

Calorimetry and the Energy Content of Foods

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OBJECTIVES

1. To determine the energy released, in calories per gram, by food samples using a simple calorimetry experiment.
2. To compare relative caloric values of food samples high in fat versus food samples high in carbohydrates.
3. To identify the differences between this simple calorimetry experiment and constant-pressure calorimetry.
4. To analyze how use of an open system impacts experimental results.

Background Information

Calorimetry is a technique used to determine heat transfer(q) for a physical or chemical process. A calorimeter is a device used to measure heat transfer. There are two types of calorimetry – constant-volume calorimetry and constant pressure calorimetry. In a constant-pressure calorimetry, the calorimeter is cup made of an insulating material, such as Styrofoam, and it is assumed that there is no transfer of energy between the system (the calorimeter) and the surroundings (everything outside the calorimeter). This is called an isolated system and is represented by the equation

$$q_{\text{sys}} = 0$$

where q_{sys} is the heat transfer to or from the system. Let's say we want to determine the identity of a piece of metal using constant-pressure calorimetry. We could do so by determining and then comparing the specific heat of the unknown metal to the specific heats of a set of known metals. The experiment would involve placing water of known temperature and mass in a constant-pressure calorimeter with the unknown metal of known temperature and mass. The equation for the isolated system must now account for all of the components within the calorimeter

$$q_{\text{metal}} + q_{\text{H}_2\text{O}} = 0$$

Since $q = m \mathcal{S} \Delta T$, the equation can further expand to

$$[(m_{\text{metal}})(\mathcal{S}_{\text{metal}})(T_f - T_{i \text{ metal}})] + [(m_{\text{H}_2\text{O}})(\mathcal{S}_{\text{H}_2\text{O}})(T_f - T_{i \text{ H}_2\text{O}})] = 0$$

where m is the mass of the metal or the water, $\mathcal{S}$ is the specific heat of the metal or water, T_f is the thermal equilibrium temperature and T_i is the initial temperature of either the metal or the water. If every variable in the equation is known through direct measurement except the specific heat of the metal, then we can solve for $\mathcal{S}_{\text{metal}}$ and identify it.

In today's simple calorimetry experiment, we are working with an open system. An open system is able to exchange both matter and heat with the surroundings. Our components won't be contained completely within the calorimeter, though the experiment does take place at constant pressure (atmospheric pressure). Our simple calorimetry experiment makes use of water to "capture" some of the heat released by combusting (burning) food. If we know the mass of water (m_{H_2O}), the specific heat of water (S_{H_2O}), and measure the change in temperature of the water (ΔT_{H_2O}), we can estimate the heat transfer (q) with this simple equation

$$q = (m_{H_2O})(S_{H_2O})(\Delta T_{H_2O})$$

From there we can determine the approximate energy content of food and make comparisons.

EXPERIMENT OVERVIEW

All human activity requires burning (metabolizing) food for the purposes of generating energy. In this experiment, you will determine the energy released in calories per gram of walnuts and two types of popcorn when they burn. This is analogous to how your body uses foods to generate energy. Since walnuts and cashews are high in fat and popcorn is primarily composed of carbohydrates, the results will give you an indication of the relative caloric values of fats and carbohydrates.

PROCEDURE

1. A sample of food (one walnut or about 5 pieces of popcorn) was placed on a watch glass. The food sample and the watch glass were massed together on a top-loading balance. The mass was recorded in the Table 1.
2. An empty can and holder were massed on a top-loading balance; the mass was recorded. Then, approximately 100 mL of cold water was added to the can. The combination of the can, holder and water were massed. These masses were recorded in the Table 1.
3. The apparatus is shown in Figure 1. A ring stand and o-ring were used to suspend the can above the food sample. A digital thermometer was used to stir the water gently, but the thermometer did not touch the bottom of the can while stirring. The initial temperature of the water was recorded in the data table.

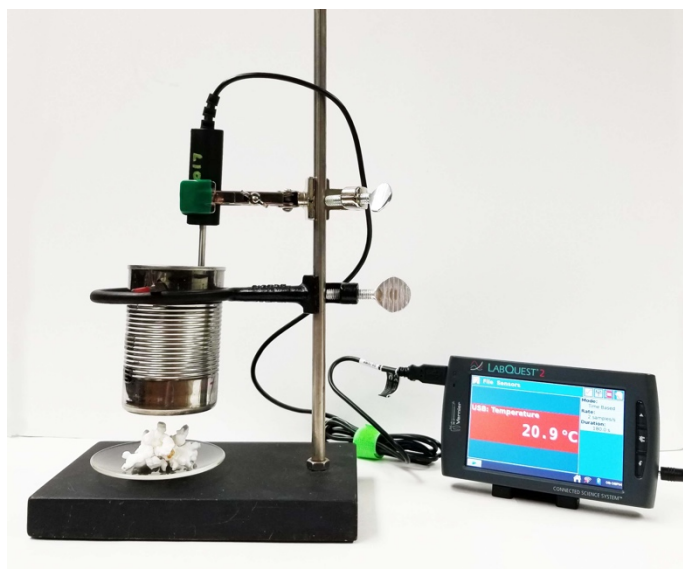


Figure 1. Apparatus for measuring energy transfer from combustion of food.

4. The sample was then burned. The burning procedure is different for popcorn and walnuts. For popcorn, the sample was placed on the watchglass under the center of the can, and a wooden splint was used to light it. Popcorn burned rapidly. For the walnut, the sample was held with a pair of tongs in the Bunsen burner for approximately 30 seconds until it was burning well and then placed on the watchglass. The walnuts burned for several minutes. VERY IMPORTANT NOTE: The can should be as close as possible to the burning item so that the heat is transferred efficiently. CAUTION: Wear eye protection and keep hair and clothing away from open flames.
5. The water was allowed to heat until the food sample stopped burning. Once the sample stopped burning, the water was stirred with the thermometer until the temperature stopped rising. This final temperature of the water was recorded in Table 1.
6. The final mass of the food sample and food holder was determined and recorded in Table 1.
7. The procedure was repeated a second time for the walnut sample, using a new 100 mL portion of cold water.

Table 1. Experimental Observations

Food Type →	Popcorn	Walnut
Mass of empty can (g)	57.31	57.31
Mass of can and water (g)	156.78	156.36
Initial Mass of food and holder (g)	38.51	38.13
Final mass of food and holder (g)	37.90	37.85
Initial temperature of water (°C)	20.3	20.7
Final temperature of water (°C)	31.2	34.1

DATA ANALYSIS

Fill in the Table 2 with the experimental results by following these steps. Write out the calculation and the answer in the spaces provided in the table.

1. Calculate the mass of water heated for each sample and trial by subtracting the mass of the empty can from the mass of the can and water. Enter your answer in the results table below.
2. Calculate the mass (in grams) of each food sample burned by subtracting the final mass of food/holder from the initial mass of food/holder. Enter your answer in the results table below.
3. Calculate the change in temperature of the water, ΔT , for each sample and trial by subtracting the initial temperature from the final temperature. Enter your answer in the results table.
4. Calculate the heat absorbed by the water, q , using the equation: $q = m \mathcal{S} \Delta T$ where m is the mass of water (in grams), $\mathcal{S}$ is the specific heat of the water (in J/g °C), and ΔT is the change in temperature of the water (in °C).
5. Convert the heat transfer, q , to units of kilojoule. Then, use the results from steps 2 and 4 to calculate the energy content in kiloJoules/gram food.
6. Next, calculate the energy content in Calories/gram (4.184 kJ = 1 Calorie).
7. Finally, calculate the percent error.

$$\% \text{ error} = \frac{\text{Experimental value} - \text{Accepted value}}{\text{Accepted value}} \times 100$$

You will need to calculate the accepted values in units of Calories/gram first. Using the information on the package label (popcorn) or the data table (walnut) at the end of this lab activity, divide the Calories per serving by the serving mass in grams.

Table 2. Experimental Results

	Popcorn	Walnut
1. Mass of water heated (g)		
2. Mass of food sample burned (g)		
3. ΔT of water ($^{\circ}\text{C}$)		
4. Heat of Rxn (J)		
5. Energy Content (kJ/gram)		
6. Energy Content (Calorie/gram)		
7. Percent Error (%)		

POST LAB QUESTIONS

1. Based on your calculated energy content for each food sample, make a general statement about the relative energy content of fats and carbohydrates.
2. Write a statement comparing your energy content values (in calories per gram) with the accepted values of walnuts and popcorn. List two experimental errors might account for the differences.
3. The set up used in this experiment represents an open system. What does open system mean in the context of thermochemistry? How would you expect the results to differ if we did the experiment in an isolated system?

Food	Grams	Calories	Protein (g)	Carb. (g)	Fiber (g)	Fat (g)	Sat. fat (g)
Almonds, dried	70	425	13	13	1.8	38	28
Brazil nuts; unsalted	70	457	10	7	2	47	31
Cashews, unsalted	70	392	12	20	0.9	32	28
Peanuts, roasted	50	290	13	9	1.2	25	16
Pecans, raw, halves	52	343	5	7	1.1	35	25
Sesame seeds, dry	50	280	9	10	3.1	24	13
Sunflower seeds	50	280	12	10	1.9	26	7
Walnuts, raw 	50	325	7	8	1	32	7

*adapted from https://en.wikipedia.org/wiki/Table_of_food_nutrients#Nuts_and_seeds



Nutrition Facts			
about 2.5 servings per bag, about 30 servings per container			
Serving size 2 tbsp (34g) unpopped (makes about 5 cups popped)			
	Per serving	Per 1 cup popped	
Calories	160	30	
	% DV*	% DV*	
Total Fat	10g 13%	2g	3%
Saturated Fat	5g 25%	1g	5%
Trans Fat	0g	0g	
Polyunsaturated Fat	1g	0g	
Monounsaturated Fat	3.5g	0.5g	
Cholesterol	0mg 0%	0mg	0%
Sodium	340mg 15%	50mg	2%
Total Carbohydrate	18g 7%	3g	1%
Dietary Fiber	3g 11%	less than 1g	2%
Total Sugars	0g	0g	
Incl. Added Sugars	0g 0%	0g	0%
Protein	2g	0g	
Vitamin D	0mcg 0%	0mcg	0%
Calcium	0mg 0%	0mg	0%
Iron	0.5mg 2%	0mg	0%
Potassium	0mg 0%	0mg	0%

Nutrients in 100 g of nuts

Nutrients	Units	Almonds	Brazil nuts	Cashews	Hazelnuts	Macadamias	Pecans	Pines nuts	Pistachios	Walnuts
Calories	kcal	578	656	574	628	718	691	629	557	654
Proteins	g	21	14	15	15	8	9	12	21	15
Fats	g	51	66	46	61	72	72	61	44	65
Carbohydrates	g	20	13	33	17	14	14	19	28	14
Fiber	g	12	5	3	10	9	10	11	10	7
Calcium	mg	248	176	45	114	85	70	8	107	98
Iron	mg	4	3	6	5	4	3	3	4	3
Magnesium	mg	275	225	260	163	130	121	234	121	158
Phosphorus	mg	474	600	490	290	188	277	35	490	346
Potassium	mg	728	600	565	680	368	410	628	1025	441
Sodium	mg	1	2	16	0	5	0	72	1	2
Zinc	mg	3	5	6	2	1	5	4	2	3
Copper	mg	1	2	2	2	1	1	1	1	2
Vitamin C	mg	0	1	0	6	1	1	2	5	1
Thiamin	mg	0.2	1	0.2	0.6	1.2	0.7	1.2	0.9	0.3
Riboflavin	mg	0.8	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.1
Niacin	mg	4	2	1	2	2.5	1	4	1	2
Pantothenic acid	mg	0	0	1	1	1	1	0	1	2
Vitamin B6	mg	0.1	0.3	0.3	0.6	0.3	0.2	0.1	1.7	0.5
Folate	mcg	29	4	69	113	11	22	58	51	98
Vitamin B12	mcg	0	0	0	0	0	0	0	0	0
Vitamin A	IU	10	0	0	40	0	77	29	553	41
Vitamin A	RE	1	0	0	4	0	8	3	55	4
Vitamin E	mg	26	8	1	15	1	4	NA	5	3