Biophysical Chemistry Laboratory Manual | Department of Chemistry and Physics

1-2023

Bomb Calorimeter

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1 Abstract

The purpose of this laboratory is to determine the heat of combustion of a sample of sugar and artificial sweeteners by using an IKA Bomb Calorimeter (C200si).

2 Introduction

2.1 Dissociation Constant

Calorimetry deals with the accurate measurements of absorbed or evolved heat during a chemical reaction, or simply measuring the quantitatively the flow of heat in a reaction [1]. The need for increasingly accurate reference measurements and the limited effects of experimental technique mean that more advanced instrumentation is often the single best way to improve calorimetric accuracy in precision. We used the IKA Bomb Calorimeter (C200si) (Fig. 1) that can be employed to measure the heat generated by the combustion of a sample in the presence of oxygen in a closed decomposition vessel surrounded by water under controlled conditions.

Figure 1. An IKA Bomb Calorimeter (C200si) equipment and vessel as used in this experiment.

As seen in Fig. 2, a bomb calorimeter typically consists of a metal bomb designed to withstand heat and pressure, a large Dewar flask to hold the bomb and a known volume of water, a means of remotely igniting the sample (typically electrically, through the use of a fuse wire), and a means of accurately measuring the temperature of the water. During the process, when the fuse wire and pellet are ignited in the bomb, heat is given off during this combustion reaction. The bomb, used in bomb calorimetry, is a completely sealed and oxygen filled metal container. This is placed in an insulated jacket containing a pail of water and a thermometer —all combined to form the calorimeter [2,3]. The bomb allows for both a constant volume of the container and for no inflow or outflow of heat (Δq) and its insulated jacket serves as an ideal environment for the bomb.

All the conditions surrounding the bomb and its calorimeter, allow for a theoretically adiabatic reaction to take place. Hence, the change in internal energy (ΔU) is equal to the change in work (ΔW) done by the bomb during the reaction [4].

$$\Delta U = \Delta W \qquad \text{Eq. 1}$$

All through the adiabatic process, the change in heat of the system is zero, rendering the change in enthalpy equal to the change in heat [4].

$$\Delta H = \Delta q \qquad \text{Eq. 2}$$

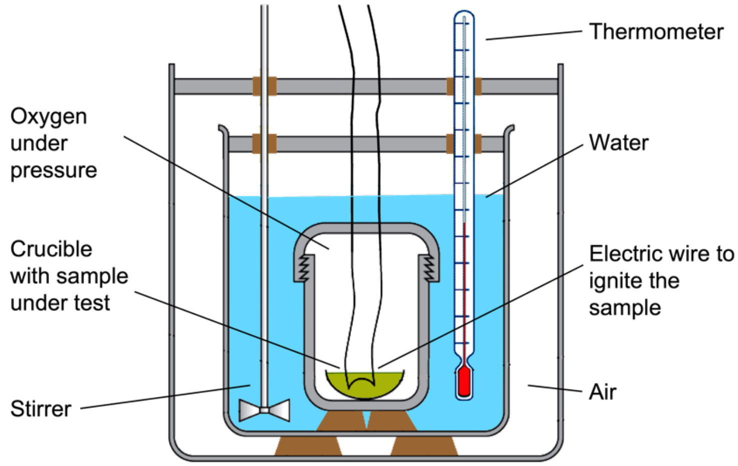

Figure 2. A diagram of a typical bomb calorimeter. [7]

In practice, the adiabatic conditions are not perfect and there is some exchange of heat in the bomb. Through the use of a calibration sample of known combustion value (often benzoic acid [5]), the heat capacity of the calorimeter system can be determined, allowing for the calculation of the heat of combustion of a sample of known mass by the net temperature change and the heat capacities of the combined water-calorimeter system. To aid in calculation, a fuse wire with standardized heat of combustion per unit length can be used [6], and a small quantity of water can be inserted into the bomb in advance.

The typical combustion reaction seems to resemble this form:

$$\text{Organic Compound (s)} + \text{A}\ \text{O}_2\ \text{(g)} \rightarrow \text{B}\ \text{CO}_2\ \text{(g)} + \text{C}\ \text{H}_2\text{O (g)}$$

and when balanced [8],

$$\text{C}_x\text{H}_y\text{O}_z(\text{s}) + \left(x + \frac{y}{4} - \frac{z}{2}\right)\text{O}_2(\text{g}) \rightarrow x\ \text{CO}_2(\text{g}) + \left(\frac{y}{2}\right)\text{H}_2\text{O}(\text{g})$$

In this experiment, we will measure the heat of combustion of sucrose:

$$\text{C}_{12}\text{H}_{22}\text{O}_{11}(\text{s}) + 12\ \text{O}_2(\text{g}) \rightarrow 12\ \text{CO}_2(\text{g}) + 11\ \text{H}_2\text{O}(\text{l}), \qquad \Delta_\text{c}H^\text{o} = -1108365\ \text{cal/mol}$$

3 Experimental Procedure

This experiment proceeds through several discrete steps:

1. Assemble and clean the bomb calorimeter.
2. Place pellets of benzoic acid inside the bomb and threaded into the bomb the measured lengths of fuse wire, in contact with the samples.
3. Seal and tight the bomb.
4. Flushed it twice with 10 atm of O_2 gas to purge N_2 (to preclude the formation of nitric acid), then fill it with 25 atm of O_2 gas.
5. Place the bomb in the calorimeter.
6. Fill the calorimeter with precisely 2000. mL of water.
7. Seal the cover and turn on the stirrer.
8. After establishing a baseline level of temperature, record the temperature (T_initial) and proceed to ignite the sample remotely.

9. Once the temperature has equilibrated, and another baseline is reached, record the temperature (T_{final}) remove the bomb from the calorimeter and vent it, before being cleaned and dried for the next trial.
10. Use the following table to record your data:

Sample	Mass (g)	Fuse length (cm)	T_{initial}	T_{final}
Benzoic Acid 1				
Benzoic Acid 2				
Sucrose				

Table 1. Data

4 Calculations

Perform your calculations in Excel. Use table 2 below to write your results.

4.1 Calculation of ΔT

Determine the temperature difference ΔT using the following equation:

$$\Delta T = T_{\text{final}} - T_{\text{initial}} \qquad \text{Eq. 3}$$

4.2 Calculation of C and C_0

- The total heat capacity is given by

$$C = mC_{\text{H}_2\text{O}} + C_0 \qquad \text{Eq. 4}$$

where $C_{\text{H}_2\text{O}}$ is the specific heat capacity of water, and C_0 is the heat capacity of the calorimeter.

- Use a value of $C_{\text{H}_2\text{O}} = 0.999\ \text{cal/g}^{\text{o}}\text{C}$, a density of $\rho_{\text{H}_2\text{O}} = 1\ \text{g/mL}$, and a known volume of $2000\ \ \text{mL}$ of water, to find $mC_{\text{H}_2\text{O}}$.
- Find the total heat capacity C for each benzoic acid sample by using

$$C = \frac{\Delta_{\text{c}}H^{\text{o}}m + e_3}{\Delta T} \qquad \text{Eq. 5}$$

- where $\Delta_{\text{c}}H^{\text{o}}$ is the heat of combustion of benzoic acid ($-6318\ \text{cal/g}$), m is the mass of the benzoic acid sample, e_3 is the heat of combustion of the wire, calculable from the heat of combustion of the wire ($-2.3\ \text{cal/m}$) and the length of the wire:

$$e_3 = -2.3\ \text{cal/m} \times \text{length (in meters)} \qquad \text{Eq. 5}$$

- Use Eq. 4 and the result from Eq. 5 to find a value for C_0 for each benzoic acid sample.
- Using the values found of C and C_o for each benzoic acid sample, find the average values of C_{avg} and $C_{0_{\text{avg}}}$.
- Use Eq. 5 and the data for the Sucrose to find its heat of combustion ($\Delta_{\text{c}}H^{\text{o}}_{\text{sucrose}}$)
- Find the energy difference for the Sucrose ($\Delta_{\text{c}}U^{\text{o}}_{\text{sucrose}}$), using the following equation:

$$\Delta U = C_{\text{avg}}\Delta T \qquad \text{Eq. 6}$$

- Find the percentage error for the heat of combustion ($\Delta_{\text{c}}H^{\text{o}}_{\text{sucrose}}$), using the accepted value of $-1108365\ \text{cal/mol}$.

Variable	Value
C_1	
C_2	
C_{avg}	
C_{0_1}	
C_{0_2}	
$C_{0_{avg}}$	
$\Delta_c U^o_{sucrose}$	
$\Delta_c H^o_{sucrose}$	
% Error	

Table 2. Tabulated results and uncertainties

5 Questions

1. How does the bomb calorimetry data for the artificial sweeteners compare to the calorie count on the package?
2. Explain why artificial sweeteners have zero calories? Make sure to focus on bonding and include sugar metabolism in your answer.
3. Draw a sucralose molecule and one of sucrose. Using your knowledge of chemical structure and bonding, explain why sucralose has zero calories.
4. Provide a chemical explanation of the sweetness strength of artificial sweeteners. (200 times sweeter than sugar by weight)
5. When food scientists are determining the calories in new foods, they use bomb calorimetry. How can they distinguish between digestible and nonmetabolizable molecules?
6. Create at least three questions that relate to this experiment.

6 References

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