

# 36

## Calorimetry Part 2

*Calorimeters are designed to minimize energy exchange between their contents and the external environment. They range from simple coffee cup calorimeters used by introductory chemistry students to sophisticated bomb calorimeters used to determine the energy content of food.*

### 36.1 Bomb Calorimetry

#### Learning Objectives

By the end of this section, you will be able to:

- Understand the function of a bomb calorimeter.

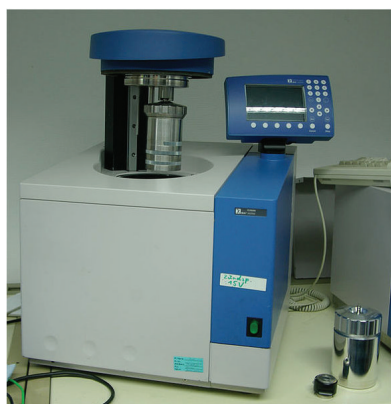
If the amount of heat absorbed by a calorimeter is too large to neglect or if we require more accurate results, then we must take into account the heat absorbed both by the solution and by the calorimeter.

The calorimeters described are designed to operate at constant

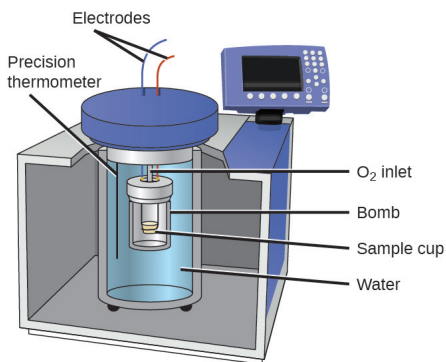
(atmospheric) pressure and are convenient to measure heat flow accompanying processes that occur in solution. A different type of calorimeter that operates at constant volume, colloquially known as a bomb calorimeter, is used to measure the energy produced by reactions that yield large amounts of heat and gaseous products, such as combustion reactions. (The term “bomb” comes from the observation that these reactions can be vigorous enough to resemble explosions that would damage other calorimeters.) This type of calorimeter consists of a robust steel container (the “bomb”) that contains the reactants and is itself submerged in water ([Figure 36.1](#)). The sample is placed in the bomb, which is then filled with oxygen at high pressure. A small electrical spark is used to ignite the sample. The energy produced by the reaction is absorbed by the steel bomb and the surrounding water. The temperature increase is measured and, along with the known heat capacity of the calorimeter, is used to calculate the energy produced by the reaction. Bomb calorimeters require calibration to determine the heat capacity of the calorimeter and ensure accurate results. The calibration is accomplished using a reaction with a known  $q$ , such as a measured quantity of benzoic acid ignited by a spark from a nickel fuse wire that is weighed before and after the reaction. The temperature change produced by the known reaction is used to determine the heat capacity of the calorimeter. The calibration is generally performed each time before the calorimeter is used to gather research data.

Figure 36.1

(a) A bomb calorimeter is used to measure heat produced by reactions involving gaseous reactants or products, such as combustion. (b) The reactants are contained in the gas-tight “bomb,” which is submerged in water and surrounded by insulating materials. (credit a: modification of work by “Harbor1”/Wikimedia commons)



(a)



(b)

## Link to Learning

Watch how a bomb calorimeter is prepared for action.

You can also look at [calorimetric calculations](#) using sample data.

## Example 36.1

### Bomb Calorimetry

When 3.12 g of glucose,  $C_6H_{12}O_6$ , is burned in a bomb calorimeter, the temperature of the calorimeter increases from 23.8 °C to 35.6 °C. The calorimeter contains 775 g of water, and the bomb itself has a heat capacity of 893 J/°C. How much heat was produced by the combustion of the glucose sample?

### Solution

The combustion produces heat that is primarily absorbed by the water and the bomb. (The amounts of heat absorbed by the reaction

products and the unreacted excess oxygen are relatively small and dealing with them is beyond the scope of this text. We will neglect them in our calculations.)

The heat produced by the reaction is absorbed by the water and the bomb:

$$\begin{aligned}q_{\text{rxn}} &= -(q_{\text{water}} + q_{\text{bomb}}) = -[(4.184 \text{ J/g} \\ &^{\circ}\text{C}) \times (775 \text{ g}) \times (35.6^{\circ}\text{C} - 23.8^{\circ}\text{C}) + 893 \text{ J/}^{\circ}\text{C} \times (35.6^{\circ}\text{C} - 23.8^{\circ}\text{C})] \\ &= -(38,300 \text{ J} + 10,500 \text{ J}) = -48,800 \text{ J} = -48.8 \\ \text{kJ} \\ q_{\text{rxn}} &= -(q_{\text{water}} + q_{\text{bomb}}) = -[(4.184 \text{ J/g} \\ &^{\circ}\text{C}) \times (775 \text{ g}) \times (35.6^{\circ}\text{C} - 23.8^{\circ}\text{C}) + 893 \text{ J/}^{\circ}\text{C} \times (35.6^{\circ}\text{C} - 23.8^{\circ}\text{C})] \\ &= -(38,300 \text{ J} + 10,500 \text{ J}) = -48,800 \text{ J} = -48.8 \text{ kJ}\end{aligned}$$

This reaction released 48.7 kJ of heat when 3.12 g of glucose was burned.

### Check Your Learning

When 0.963 g of benzene,  $\text{C}_6\text{H}_6$ , is burned in a bomb calorimeter, the temperature of the calorimeter increases by  $8.39^{\circ}\text{C}$ . The bomb has a heat capacity of  $784 \text{ J/}^{\circ}\text{C}$  and is submerged in 925 mL of water. How much heat was produced by the combustion of the benzene sample?

### Answer

Since the first one was constructed in 1899, 35 calorimeters have been built to measure the heat produced by a living person.<sup>2</sup> These whole-body calorimeters of various designs are large enough to hold an individual human being. More recently, whole-room calorimeters allow for relatively normal activities to be performed, and these calorimeters generate data that more closely reflect the real world. These calorimeters are used to measure the metabolism of individuals under different environmental conditions, different dietary regimes,

and with different health conditions, such as diabetes.

For example Carla Prado's team at University of Alberta undertook whole-body calorimetry to understand the energy expenditures of women who had recently given birth. Studies like this help develop better recommendations and regimens for nutrition, exercise, and general wellbeing during this period of significant physiological change. In humans, metabolism is typically measured in Calories per day. A nutritional calorie (Calorie) is the energy unit used to quantify the amount of energy derived from the metabolism of foods; one Calorie is equal to 1000 calories (1 kcal), the amount of energy needed to heat 1 kg of water by 1 °C.

## Chemistry in Everyday Life

### Measuring Nutritional Calories

In your day-to-day life, you may be more familiar with energy being given in Calories, or nutritional calories, which are used to quantify the amount of energy in foods. One calorie (cal) = exactly 4.184 joules, and one Calorie (note the capitalization) = 1000 cal, or 1 kcal. (This is approximately the amount of energy needed to heat 1 kg of water by 1 °C.)

The macronutrients in food are proteins, carbohydrates, and fats or oils. Proteins provide about 4 Calories per gram, carbohydrates also provide about 4 Calories per gram, and fats and oils provide about 9 Calories/g. Nutritional labels on food packages show the caloric content of one serving of the food, as well as the breakdown into Calories from each of the three macronutrients ([Figure 36.2](#)).

Figure 36.2

(a) Macaroni and cheese contain energy in the form of the

macronutrients in the food. (b) The food's nutritional information is shown on the package label. In the US, the energy content is given in Calories (per serving); the rest of the world usually uses kilojoules. (credit a: modification of work by "Rex Roof"/Flickr)



(a)

Sample label for macaroni & cheese

Nutrition Facts	
Serving Size 1 cup (228g) Servings Per Container 2	
Amount Per Serving	
<b>Calories 250</b>	<b>Calories from Fat 110</b>
% Daily Value*	
<b>Total Fat 12g</b>	18%
Saturated Fat 3g	13%
Trans Fat 3g	
<b>Cholesterol 30mg</b>	10%
<b>Sodium 470mg</b>	20%
<b>Total Carbohydrates 31g</b>	12%
Dietary Fiber 0g	0%
Sugars 5g	
<b>Protein 5g</b>	
*Percent Daily Values are based on a 2,000 calorie diet. Your Daily Values may be higher or lower depending on your calorie needs.	
	Calories 2,000 2,500
Total Fat	Less than 65g 80g
Sat Fat	Less than 20g 25g
Cholesterol	Less than 300mg 300mg
Sodium	Less than 2,400mg 2,400mg
Total Carbohydrate	300g 375g
Dietary Fiber	25g 30g

① Start here  
② Check Calories  
③ Limit these nutrients  
④ Get enough of these nutrients  
⑤ Footnote

⑥ Quick guide to % DV  
• 5% or less is low  
• 20% or more is high

(b)

For the example shown in (b), the total energy per 228-g portion is calculated by:

$$(5\text{g protein} \times 4\text{Calories/g}) + (31\text{g carb} \times 4\text{Calories/g}) + (12\text{g fat} \times 9\text{Calories/g}) = 252\text{Calories}$$

$$5\text{g protein} \times 4\text{Calories/g} + (31\text{g carb} \times 4\text{Calories/g}) + (12\text{g fat} \times 9\text{Calories/g}) = 252\text{Calories}$$

So, you can use food labels to count your Calories. But where do the values come from? And how accurate are they? The caloric content of foods can be determined by using bomb calorimetry; that is, by burning the food and measuring the energy it contains. A sample of food is weighed, mixed in a blender, freeze-dried, ground into powder, and formed into a pellet. The pellet is burned inside a bomb calorimeter, and the measured temperature change is converted into

energy per gram of food.

Today, the caloric content on food labels is derived using a method called the Atwater system that uses the average caloric content of the different chemical constituents of food, protein, carbohydrate, and fats. The average amounts are those given in the equation and are derived from the various results given by bomb calorimetry of whole foods. The carbohydrate amount is discounted a certain amount for the fiber content, which is indigestible carbohydrate. To determine the energy content of a food, the quantities of carbohydrate, protein, and fat are each multiplied by the average Calories per gram for each and the products summed to obtain the total energy.

## Link to Learning

The [US Department of Agriculture](#) (USDA) National Nutrient Database has a database containing nutritional information on over 8000 foods.

## Footnotes

1. Francis D. Reardon et al. "The Snellen human calorimeter revisited, re-engineered and upgraded: Design and performance characteristics." *Medical and Biological Engineering and Computing* 8 (2006)721-28, <http://link.springer.com/article/10.1007/s11517-006-0086-5>.

## Link to Supplemental Exercises

[Supplemental exercises](#) are available if you would like more practice with these concepts.



*General College Chemistry.*

[https://books.byui.edu/general\\_college\\_chemistry](https://books.byui.edu/general_college_chemistry)



**CC BY:** This work is released under a CC BY license, which means that you are free to do with it as you please as long as you properly attribute it.