

Determination of the Molar Enthalpy of Combustion of Paraffin Wax

IB Chemistry HL

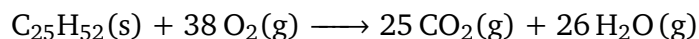
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1 Purpose

The purpose of this lab was to determine the molar enthalpy of the combustion of Paraffin Wax ($\text{C}_{25}\text{H}_{52}(\text{s})$) in the following reaction:



2 Evidence

2.1 Qualitative Observations

The Paraffin Wax candle appears white and opaque, with the colour fading into orange nearing the bottom. Upon touch, the Paraffin Wax feels slightly slippery, and after putting the candle down, the slippery sensation transfers to your hands.

The Paraffin Wax candle was able to be attached to the watchglass by exposing the bottom of the candle to a flame, in which the melted paraffin wax at the bottom was able to stick onto the watchglass. This indicates that melted paraffin

wax exhibits adhesive properties.

The container surrounding the base of the Paraffin Wax candle does not leave any openings for air to escape other than the opening at the top.

These observations are shown in Figure 1.



Figure 1: Appearance of the Paraffin Wax candle attached to watchglass within container.

The can containing the water has a proportionally greater height than diameter. The opening at the top of the can is significantly wider than the diameter of the thermometer, indicating that the space within the can is not entirely closed and isolated. The two holes allowing for the rod to pass through does wrap

around the rod tightly, however because it is a manually created hole, it still allows for passage of air within the can and outside the can. These observations are shown in Figure 2.



Figure 2: Appearance of can used to contain the water from a top view

The Aluminium Foil surrounding the can leaves an opening at the top between the ring and the diameter of the can, as seen in Figure 2.

The process of conducting a trial involved raising the ring along the Ring Stand, lighting the candle, and lowering the ring. This means that there is an interval of time from lighting the candle where combustion was not taking place within the calorimeter. Additionally, after lowering the ring to a reasonable height where the bottom of the aluminium foil surrounding the can meets the top of the container surrounding the candle, the two ends of the aluminium foil become separated due to the significantly larger diameter of the container at the bottom. This leaves a few openings at the side of the aluminium foil cylinder.

Some of these observations can be seen in Figure 3.

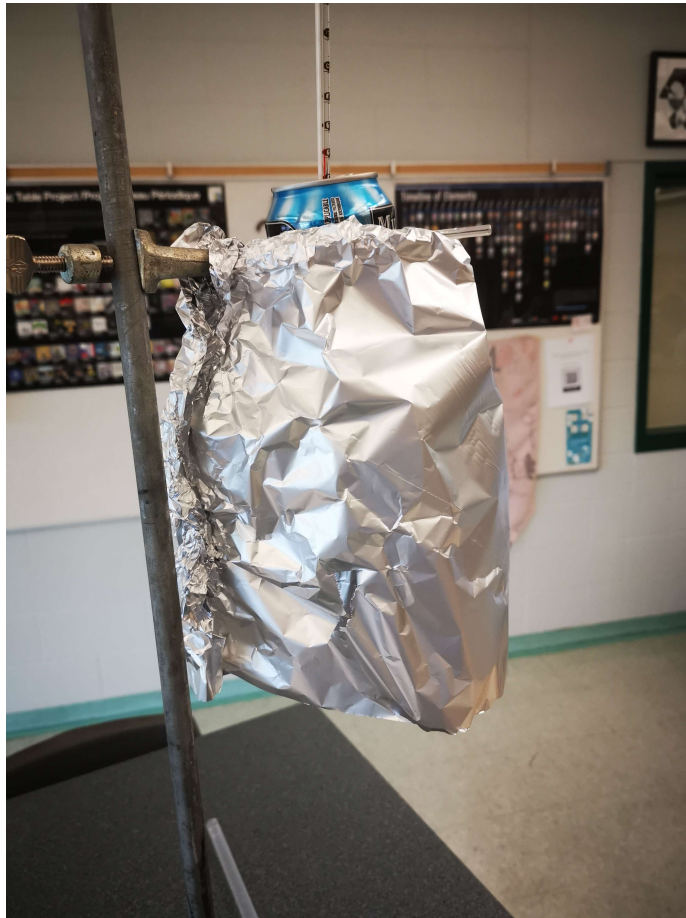


Figure 3: View of aluminium foil attached around elevated ring on ring stand

As seen in Figure 4, there is a black stain on the bottom of the can containing the bottom. This is presumably solid carbon produced by incomplete combustion from previous calorimetry experiments.



Figure 4: Appearance of black stain on the bottom of the can containing water

2.2 Quantitative Data

The raw data recorded from the experiment is recorded in Table 1. Note that when measuring the mass of the water, the lab scale was tared with the can, then water was added into the can. Therefore, the mass recorded doesn't need to be subtracted by the mass of the can.

Trial Number	1	2	3
Mass of can /g ($\pm 0.003\text{g}$)	13.039	15.769	15.080
Mass of water /g ($\pm 0.003\text{g}$)	50.141	50.112	50.105
Initial mass of candle and watch glass /g ($\pm 0.003\text{g}$)	106.907	106.209	105.691
Final mass of candle and watch glass /g ($\pm 0.003\text{g}$)	106.209	105.691	105.240
Initial Temperature of water / $^{\circ}\text{C}$ ($\pm 0.3^{\circ}\text{C}$)	23.8	25.0	25.0
Final Temperature of water / $^{\circ}\text{C}$ ($\pm 0.3^{\circ}\text{C}$)	60.7	51.2	52.6

Table 1: Raw data recorded from each trial during the experiment

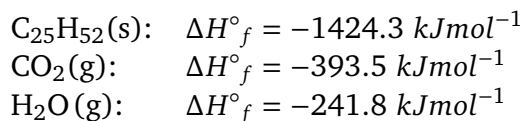
Something else to keep in mind is that the final temperature of the water was determined by setting a timer for 5 minutes and recording the temperature afterwards. However, for the first trial, we forgot to consider after what period of time would we record the final temperature. Therefore, that trial simply involved noting the temperature after twenty 15 second intervals which was manually counted. This demonstrates a reason why the final temperature of the water for the first trial was significantly different than the two other trials.

3 Analysis

3.1 Calculation of theoretical molar enthalpy of combustion

The theoretical molar enthalpy of combustion for Paraffin Wax ($\text{C}_{25}\text{H}_{52}(\text{s})$) will be calculated using Hess' Law.

With ΔH_f° being the molar enthalpy of formation for some compound, the following values will be used.



These values can then be used to calculate the theoretical molar enthalpy of combustion for Paraffin Wax.

let ΔH_{comb}° = calculated theoretical molar enthalpy of combustion
for Paraffin Wax /kJ

n = the amount of a compound /mol

ΔH_f° = the molar enthalpy of formation for a compound /kJmol⁻¹

$$\begin{aligned}\Delta H_{comb}^\circ &= \sum nH_f^\circ \text{products} - \sum nH_f^\circ \text{reactants} \\ \Delta H_{comb}^\circ &= \left((25\text{mol})(-393.5\text{kJmol}^{-1}) + (26\text{mol})(-241.8\text{kJmol}^{-1}) \right) \\ &\quad - (1\text{mol})(-1424.3\text{kJmol}^{-1}) \\ \Delta H_{comb}^\circ &= -14700\text{kJ} \\ \Delta H_{comb}^\circ &= -14.7\text{MJ}\end{aligned}$$

3.2 Calculation of experimental molar enthalpy of combustion

The system of the calorimetry experiment will be the combustion of the Paraffin Wax, and the surroundings will be the water and the can. We will make the assumption that the can is made out of aluminium ("Drink can", 2023).

The systems and surroundings are presented in Table 2 along with what they entail. Note that q equals to the total heat in J.

System	Surroundings
Combustion of Paraffin Wax	Water + Aluminium Can
ΔE_p	ΔE_k
$q_1 = nH^\circ_{comb}$	$q_2 = m_{water}c_{water}\Delta T_{water}$
	$q_3 = m_{Al}c_{Al}\Delta T_{Al}$

Table 2: System and surroundings of the calorimeter.

Given that $q_1 = q_2 + q_3$, the value of nH°_{comb} can then be calculated. A sample calculation is shown below for Trial 1.

$$q_1 = q_2 + q_3$$

$$nH^\circ_{comb} = m_{water}c_{water}\Delta T_{water} + m_{Al}c_{Al}\Delta T_{Al}$$

where H°_{comb} = calculated experimental molar enthalpy of combustion of Paraffin Wax /J

n = amount of Paraffin Wax combusted /mol

m = mass of a component in the surroundings /g

c = specific heat capacity of a component in the surroundings /Jg⁻¹°C⁻¹

ΔT = change in temperature of a component in the surroundings /°C

$$H^\circ_{comb} = \frac{m_{water}c_{water}\Delta T_{water} + m_{Al}c_{Al}\Delta T_{Al}}{n}$$

In order to be able to calculate n , the molar mass of Paraffin Wax (C₂₅H₅₂(s)) must be calculated first.

$$M_{C_{25}H_{52}(s)} = \sum (M_{element} \times n_{element})$$

where M = molar mass of an element or compound g/mol⁻¹

n = amount of an element or compound /mol

$$\begin{aligned} M_{C_{25}H_{52}(s)} &= (25mol)(12.02g/mol^{-1}) + (52mol)(1.01g/mol^{-1}) \\ &= 352.77g \end{aligned}$$

$$\begin{aligned}
& m_{water}c_{water}\Delta T_{water} + m_{Al}c_{Al}\Delta T_{Al} \\
& = (50.141g \pm 0.003g)(4.19Jg^{-1}^{\circ}C^{-1})(60.7^{\circ}C \pm 0.3^{\circ}C - 23.8^{\circ}C \pm 0.3^{\circ}C) \\
& + (13.039g \pm 0.003g)(0.897Jg^{-1}^{\circ}C^{-1})(60.7^{\circ}C \pm 0.3^{\circ}C - 23.8^{\circ}C \pm 0.3^{\circ}C)
\end{aligned}$$

$$\begin{aligned}
& m_{water}c_{water}\Delta T_{water} + m_{Al}c_{Al}\Delta T_{Al} \\
& = (50.141g \pm 0.006g)(4.19Jg^{-1}^{\circ}C^{-1})(36.9^{\circ}C \pm 2\%) \\
& + (13.039g \pm 0.02g)(0.897Jg^{-1}^{\circ}C^{-1})(36.9^{\circ}C \pm 2\%)
\end{aligned}$$

$$m_{water}c_{water}\Delta T_{water} + m_{Al}c_{Al}\Delta T_{Al} = 8.18 \times 10^3 J \pm 4\%$$

$$n = (106.907 \pm 0.003g - 106.209g \pm 0.003g)\left(\frac{1mol}{352.77g}\right)$$

$$n = (0.698g \pm 0.9\%)\left(\frac{1mol}{352.77g}\right)$$

$$n = 1.98 \times 10^{-3}mol \pm 0.9\%$$

$$H^{\circ}_{comb} = \frac{8.18 \times 10^3 J \pm 4\%}{1.98 \times 10^{-3}mol \pm 0.9\%}$$

$$H^{\circ}_{comb} = -4.1MJmol^{-1} \pm 0.2MJmol^{-1}$$

$$H^{\circ}_{comb} = -4.1MJ \pm 0.2MJ$$

Table 3 presents the calculated experimental molar enthalpies of combustion for each trial.

Trial Number	Experimental molar enthalpy of combustion /MJ ($\pm 0.2MJ$)
1	-4.1
2	-4.2
3	-4.8

Table 3: Calculated experimental molar enthalpy of combustion for each trial

The average experimental molar enthalpy of combustion for Paraffin Wax

can then be calculated, as shown below.

$$\overline{\Delta H^\circ_{comb}} = \frac{\sum \Delta H^\circ_{comb}}{N}$$

where $\overline{\Delta H^\circ_{comb}}$ = calculated average experimental molar enthalpy /MJ

ΔH°_{comb} = calculated experimental molar enthalpy for a trial /MJ

N = number of trials conducted

$$\begin{aligned}\overline{\Delta H^\circ_{comb}} &= \frac{(-4.1MJ \pm 0.2MJ) + (-4.2 \pm 0.2MJ) + (-4.8 \pm 0.2MJ)}{3} \\ &= -4.4MJ \pm 0.2MJ\end{aligned}$$

Note that the decision of what the uncertainty of the averaged value would be is based on all of the uncertainties of the individual values calculated from each trial, in which it would be reasonable for the final averaged value to follow the same pattern.

Finally, the percent error can be calculated using this averaged value as the experimental molar enthalpy of combustion.

$$\begin{aligned}\%_{err} &= \left| \frac{\text{experimental} - \text{theoretical}}{\text{theoretical}} \times 100\% \right| \\ &= \left| \frac{-4.4MJ - (-14.7MJ)}{-14.7MJ} \times 100\% \right| \\ &= 70.3\%\end{aligned}$$

4 Conclusion

4.1 Summary

The theoretical value of the molar enthalpy of the combustion of Paraffin Wax ($C_{25}H_{52}(s)$) was determined to be -14.7MJ.

Experimentally, the molar enthalpy of the combustion of Paraffin Wax was determined to be $-4.4MJ \pm 0.2MJ$.

The experiment value calculated, including any values within the range given by the uncertainty, is way less (in magnitude) from the theoretical value, yielding a percent error of 70.3%. This indicates that the experiment was unsuccessful.

Analyzing the precision and accuracy of the calculated experimental molar enthalpies of combustion, it becomes evident that the data was precise but not accurate, as the three values ($-4.1MJ$, $-4.2MJ$, $-4.8MJ$) did not vary that much from each other given only a $0.7MJ$ range. Of course, more trials would be necessary to be able to achieve a better assessment of the precision in the experimental molar enthalpies of combustion; however, this range from just the 3 trials is enough to indicate that the data was precise but not accurate, therefore indicating that the unsuccessfulness of the experiment was due to systematic errors.

Another thing to add that was interesting was that even though the first trial was not timed accurately, its experimental molar enthalpy of combustion happened to be closer to that of the second trial than that of the third trial.

4.2 Evaluation

4.2.1 Delay between lighting candle and assembling calorimeter

One notable systematic source of error was the presence of a delay between lighting the candle and lowering the ring on the ring stand, which held the can and the aluminium foil and therefore needed to be lowered in order to form an enclosed calorimeter (at least enclosed to the calorimeter's greatest potential).

This source of error is one that would cause the experimental value to be lower than the theoretical value. Because the paraffin wax started combusting before the calorimeter was enclosed, some of the heat released from the combustion reaction is going into the surroundings of the room rather than the surroundings of the calorimeter. This entails that some of the heat that should've transferred into the can of the water was instead released into the air. What this means is that the value of the final temperature of the water measured will be lower than expected, directly causing the value of ΔT to be lower than expected as well for both the can and the water.

Referring back to the equation

$$H^{\circ}_{comb} = \frac{m_{water}c_{water}\Delta T_{water} + m_{Al}c_{Al}\Delta T_{Al}}{n}$$

it becomes evident that the value of H°_{comb} will be lower than expected as well, as since ΔT_{water} and ΔT_{Al} ultimately are the same value, then

$$H^{\circ}_{comb} = \frac{\Delta T(m_{water}c_{water} + m_{Al}c_{Al})}{n}$$

therefore indicating a proportional relationship between H°_{comb} and ΔT .

4.2.2 Opening at the top of the calorimeter

The opening at the top of the calorimeter that is the circular space formed between the can and the ring is a systemic error that explains a reason why the experimental value was lower than the theoretical value.

This source of error is similar to the delay between lighting the candle and assembling the calorimeter, in which some of the heat released from the combustion reaction is going into the surroundings of the room rather than the surroundings of the calorimeter. However, rather than a large amount of heat being lost during a small interval of time, the heat lost during the experiment was attributed to part of the heat increasing the temperature of the can and the water and part of the heat escaping through the opening. Nevertheless, the value of the final temperature of the water measured will be lower than, directly causing the value of ΔT to be lower than expected as well for both the can and the water.

Referring back to the equation

$$H^{\circ}_{comb} = \frac{m_{water}c_{water}\Delta T_{water} + m_{Al}c_{Al}\Delta T_{Al}}{n}$$

it becomes evident that the value of H°_{comb} will be lower than expected as well, as since ΔT_{water} and ΔT_{Al} ultimately are the same value, then

$$H^{\circ}_{comb} = \frac{\Delta T(m_{water}c_{water} + m_{Al}c_{Al})}{n}$$

therefore indicating a proportional relationship between H°_{comb} and ΔT .

4.3 Suggested Improvements

4.3.1 Solution to delay between lighting candle and assembling calorimeter

The main concern had for lighting the candle was safety in being able to light the candle within a calorimeter. Our immediate thought was to create a temporary opening in the aluminium foil and light the candle through the hole; however, the safety concern was that the experimenter would not be able to completely see where their hand would be within the calorimeter while attempting to light the candle.

A potential solution for the source of error of there being a delay between lighting the candle and assembling the calorimeter while maintaining a level of safety is to use a BBQ lighter instead of a small butane lighter and follow the

approach of lighting through a small gap in the aluminium foil. The small radius of a BBQ lighter would allow for the experimenter to be able to see within the calorimeter despite it being fully assembled, and the length of the BBQ lighter allows for the experimenter to keep their hand outside of the calorimeter.

4.3.2 Solution to opening at the top of the calorimeter

A potential solution to address the source of error of the opening at the top of the calorimeter is to place a stable cover on top of the ring. This gets rid of the opening at the top of the calorimeter while removing the necessity of the more expensive bomb calorimeter. One consideration is required for this approach, however; as the thermometer within the can still needs to be visible. This suggests that there will still need to be an opening at the top of the calorimeter, but a significantly smaller hole may significantly assist in dedicating more of the combustion reaction's released heat towards the kinetic energy of the water and can.

References

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