Combustion Enthalpy Experiment – Eden Tomes

# Research Question:

*How does the number of carbon atoms present in a chemical compound affect the enthalpy of combustion?*

# Rationale:

Combustion reactions, which involve the exothermic oxidation of fuels, are essential for energy production in industries, transportation, and everyday applications. The enthalpy of combustion (), defined as the energy released per mole of a substance during complete combustion, is an important parameter for evaluating fuel efficiency and environmental impact (*Atkins & de Paula*, 2010). Carbon, a primary component of hydrocarbons and organic fuels, plays a key role because its oxidation to carbon dioxide releases significant heat (*Glassman & Yetter*, 2008). While much research has focused on pure fuels, there is a gap in our understanding of how variations in carbon amounts within different alcohols influence combustion energetics.

This experiment is the product of several modifications made to a base experiment that involved investigating the enthalpy of combustion for different foods, including alteration of the substances tested and the use of a more reliable experimental method (the addition of a heat shield, conducting multiple trials). This modified experiment investigates the enthalpy of combustion for a series of alcohols: ethanol, pentanol, and methanol, using calorimetry measurements. The study is designed to show the effect of varying carbon amounts on the energy released during combustion. These modifications enhance the effectiveness of the experiment in testing the new research question.

Understanding how carbon molecules affect a chemical’s enthalpy of combustion has implications for the formulation and optimization of fuels. Insights into combustion can help areas such as biofuel production and energy systems, where balancing energy density, cost, and emissions is important (*IEA*, 2021). In addition, the experimental data will contribute to the broader field of thermochemistry by providing evidence that can help with predictive models in combustion science.

# Method:

***Original Experiment***

The original experiment aimed to determine the enthalpy of combustion of solid food samples using a simple calorimetry setup. A test tube clamped above a food tray held 10 mL of water, measured via a glass thermometer and 10 mL measuring cylinder. The initial water temperature was recorded, and the pre-weighed food (e.g., nuts, crisps) was ignited using a Bunsen burner. Once aflame, the food was positioned 2 cm beneath the test tube, and the temperature change was monitored. After combustion ceased, the final water temperature was recorded, and the mass of the burned food was measured. Observations of flame color and soot deposition were noted. The heat absorbed by the water  
() was calculated, and the enthalpy of combustion per gram of food was derived. Only one trial per food type was conducted, and no heat shield was used, leading to potential heat loss.

## Modifications

Modifications addressed key limitations: the heat shield reduced environmental heat loss, the digital thermometer enhanced measurement precision, and the repeated trials improved data robustness. Liquid fuels required careful handling to prevent spillage, and combustion efficiency was monitored via flame consistency.

***Modified Experiment***

The modified experiment replaced solid foods with liquid alcohols (ethanol, pentanol, methanol) and incorporated enhancements to improve accuracy. A heat shield surrounded the setup to minimize heat loss, a digital thermometer replaced the glass one for precise temperature readings, and each alcohol was tested in three trials to ensure reliability. The setup used a spirit burner containing the alcohol, with initial and final masses recorded to determine the amount of fuel consumed. For each trial, approximately 200 grams of water was measured in a beaker and then heated in a metal can clamped above the burner. After ignition, the flame heated the water until its temperature had risen by a certain amount (20 degrees for ethanol and pentanol, 10 degrees for methanol). Temperature changes were recorded digitally, and the enthalpy of combustion () was calculated per gram using 

# Results:

Figure 1 (Results Table):

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| --- | --- | --- | --- | --- | --- |
| **Alcohol** | **Carbon Atoms** | **Average Combustion Enthalpy (kJ/g)** | **Mol. Weight (g/mol)** | **Theoretical Value (kJ/g)** | **% Error** |
| Methanol | 1 | -6.29 ± 0.34 | 32.04 | -22.65 | 72.2% |
| Ethanol | 2 | -5.91 ± 0.20 | 46.07 | -29.69 | 80.1% |
| Pentanol | 5 | -11.70 ± 0.64 | 88.15 | -37.79 | 69.0% |

Worked example for methanol trial 1



# Discussion:

The experimental data indicate that as the number of carbon atoms in the alcohol molecules increases, the magnitude of the combustion enthalpy becomes greater (i.e., more negative). Specifically, pentanol (with 5 carbon atoms) exhibited a noticeably more exothermic combustion enthalpy compared to methanol (1 carbon) and ethanol (2 carbons). Although the theoretical trend based on bond enthalpy data predicts a clear increase in energy release with additional carbon atoms, the experimental results for methanol and ethanol are very similar. This suggests that while the overall trend is present, the proportional increase in energy release with each additional carbon atom is not strictly linear in the measured data.

## Theoretical Explanation

The combustion of alcohols involves breaking bonds (such as C–H and C–C) and forming new bonds in the products, notably in carbon dioxide and water. Theoretically, as the number of carbon atoms increases, the total energy released during these bond rearrangements should also increase, leading to a more exothermic reaction (*Glassman & Yetter*, 2008). The observation that pentanol shows a larger magnitude of combustion enthalpy is consistent with this theoretical expectation. However, the near-identical values for methanol and ethanol indicate that experimental factors may be masking the expected gradation, highlighting some deviations from the bond enthalpy predictions.

## Limitations and Uncertainties

Several factors may have contributed to the discrepancies between the experimental and theoretical trends:

* **Measurement Precision:** The instruments used provided readings only to one decimal place, potentially limiting the precision of temperature and mass measurements.
* **Variability in Experimental Conditions:** Some trials were conducted on different days, which introduced variability. For example, an anomaly in the ethanol trial—specifically, the inconsistency in the recorded alcohol mass after trial 2—was likely due to the use of a different spirit burner.
* **Data Borrowing:** Data for pentanol's trials were obtained from another group because the experiment was cut short by time constraints. This external data source may have introduced additional uncertainties.

These limitations and uncertainties could account for the observed deviations from the theoretical predictions and any anomalies in the experimental results.

# References:

* Atkins, P. and De Paula, J. (2010). *Physical Chemistry*. 9th ed. [online] Oxford University Press. Available at: <https://tech.chemistrydocs.com/Books/Physical/Atkins-Physical-Chemistry-9e-by-Peter-Atkins-and-Julio-de-Paula.pdf> [Accessed 3 Mar. 2025].
* Glassman, I. and Yetter, R.A. (2008). *Combustion (Fourth Edition)*. [online] Available at: <https://research.iaun.ac.ir/pd/ekianpour/pdfs/UploadFile_8224.pdf> [Accessed 3 Mar. 2025].
* International Energy Agency (IEA) (2021). *World Energy Outlook 2021 – Analysis*. [online] IEA.org. Available at: <https://www.iea.org/reports/world-energy-outlook-2021> [Accessed 3 Mar. 2025].

# Appendix:

## Full results/calculation tables

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Methanol** | Alcohol Mass (g) | Water Temp (°C) | Water Mass (g) | Combustion Enthalpy (kJ/g) | Bond Enthalpy | Absolute Uncertainty | Percentage / Relative Uncertainty | Percentage Error |
| Trial 1 Before | 136.3 | 26.7 | 199.8 |  |  |  |  |  |
| Trial 1 After | 134.9 | 36.7 | 199.8 | -5.971165714 | -22.64846966 | 0.304534312 | 5.100081405 | 73.64% |
| Trial 2 Before | 134.9 | 26.8 | 200.2 |  |  |  |  |  |
| Trial 2 After | 133.6 | 36.8 | 200.2 | -6.44336 | -22.64846966 | 0.35342533 | 5.485109167 | 71.55% |
| Trial 3 Before | 133.6 | 27.3 | 200.7 |  |  |  |  |  |
| Trial 3 After | 132.3 | 37.3 | 200.7 | -6.459452308 | -22.64846966 | 0.354307992 | 5.485108884 | 71.48% |
| Average: |  |  |  | -6.291326007 | -22.64846966 | 0.337422545 | 5.356766485 | 72.22% |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Ethanol** | Alcohol Mass (g) | Water Temp (°C) | Water Mass (g) | Combustion Enthalpy (kJ/g) | Bond Enthalpy | Absolute Uncertainty | Percentage / Relative Uncertainty | Percentage Error |
| Trial 1 Before | 162.1 | 25.5 | 200 | -8.009371429 | -29.68655032 | 0.27116487 | 3.385594895 | 73.02% |
| Trial 1 After | 160 | 45.6 | 200 |  |  |  |  |  |
| Trial 2 Before | 160 | 27.7 | 202.9 |  |  |  |  |  |
| Trial 2 After | 141.8 | 47.6 | 202.9 | -0.928229596 | -29.68655032 | 0.004892524 | 0.527081258 | 96.87% |
| Trial 3 Before | 141.8 | 26.6 | 199.4 |  |  |  |  |  |
| Trial 3 After | 139.9 | 46.6 | 199.4 | -8.781995789 | -29.68655032 | 0.328310943 | 3.738454798 | 70.42% |
| Average: |  |  |  | -5.906532271 | -29.68655032 | 0.201456112 | 2.550376984 | 80.10% |

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Pentanol** | Alcohol Mass (g) | Water Temp (°C) | Water Mass (g) | Combustion Enthalpy (kJ/g) | Bond Enthalpy | Absolute Uncertainty | Percentage / Relative Uncertainty | Percentage Error |
| Trial 1 Before | 165 | 27.5 | 203.1 |  |  |  |  |  |
| Trial 1 After | 164 | 47.6 | 203.1 | -17.08038504 | -37.78761223 | 1.209266718 | 7.079856311 | 54.80% |
| Trial 2 Before | 164 | 28.1 | 205.6 |  |  |  |  |  |
| Trial 2 After | 162.4 | 48.2 | 205.6 | -10.8066444 | -37.78761223 | 0.479108661 | 4.43346374 | 71.40% |
| Trial 3 Before | 161.9 | 23.8 | 198.5 |  |  |  |  |  |
| Trial 3 After | 159.6 | 43.8 | 198.5 | -7.221947826 | -37.78761223 | 0.223500679 | 3.094742368 | 80.89% |
| Average: |  |  |  | -11.70299242 | -37.78761223 | 0.637292019 | 4.869354139 | 69.03% |