximately the same. These results are consistent with the results we got in class for a real nut burning. The sources of error could be energy lost to the environment or slightly different masses of the original nuts.

Sample Energy Values

Food	Energy value (Cal/g)
canola oil	8.8
nuts	5.5
sugar	3.9
McDonald's french fries	3.4
spaghetti (cooked)	1.6
turkey sandwich	1.6
apple	0.5
milk (fat free)	0.3

Fuel	Energy value (Cal/g)
gasoline	11.0
crude oil	10.8
natural gas (liquefied)	10.5
kerosene	8.7
coal	6.1
wood	3.8
TNT (dynamite)	3.8
charcoal	3.3