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CHEMICAL EDUCATION

A low-cost experiment on the determination of heat of combustion based on a thermistor

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A low-cost calorimeter for the determination of heat of combustion of low molecular weight compounds was assembled using easily available materials. A thermistor was employed for the measurement of the temperature change accompanying the combustion reaction. The assembled calorimeter give satisfactory results for the low molecular weight alcohols and hydrocarbons, with errors not exceeding 5 %.

Key Words: heat of combustion, calorimeter, low-cost experiment, thermistor

THE HEAT OF COMBUSTION OF A SUBSTANCE IS A VERY IMPORTANT thermochemical quantity. It expresses the amount of heat released when an organic compound reacts with oxygen, forming carbon dioxide and water. It furnishes information about the relative stability of an organic compound since it indicates the energy stored in the bonds of a molecule. It provides a basis for the measurement of the heating values of fuels and the calorie content of food.

Considering the importance of the concept of heat of combustion, it is surprising to note that this topic is seldom part of a laboratory course in basic chemistry. The main reason for this omission is that the measurement is not easily done. The most common method for the determination of this property involves the use of a bomb calorimeter which is quite expensive.

A number of procedures using inexpensive set-ups have been reported. A simplified set-up for the measurement of the heat of combustion of liquids is commercially available (1); however, it is relatively fragile since it involves an all-glass system. A low-cost constant-pressure combustion calorimeter has been described by Row and Browley (2) involving a "tin-can" assembly and an electrical firing system. Another low-cost set-up is a ruggged and easily constructed assembly composed of a heating can and an alcohol lamp, but gives a satisfactory accuracy of less than 10% (3).

In this paper, a low-cost experiment using an easily fabricated calorimeter for the measurement of the heat of combustion of some low molecular weight organic compounds is described. Readily available materials are used in the construction of the equipment. Unlike previously reported calorimeters, a thermistor is employed as the temperature sensor. This semiconductor component offers a greater sensitivity than the widely used mercury glass thermometer. Furthermore, it presents a highly rugged and a more convenient means of reading the temperature.

Experimental

Construction of the Calorimeter

The calorimeter consists of a heating can (water reservoir), a miniburner containing the liquid sample, and an insulating jacket of PVC tube. Figure 1A shows a diagram of the calorimeter assembly.

The heating can is derived from a tin can which has a volume of about 200 mL. Holes are drilled on the top for holding the electronic thermometer and the stirrer. It is set inside at the upper portion of the PVC tube where it is supported by a pair of parallel wires passing through the tube.

The miniburner is fabricated from a small vial with a rubber cap. A small piece of glass tubing serving as a burner's tip is inserted through the rubber cap. A cotton wool is made as a wick which extends from the tip to the bottom of the vial. Figure 1B shows the design of the miniburner.

The PVC tube (diameter, 8 cm) serves as an insulator to prevent significant loss of heat. It also provides a shield to protect the burner flame from air drafts. Holes are drilled at the lower half of the pipe to allow passage of air into the burning chamber.

Temperature Sensor

A 1 k ohm thermistor is employed as the temperature sensor. The lead wires of the thermistor are soldered to two separate insulated wires about 30 cm in length. The wires are inserted into a plastic tube (length 10 cm) with the thermistor head exposed at the tip of the tube. The thermistor is glued in place taking care that the thermistor surface is free from glue. The wires of the probe are connected to a Wheatstone bridge circuit configured in the deflection mode (Fig. 2). The response of the sensor is taken with a digital volt meter (DVM) or a digital mul-

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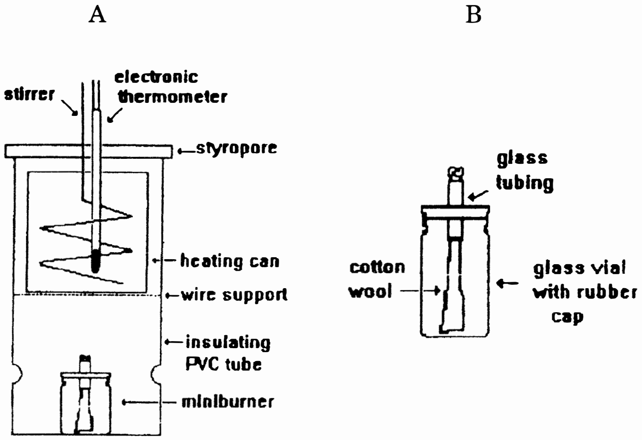

Figure 1. Cross-section of (A) the calorimeter assembly and (B) the miniburner

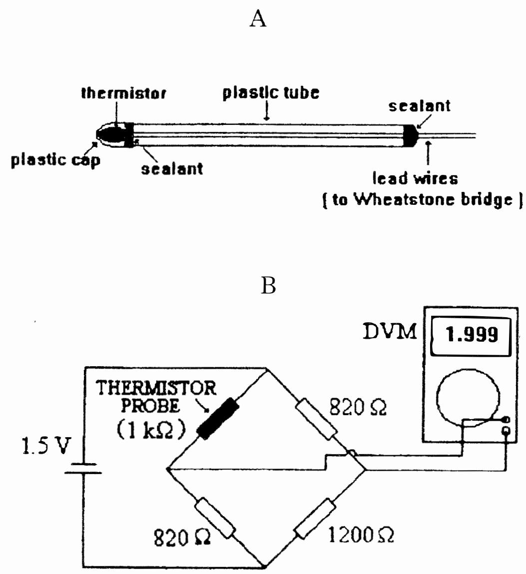

Figure 2. Diagrams of (A) thermistor probe and (B) the electronic thermometer circuit

timeter. The calibration curve for the temperature sensor is shown in Fig. 3.

Determination of the Heat Capacity of the Calorimeter

The heating can is filled up to capacity with water at room temperature, with the outside portion wiped dry and clean. The response of the thermistor sensor to the system is initially recorded. The miniburner is filled up to about three-fourths of its capacity with a standard liquid (in this case, acetone). The burner is weighed, lighted and

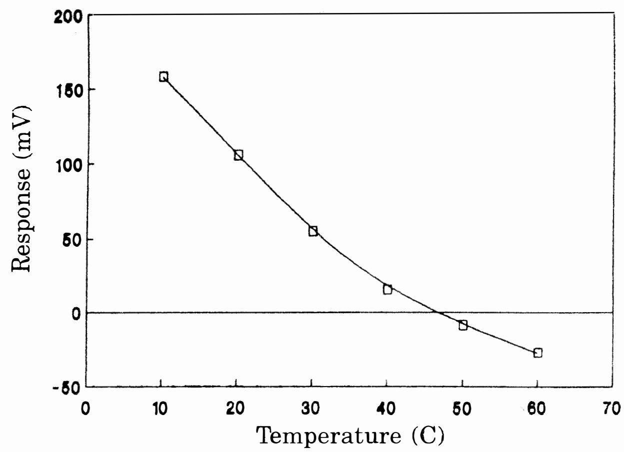

Figure 3. A calibration curve showing the response of the electronic thermometer with temperature

immediately placed in the combustion chamber of the calorimeter assembly. The water is continuously stirred during combustion. When the meter display has decreased by 20 to 30 mV units, the burner is extinguished and immediately weighed. This change in voltage corresponds to a temperature increase of 4 - 6 °C. Higher temperature change results in greater error due to heat lost through radiation. The final reading of the meter is recorded.

The calorimeter constant (in kJ/mV) is calculated from the heat released by the mass of acetone burnt per degree change in temperature. The formula used is as follows:

$$K = (\Delta H_{ac}) (\Delta W) / (\Delta T) \qquad (1)$$

where ΔH_{ac} is the heat of combustion of acetone (30.7 kJ/g), ΔT is the change in the sensor response expressed in mV after the combustion, and ΔW is the loss in weight of the miniburner, corresponding to the amount the amount of liquid burnt. The heat capacity indicates the amount of heat, in kJ, equivalent to 1 mV change in the sensor response.

Determination of the Heat of Combustion

The heat of combustion of an organic liquid is determined by replacing acetone in the miniburner with the test liquid and proceeding as before.

The molar heat of combustion is calculated from eq. 2:

$$\Delta H = K (\Delta T) / (\Delta W / M) \qquad (2)$$

where K is the heat capacity of the calorimeter, ΔT is the temperature change caused by the burning of the test liquids, ΔW is the loss in weight due to burning, and M is the molecular weight of the test liquid.

Results and Discussion

In the calorimeter set-up, the heat liberated during the combustion of the test substances is absorbed by the water reservoir. This heat is generated near the tip of the miniburner. Any loss of heat is minimized by the insulating jacket. The temperature change in the heating can provides a measure of the amount of heat released by the burning of the liquids.

The adequacy of the simple fabricated calorimeter can be judged from typical results shown in Table 1. The values of the heat of combustion of the test liquids show a good agreement with the accepted values. Errors better than 5 % were obtained in a series of six measurements.

Table 1. Heat of combustion of alcohols and hydrocarbons

Alcohol Series	Experimental Value (kJ/mole)	Accepted Value (kJ/mole)	% error
Methanol	734	727	0.96
Ethanol	1390	1367	1.91
1-Propanol	2085	2020	3.22

Hydrocarbon Series	Experimental Value (kJ/mole)	Accepted Value (kJ/mole)	% error
Pentane	3350	3509	4.53
Hexane	4210	4163	1.13
Heptane	4780	4811	0.64

The results obtained for a homologous series of alcohols and hydrocarbons can be used to demonstrate the dependence of the heat of combustion with the length of the hydrocarbon chain in the molecule (Fig. 4).

The accuracy of the measurement can be ensured through careful weighing and temperature measurement. A balance capable of measuring down to 0.01 g will provide satisfactory results. The completeness of combustion, likewise, can be optimized by keeping the flame as small as possible. This is done by adjusting the wick of the burner and allowing enough access of air.

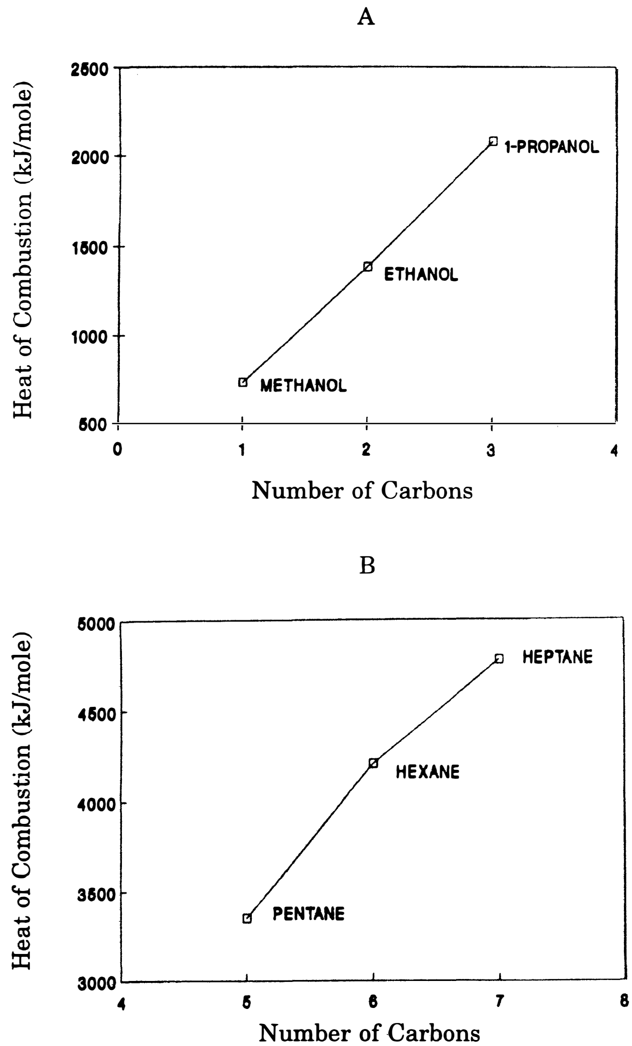

Figure 4. Variation of the heat of combustion with molecular size of (A) alcohol homologous series and (B) hydrocarbon homologous series

Conclusion

The combustion calorimeter described in this paper is inexpensive and easily constructed. Including the multimeter used for obtaining the response of the thermistor, the total cost of the calorimeter assembly is only around 1% of a commercial combustion calorimeter. All of the materials are easily obtained from the hardware and electronic shops. The multimeter is the most expensive component of the calorimeter assembly, being at least 95 % of the total cost of the assembly. It should however be realized that the multimeter can be used not only for this experiment but also for a number of other experiments (4, 5).

The use of a thermistor facilitated the sensitive measurement of small changes in temperature. The reading of the thermistor response from the multimeter is much more convenient than reading the fine calibration lines of a mercury thermometer. Though made from relatively crude materials, the calorimeter is capable of yielding accurate results. Relatively simple techniques are needed to ensure good accuracy in the measurement.

This experiment can be used to demonstrate thermochemical concepts in general chemistry and physical chemistry laboratory courses. Experiments based on this set-up can be used to facilitate an understanding of the concept of bond energy. The results can be utilized to explain the heating value of fuels, as well as the calorie content of different types of food.

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