

The Great Peanut Problem

Calorimetry



Introduction

All human activity requires “burning” food for energy. How much energy is released when food burns in the body? How is the calorie content of food determined? Let’s investigate the calorie content of different snack foods, such as popcorn, peanuts, marshmallows, and cheese puffs.

Concepts

- Combustion reaction
- Nutritional Calorie
- Calorimetry
- Calorie content of foods

Background

What does it mean to say that we burn food in our bodies? The digestion and metabolism of food converts the chemical constituents of food to carbon dioxide and water. This is the same overall reaction that occurs when organic molecules—such as carbohydrates, proteins, and fats—are burned in the presence of oxygen. The reaction of an organic compound with oxygen to produce carbon dioxide, water, and heat is called a *combustion reaction*. The chemical equation for the most important reaction in our metabolism, the combustion of glucose, is shown in Equation 1.



Within our bodies, the energy released by the combustion of food molecules is converted to heat energy (to maintain our constant body temperature), mechanical energy (to move our muscles), and electrical energy (for nerve transmission). The total amount of energy released by the digestion and metabolism of a particular food is referred to as its *calorie content* and is expressed in units of nutritional Calories (note the uppercase C). A *nutritional Calorie*, abbreviated Cal, is equivalent to a unit of energy called a kilocalorie, or 1000 calories (note the lower case c). One calorie is defined as the amount of heat required to raise the temperature of 1 gram of water by 1 °C. (This is also the definition of the specific heat of water.) The calorie content of most prepared foods is listed on their nutritional information labels.

Nutritionists and food scientists measure the calorie content of food by burning the food in a special device called a calorimeter. *Calorimetry* is the measurement of the amount of heat energy produced in a reaction. Calorimetry experiments are carried out by measuring the temperature change in water that is in contact with or surrounds the reactants and products. (The reactants and products together are referred to as the system, the water as the surroundings.)

In a typical calorimetry experiment, the reaction of a known mass of reactant(s) is carried out either directly in or surrounded by a known quantity of water and the temperature increase or decrease in the water surroundings is measured. The temperature change (ΔT) produced in the water is related to the amount of heat energy (q) absorbed or released by the reaction system according to the following equation:

$$q = m \times s \times \Delta T \quad \text{Equation 2}$$

where m is the mass of water, s is the specific heat of water, and ΔT is the observed temperature change. As mentioned above, the specific heat of water—defined as the amount of heat required to increase the temperature of one gram of water by 1 °C—is equal to 1 cal/g·°C.

Experiment Overview

The purpose of this experiment is to determine the amount of heat energy released when different snack foods burn and identify patterns in the calorie or energy content of snack foods.

Pre-Lab Questions

1. A candy bar has a total mass of 2.5 ounces. In a calorimetry experiment, a 1.0-g sample of this candy bar was burned in a calorimeter surrounded by 1000. g of water. The temperature of the water in contact with the burning candy bar was measured and found to increase from an initial temperature of 21.2 °C to a final temperature of 24.3 °C.
 - a. Calculate the amount of heat in *calories* released when the 1.0-g sample burned.
 - b. Convert the heat in calories to nutritional Calories and divide by the mass of the burned sample in grams to obtain the *energy content* (also called fuel value) in units of Calories per gram.
 - c. Multiply this value by the total number of grams in the candy bar to calculate the total *calorie content* of the candy bar in Calories. *Hint:* Convert the mass in ounces to grams.
2. Consult the nutritional labels on two of your favorite snack foods: Report their total calorie content (total Calories) and calculate their fuel value (Calories per gram).

Materials

Balance, centigram (0.01 g precision)	Matches
Calorimeter and lid*	Snack foods (cheese puffs, peanuts, marshmallows, popcorn, etc.), 2 pieces
Erlenmeyer flask with plastic spill-rim collar, 125-mL	Stirring rod
Food holder (cork) and pin	Thermometer or temperature sensor
Graduated cylinder, 50-mL	Water

*Or “soda-can” calorimeter. See the *Alternative Procedure* section.

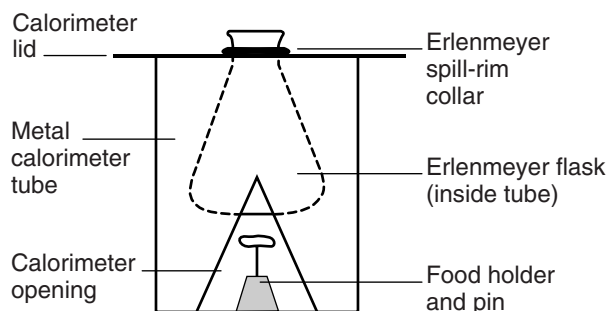
Safety Precautions

Wear safety goggles whenever working with chemicals, glassware, or heat in the laboratory. Exercise care when handling hot glassware and equipment. Allow the burned snack food sample to cool before handling it. The food-grade items that have been brought into the lab are considered laboratory chemicals and are for laboratory use only. Do not taste or ingest any materials in the chemistry laboratory. Wash hands thoroughly with soap and water before leaving the lab.

Procedure

Part A. Setting Up the Calorimeter

1. Place the calorimeter upright so that the triangle opening is at the base.
2. Place the mouth of the Erlenmeyer flask through the hole in the calorimeter lid and slide and snap the plastic spill-rim attachment onto the neck of the Erlenmeyer flask.
3. Place the flask and lid assembly onto the top of the calorimeter so that the flask is centered inside the calorimeter.



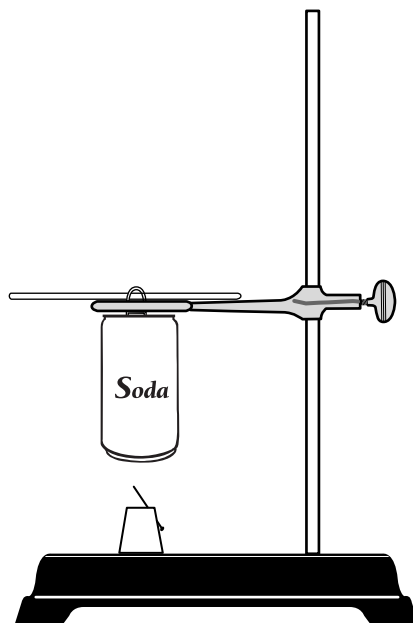
Part B. The Calorimetry Experiment

4. Measure 50.0 mL of water in a graduated cylinder and pour the water into the Erlenmeyer flask in the calorimeter.
5. Measure the temperature of the water with a thermometer or temperature sensor and record the “initial temperature” of water in the Data Table.
6. Obtain a snack food sample and identify the sample (peanuts, popcorn, etc.) in the Data Table.
7. Place the snack food sample on the food holder and measure the combined mass of the sample and the food holder. Record the “initial mass” of the food sample and holder in the Data Table.

- Place the food sample and food holder near the triangle opening in the calorimeter and light the food with a match.
- Quickly slide the food sample and food holder into the base of the calorimeter through the triangle opening. Center the food holder under the Erlenmeyer flask.
- As the food sample burns, gently stir the water in the calorimeter with a stirring rod. *Note:* Use a stirring rod to stir the water in the calorimeter; never stir with a thermometer.
- Allow the water to be heated until the food sample stops burning.
- When the temperature has stabilized, measure the maximum temperature that the water reaches. Record the “final temperature” of the water in the Data Table.
- Measure and record the “final mass” of the food sample and food holder after it cools.
- Clean the food holder to remove any traces of food residue.
- Repeat steps 5–14 with a second food sample.

Alternative Procedure. A “Soda-Can” Calorimeter

- Place a food sample on the food holder. Measure and record the combined mass of the food holder and sample. Place the food holder on a ring stand.
- Obtain a clean, empty soda can. Measure and record its mass.
- Add about 50 mL of tap water to the can and measure the combined mass of the can and water.
- Bend the top tab on the can up and slide a stirring rod through the hole. Suspend the can on a ring stand using a metal ring. Adjust the height of the can so that it is about 2.5 cm above the food holder.
- Insert a thermometer into the can. Measure and record the initial temperature of the water.
- Light the food sample and center it under the soda can. Allow the water to be heated until the food sample stops burning. Record the maximum (final) temperature of the water in the can.
- Measure and record the final mass of the food holder and sample.
- Clean the bottom of the can and remove any food residue from the food holder. Repeat the procedure with a second food sample.



Measuring Calories

Data Table. *The Calorimetry Experiment*

Food Sample	Initial Mass (Food Sample and Holder), g	Final Mass (Food Sample and Holder), g	Initial Temperature (Water), °C	Final Temperature (Water), °C

Post-Lab Calculations and Analysis *(Use a separate sheet of paper to answer the following questions.)*

Construct a *Results Table* to enter all of the following information and summarize the results.

- Determine the mass of water heated in the calorimeter for each food sample.
- Calculate the change in temperature (ΔT) for each sample.
- Use the heat equation (Equation 2) to calculate the heat (q) absorbed by the water in the calorimeter for each food sample. Report the results in *calories*, *kilocalories*, and *nutritional Calories*.
- Subtract the final mass of the food sample and holder from the initial mass to determine the mass in grams of the food sample that burned in each experiment.
- Use the results from Questions #3 and 4 to calculate the energy content (fuel value) of the food sample in units of *Calories per gram* (Cal/g).
- Record your results for the energy content of foods along with those of other groups in the class on the overhead projector or the board. Be sure to record the identity of the food sample.
- Copy all of the results and use the class data to calculate the *average energy content* in units of Cal/g for different types of snack foods. Construct a *Class Results Table* to summarize the results.
- Rank the snack foods in order of their average energy content, from highest to lowest. Which snack food has the highest energy content? The lowest?
- Based on your knowledge of the fat content of different snack foods (if necessary, consult their nutritional labels to obtain this information), make a general statement describing the relative energy content of high-fat versus low-fat snack foods.
- Consider the major sources of error in this experiment. Do you think your results are off on the high side or the low side? Explain.

Teacher's Notes

The Great Peanut Problem

Master Materials List *(for a class of 30 students working in pairs)*

Balance, centigram (0.01 g precision), 3	Matches, 15
Calorimeter and lid, 15*	Snack foods (Cheetos®, marshmallows, peanuts, popcorn, etc.), 30 pieces
Erlenmeyer flask with plastic spill-rim collar, 125-mL, 15*	Stirring rods, glass, 15
Food holder and pin, 15*	Thermometers or temperature sensors, 15
Graduated cylinder, 50-mL, 15	Water

*These items are included in the Economy-choice Calorimeter available from Flinn Scientific (Catalog No. AP4533.)

Safety Precautions

Wear safety goggles whenever working with chemicals, glassware, or heat in the laboratory. Exercise care when handling hot glassware and equipment. Allow the burned snack food sample to cool before handling it. The food-grade items that have been brought into the lab are considered laboratory chemicals and are for laboratory use only. Do not taste or ingest any materials in the chemistry laboratory. Burning different foods may generate a large amount of smoke—perform this experiment in a well-ventilated room. Do not use peanuts in this experiment if any students are allergic to peanuts.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. All of the burned food samples should be allowed to cool and then disposed of in the trash according to Flinn Suggested Disposal Method #26a.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12

- Evidence, models, and explanation
- Constancy, change, and measurement

Content Standards: Grades 9–12

- Content Standard A: Science as Inquiry
- Content Standard B: Physical Science, structure and properties of matter, chemical reactions, interactions of energy and matter
- Content Standard G: History and Nature of Science, nature of scientific knowledge

Lab Hints

- The laboratory work for this experiment can reasonably be completed in one 50-minute lab period. This should be sufficient time for students to perform two trials, either of the same food or different foods. Carrying out the experiment on two samples of the same food is preferred from the point of view of averaging experimental error, but many students will be curious and want to test different foods. Using the class data to calculate the average energy content of different foods should eliminate some of the fluctuations due to random error.
- Wrap the cork food holder in aluminum foil to prevent the cork from burning. Students should practice sliding the food holder and food assembly into the calorimeter. This should be done quickly after the food has been ignited. The food holder assembly should be centered under the flask and remain upright. For best results, pin the food sample at one end so the sample “points up” and the length is parallel to the pin. The food sample does not have to be completely engulfed

in flame before it is placed in the calorimeter. A small flame on the food sample will spread and engulf it over time.

- The food samples burn with a flame only until they turn to charcoal on the outside. Let the samples smolder for a minute or two inside the calorimeter; the temperature of the water will continue to increase after the flame has been extinguished. Measure the maximum temperature of the water inside the calorimeter flask.
- The burning food sample should be close to but not touching the Erlenmeyer flask in the calorimeter. If the food sample is too close to the bottom of the flask, it may extinguish early due to a lack of oxygen. Black soot will deposit on the bottom of the Erlenmeyer flask in the calorimeter when the food sample burns. This should be wiped off with a little water and a paper towel between trials.
- Avoid snack food samples with a high sugar content. These foods get soft as they burn and may fall off of the pin. Different kinds of nuts—walnuts, pecans, almonds, etc.—are also good choices for this experiment.

Teaching Tips

- The “real world” application in this experiment makes it an effective learning exercise for students who tend to lose interest in purely chemically-oriented applications of enthalpy changes and heats of reaction. (The heat of neutralization of hydrochloric acid and sodium hydroxide may not be a pressing issue for many students. Almost all students have thought about and discussed the calorie content of the foods they eat.)
- This experiment also provides an excellent opportunity to discuss chemical potential energy—the energy stored in compounds, including foods, due to their composition and structure. What is the source of the energy released when food burns? Where did that energy originally come from? Why do different types of molecules release different amounts of heat? How is this related to their structure?

Answers to Pre-Lab Questions *(Student answers will vary.)*

1. A candy bar has a total mass of 2.5 ounces. In a calorimetry experiment, a 1.0-g sample of this candy bar was burned in a calorimeter surrounded by 1000. g of water. The temperature of the water in contact with the burning candy bar was measured and found to increase from an initial temperature of 21.2 °C to a final temperature of 24.3 °C.
 - a. Calculate the amount of heat in *calories* released when the 1.0-g sample burned.
 - b. Convert the heat in calories to nutritional Calories and divide by the mass of the burned sample in grams to obtain the *energy content* (also called fuel value) in units of Calories per gram.
 - c. Multiply this value by the total number of grams in the candy bar to calculate the total *calorie content* of the candy bar in Calories. *Hint:* Convert the mass in ounces to grams.

a. Heat (q) = m (g) × s (cal/g·°C) × ΔT

$$m = 1000. \text{ g}; s = 1.0 \text{ cal/g}\cdot\text{°C}; \Delta T = 24.3 - 21.2 = 3.1 \text{ °C}$$

$$q = 1000. \text{ g} \times 1.0 \text{ cal/g}\cdot\text{°C} \times 3.1 \text{ °C} = 3100 \text{ calories per gram of candy}$$

Note to teachers: The most common mistake students will make here is to use the mass of the candy bar sample, rather than the mass of the water surroundings. Remind students that the temperature change is measured for the surroundings.

b.
$$\text{Energy content (fuel value)} = \frac{3100 \text{ calories}}{1.0 \text{ g}} \times \frac{1 \text{ kcal}}{1000 \text{ calories}} \times \frac{1 \text{ Calorie}}{1 \text{ kcal}} = 3.1 \text{ Cal/g}$$

c.
$$\text{Total calorie content} = \frac{3.1 \text{ Calories}}{\text{g}} \times \frac{454 \text{ g}}{\text{pound}} \times \frac{1 \text{ pound}}{16 \text{ oz}} \times 2.5 \text{ oz} = 220 \text{ Calories}$$

- Consult the nutritional labels on two of your favorite snack foods: Report their total calorie content (total Calories) and calculate their fuel value (Calories per gram).

The following nutritional information was obtained for representative snack foods:

Snack Food	Calorie Content (Calories per Serving)	Serving Size (Grams)	Fuel Value (Calories per Gram)
Fudge Cookies	150 Calories	29 g	5.2 Cal/g
Granola Bar	110 Calories	28 g	3.9 Cal/g
Cheese Crackers	190 Calories	39 g	4.9 Cal/g
Krispie Bar	90 Calories	22 g	4.1 Cal/g

Sample Data *(Student data will vary.)*

Data Table. *The Calorimetry Experiment*

Food Sample	Initial Mass (Food Sample and Holder), g	Final Mass (Food Sample and Holder), g	Initial Temperature (Water), °C	Final Temperature (Water), °C
Peanut (1)	3.17	2.88	36.6	53.3
Peanut (2)	3.25	3.05	41.5	52.1
Cheese Puff (1)	3.08	2.62	19.3	35.8
Cheese Puff (2)	2.86	2.64	32.9	41.1
Marshmallow (1)	3.48	3.27	47.6	50.9
Marshmallow (2)	3.09	2.89	50.7	54.2
Popcorn (1)	2.77	2.65	21.7	25.3
Popcorn (2)	2.67	2.58	25.1	28.0

Answers to Post-Lab Calculations and Analysis *(Student answers will vary.)*

To summarize the results, construct a Results Table and enter all of the following information in it.

- Determine the mass of water heated in the calorimeter for each food sample.

The mass of the water surroundings is 50.0 g in each case.

- Calculate the change in temperature (ΔT) for each sample.

Sample calculation for peanuts, Run 1: $\Delta T = T_{\text{final}} - T_{\text{initial}} = 53.3\text{ }^{\circ}\text{C} - 36.6\text{ }^{\circ}\text{C} = 16.7\text{ }^{\circ}\text{C}$.

See the Sample Results Table for all other results.

- Use the heat equation (Equation 2) to calculate the heat (q) absorbed by the water in the calorimeter for each food sample. Report the results in *calories*, *kilocalories*, and *nutritional Calories*.

Sample calculation for peanuts, Run 1: $q = m \times s \times \Delta T = 50.0\text{ g} \times 1.0\text{ cal/g}\cdot^{\circ}\text{C} \times 16.7\text{ }^{\circ}\text{C} = 835\text{ calories}$ (0.835 kilocalories or 0.835 Calories). See the Sample Results Table for all other results.

- Subtract the final mass of the food sample and holder from the initial mass to determine the mass in grams of the food sample that burned in each experiment.

Sample calculation for peanuts, Run 1: Mass of burned food sample = $3.17\text{ g} - 2.88\text{ g} = 0.29\text{ g}$.

See the Sample Results Table for all other results.

The Great Peanut Problem *continued*

5. Use the results from Questions #3 and 4 to calculate the energy content (fuel value) of the food sample in units of *Calories per gram* (Cal/g).

Sample calculation for peanuts, Run 1: Energy content = 0.835 Calories/0.29 g = 2.9 Cal/g.

See the Sample Results Table for all other results. Note to teacher: All results have been rounded to the appropriate number of significant figures.

6. Record your results for the energy content of foods along with those of other groups in the class on the overhead projector or the board. Be sure to record the identity of the food sample.

The following Sample Results Table summarizes representative classroom data.

Snack Food	Mass of Water	Temperature Change	Heat Absorbed	Mass of Burned Food Sample	Energy Content
Peanut (1)	50.0 g	16.7 °C	0.835 Cal	0.29 g	2.9 Cal/g
Peanut (2)	50.0 g	10.6 °C	0.530 Cal	0.20 g	2.7 Cal/g
Cheese Puff (1)	50.0 g	16.5 °C	0.825 Cal	0.46 g	1.8 Cal/g
Cheese Puff (2)	50.0 g	8.2 °C	0.41 Cal	0.22 g	1.9 Cal/g
Marshmallow (1)	50.0 g	3.3 °C	0.17 Cal	0.21 g	0.81 Cal/g
Marshmallow (2)	50.0 g	3.5 °C	0.18 Cal	0.20 g	0.90 Cal/g
Popcorn (1)	50.0 g	3.6 °C	0.18 Cal	0.12 g	1.5 Cal/g
Popcorn (2)	50.0 g	2.9 °C	0.15 Cal	0.09 g	1.7 Cal/g

7. Copy all of the results and use the class data to calculate the *average energy content* in units of Cal/g for different types of snack foods. Construct a *Class Results Table* to summarize the results.

Sample Class Results Table

Snack Food	Average Energy Content
Peanuts	2.8 Cal/g
Cheese Puffs	1.9 Cal/g
Marshmallows	0.85 Cal/g
Popcorn	1.6 Cal/g

8. Rank the snack foods in order of their average energy content, from highest to lowest. Which snack food has the highest energy content? The lowest?

The average energy content ranged from 0.85 Cal/g for marshmallows to 2.8 Cal/g for peanuts. The average energy content of the foods from highest to lowest is:

peanuts > cheese puffs > popcorn > marshmallows

Note to teacher: *The total energy content in Calories per gram for all the foods is lower than the actual energy content listed on their nutritional label information. The relative ranking of the foods, however, from highest energy to lowest energy content, is the same as that predicted based on the information on the nutritional labels.*

9. Based on your knowledge of the fat content of different snack foods (if necessary, consult their nutritional labels to obtain this information), make a general statement describing the relative energy content of high-fat versus low-fat snack foods.

Peanuts and cheese curls are relatively high-fat snack foods (Calories from fat equal 76 and 63%, respectively). Popcorn and marshmallows are low-fat snacks (Calories from fat equal 10 and 0%, respectively). The average energy content of food increases as the percent fat in the food increases. Note to teacher: The amount of fat in popcorn varies a great deal depending on how it was prepared. Packaged snack food popcorn has a higher fat content than freshly popped corn. Hot-air popped corn should contain zero fat.

10. Consider the major sources of error in this experiment. Do you think your results are off on the high side or the low side? Explain.

The results for all the foods appear to be significantly lower than those calculated based on their nutritional label information.

A major source of error in the experiment is heat loss through the calorimeter. The metal calorimeter tube gets very warm throughout the calorimetry experiment, which means that the calorimeter itself, and not just the water, absorbs some of the heat given off by the burning snack food. In addition, the Erlenmeyer flask itself also absorbs a lot of heat. Heat loss through the calorimeter reduces the measured temperature change for the water surroundings, which in turn decreases the calculated value of the heat absorbed by the water. The calculated energy content values in Cal/g are likely to be lower than their actual values as a result.

A second major source of error is incomplete combustion of the food samples. All of the burning food samples produced black soot on the bottom of the Erlenmeyer flask. Also, the food samples burned for only a short time, until they became black and charred and turned to charcoal. The production of carbon means that the food molecules are not being converted to carbon dioxide and water; combustion stops at the carbon stage. This means their calculated energy contents are lower than that predicted for complete combustion. In addition, since the food samples do not burn completely, the calculated calories are not representative of the entire food sample, only of the ingredients that burned fastest.

Other minor sources of error include: (1) inadequate stirring of the water surroundings (measured temperature change is not representative of the entire water volume); and (2) the cork food holder burning during the experiment (calculated heat change includes a contribution from the heat of combustion of the cork).

Reference

This lab was adapted from *Flinn ChemTopic™ Labs, Volume 10, Thermochemistry*, Cesa, I., Ed., Flinn Scientific: Batavia, IL (2004).

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of *The Great Peanut Problem* activity, presented by Bob Lewis, is available in *Calorimetry*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *The Great Peanut Problem* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Calorimeter, Economy Choice Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP4533	Calorimeter, Economy Choice
AP6049	Flinn Digital Pocket Thermometer

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.