

Comparing the Enthalpy Change of Combustion of Different Alcohols

Aim:

Enthalpy change of combustion of an alcohol is a measure of energy transferred when one mole of alcohol burns completely in oxygen. Alcohols are series of organic compounds which all contain an –OH group. The enthalpy change can be calculated by burning the fuel to heat water. It is believed that 4.2J of energy is required to raise the temperature of 1ml of water by 1 °C; therefore I will use this theory in my calculations.

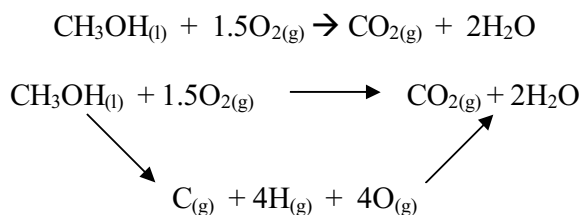
In this investigation I will use 4 different alcohols to see how the molecular structure is linked to the enthalpy change of combustion of each alcohol.

Hypothesis

Relying on my previous knowledge, I predict that alcohols with a larger molecular mass will have a greater enthalpy change of combustion than the alcohols with smaller molar mass, meaning the enthalpy change will go up as the carbon number increases. I can support this hypothesis by calculating the enthalpy change of combustion of each alcohol with bond enthalpies.

Hess's law states: 'The enthalpy change for any chemical reaction is independent of the intermediate stages, provided the initial and final conditions are the same for each route.

The following diagram is called an enthalpy cycle. It shows a reaction where methanol that combusts in air, reacts with oxygen forming carbon dioxide and water. The diagram shows direct and indirect routes:



The Hess's law states that the total enthalpy change of combustion for indirect route and the total enthalpy change of combustion of the direct route are the same. Therefore this should mean that:

$$\Delta H_1 = H_3 - H_2$$

Standard bond enthalpies for elements in their gaseous states (kJmol^{-1}):

Carbon – Carbon (C-C) = +347

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Carbon – Hydrogen (C-H) = +413

Oxygen – Hydrogen (O-H) = +464

Carbon – Oxygen (C-O) = +358

Carbon = Oxygen (C=O) = +805

Oxygen = Oxygen (O=O) = +498

When bonds are broken, energy is absorbed. This can be represented in the following equation:

$$3(\text{C-H}) + \text{C-O} + \text{O-H} + 1.5(\text{O=O}) = 3(413) + 358 + 464 + 1.5(498) \\ = 2808\text{kJ/mol}$$

When bonds are made energy is given out by the reaction:

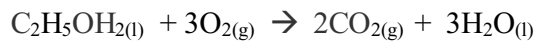
$$2(\text{C=O}) + 4(\text{O-H}) = 2(805) + 4(464) = -3466\text{kJ/mol}$$

The enthalpy change of methanol's combustion can be calculated by adding the energy taken in and given out by the reaction.

$$2808 + -3466 = -658\text{kJ/mol}$$

The same can be done for all the alcohols, giving the following results:

Ethanol:



Energy absorbed during bond breaking:

$$5(\text{C-H}) + (\text{C-C}) + (\text{C-O}) + (\text{O-H}) + 3(\text{O=O}) \\ = 5(413) + 347 + 358 + 464 + 3(498) = 4728\text{kJ/mol}$$

Energy given out during bond making:

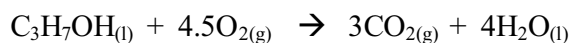
$$4(\text{C=O}) + 6(\text{O-H})$$

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$$= 4(805) + 6(464) = -6004 \text{ kJ/mol}$$

$$\text{Enthalpy change of combustion} = 4728 + -6004 = -1276 \text{ kJ/mol}$$

Propanol:



Energy taken in during bond breaking:

$$7(\text{C-H}) + 2(\text{C-C}) + (\text{C-O}) + (\text{O-H}) + 4.5(\text{O=O})$$

$$= 7(413) + 2(347) + 358 + 464 + 4.5(498) = 6648 \text{ kJ/mol}$$

Energy given out during bond making:

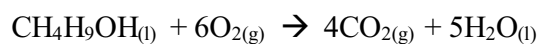
$$6(\text{C=O}) + 8(\text{O-H})$$

$$= 6(805) + 8(464) = -8542 \text{ kJ/mol}$$

Enthalpy change of combustion:

$$6648 + -8542 = -1894 \text{ kJ/mol}$$

Butanol:



Energy absorbed during bond breaking:

$$9(\text{C-H}) + 3(\text{C-C}) + (\text{C-O}) + (\text{O-H}) + 6(\text{O=O})$$

$$= 9(413) + 3(347) + 358 + 464 + 6(498) = 8568 \text{ kJ/mol}$$

Energy given out during bond making:

$$8(\text{C=O}) + 10(\text{O-H})$$

$$= 8(805) + 10(464) = -11080$$

Enthalpy change of combustion:

$$8568 + -11080 = -2512 \text{ kJ/mol}$$

It is obvious that as the molecular mass of the alcohols increases, the enthalpy change of combustion value goes up.

These results are not very accurate because bond enthalpies are an average calculated assuming that the alcohols and the products formed are in their gaseous states, where in my investigation alcohols are liquids. This suggests that the results I will get from my experiment may be different.

Apparatus:

- Calorimeter- to help to transfer energy into water
- Water-100ml
- 4 Alcohols- Methanol, Ethanol, Propanol, Butanol.
- A spirit burner- to burn the above mentioned alcohols
- A thermometer- to measure temperature accurately
- A calorimeter cover- to prevent energy loss
- A heatproof mat- to protect the surface worked on from burning
- A splint- to light the spirit burner
- A ruler- to measure the distance between the bottom of the calorimeter and the wick
- An electronic balance- to measure the weight of the alcohol precisely
- A measuring cylinder- to measure the volume of water used accurately
- A clamp stand- to hold the calorimeter
- Goggles

Preliminary Test

I carried out this experiment to make sure that I get as little errors as possible and get more accurate results. At the start of my investigation I was not sure how far I should measure from the wick to the bottom of the calorimeter, so I tried different distances using 100ml of water and got the following results:

Alcohol	Mass before(g)	Mass after(g)	Mass difference(g)	Temperature before(°C)	Temperature after(°C)	Temperature difference(°C)	Distance b/w the wick and calorimeter (cm)
Methanol (1)	197.44	197.17	0.27	20	28	8	8
Methanol (2)	197.12	196.78	0.34	20	39	19	3

Calculations

Methanol (1)

$$\text{Energy transferred} = 100 \times 4.2 \times 8 = -3360\text{J}$$

Moles used: $0.27/32 = 0.0084375$

1 mole produces: $-3360/0.0084375 = -398222.2222 = -398.2222222\text{kJ}$

Enthalpy change = -398.2222222kJ

Methanol (2)

Energy transferred = $100 \times 4.2 \times 19 = -7980$

Moles used: $0.34/32 = 0.010625$

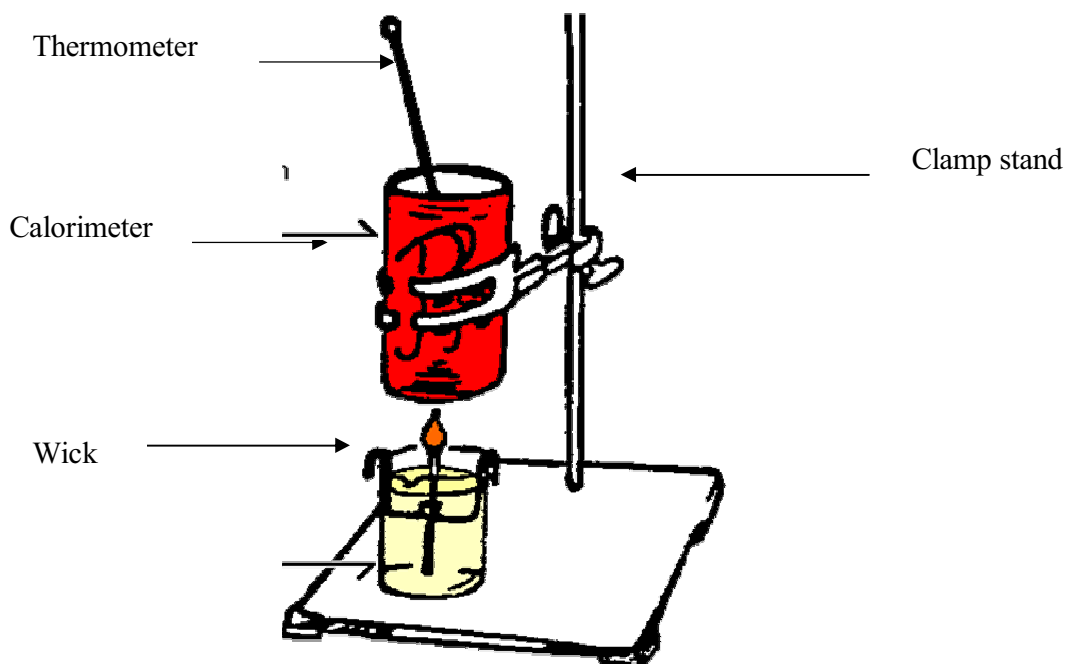
1 mole produces: $-7980/0.010625 = -751058.8235 = -751.0588235\text{kJ}$

Enthalpy change = -751.0588235kJ

Looking at these results I can conclude that 3cm from calorimeter to the wick is more accurate, since the energy transfer is more efficient.

Method:

To carry out this investigation, I will firstly pour 100ml of cold, tap water into a calorimeter and attach it to a clamp stand. Then I will measure the mass of the spirit burner with a particular alcohol in it using an electric balance. I will place the spirit burner under the calorimeter and measure the distance of 3cm from the bottom of the calorimeter to the wick with a ruler. All of this equipment will be placed on a heatproof mat. I will then light a splint and light the spirit burner with it. The alcohol will be burnt until a change of 20°C has occurred. During the experiment I will stir the water occasionally to make sure the temperature around calorimeter is even. After the change has occurred, I will replace the cover back on the spirit burner quickly and re-weigh the alcohol immediately. Goggles and a lab coat will be worn throughout the whole experiment to keep my eyes and my skin from being damaged. I will repeat this experiment with each alcohol three times to make sure that my results are reliable. I will then record my results in a table and find an average mass used to heat the water for each.



Safety:

Methanol is toxic. It can irritate the eyes and mucous membranes. It can also react vigorously with oxidising materials. That is why, to keep safe, me and my fellow students should take care when handling it to make sure it's not spilled since it can react with substances. Also none of us should stay exposed to it for too long to prevent our skin, eyes and mucous membranes being irritated.

Ethanol is a highly flammable chemical. Its vapour can easily catch fire; also inhalation may cause narcotic effects. That's why the spirit burners should be kept well away from naked flames and used in well ventilated classrooms.

Propanol is also highly flammable and can irritate skin. Therefore, it should be kept away from any naked flames and handled with gloves on, if available.

Butanol is harmful and flammable. It can easily catch fire; that is why I should take care when using it, including keeping it away from naked flames.

Fair test:

To make this investigation a fair test, I will make sure I control various factors.

- I will use the same calorimeter each time to make sure the energy transfer was the same each time.
- One balance will be used each time, since different balances can give different readings.
- Water from the tap will be used for each investigation, to make sure the accuracy of the experiment is not at risk.
- Volume of water used will be the same each time.
- The distance between the wick and the bottom of the calorimeter will be measured the same each time, so the same amount of energy is lost to the surroundings each time.
- The temperature will be measured with a thermometer.

Results:

<u>Alcohol</u>	<u>Mass before (g)</u>	<u>Mass after (g)</u>	<u>Mass difference (g)</u>	<u>Temperature before (°C)</u>	<u>Temperature after (°C)</u>	<u>Temperature difference (°C)</u>
Methanol	187.90	187.54	0.36	40	20	20
Methanol	186.76	187.44	0.32	40	20	20
Methanol	185.68	185.29	0.39	40	20	20
Average			0.35			
Ethanol	198.90	198.47	0.43	40	20	20
Ethanol	198.10	197.52	0.58	40	20	20
Ethanol	197.18	196.76	0.42	40	20	20
Average			0.47			
Propanol	222.74	222.34	0.40	40	20	20
Propanol	221.84	221.46	0.38	40	20	20
Propanol	220.86	220.47	0.39	40	20	20
Average			0.39			
Butanol	219.04	218.71	0.33	40	20	20
Butanol	218.52	218.15	0.37	40	20	20
Butanol	218.00	217.70	0.30	40	20	20
Average			0.33			

Calculations:

To calculate the H°_c of an alcohol the following must be done:

Work out the energy transferred/J. The following formula should be used:

Energy transferred/j = Mass of water x Heat capacity of water (4.2J) x Temperature change:

$$\text{Energy Transferred} = 100 \times 4.2 \times 20 = -8400\text{J}$$

This value will not change, since it was kept the same for each alcohol.

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Calculate the number of moles used:

Mass difference of the fuel/Mr of the fuel

1 mole of alcohol will produce:

Energy transferred to water/Moles used = Enthalpy change of combustion

Methanol

Average mass difference: 0.35g

Mr of Methanol: 32.0g

Moles used: $0.35/32.0 = 0.0109375\text{mol}$

1 mole produced: $-8400/0.0109375 = -768000 = -768\text{kJ/mol}$

Enthalpy change of combustion = **-768kJ/mol**

Ethanol

Average mass difference: 0.47g

Mr of Ethanol: 46.0g

Moles used: $0.47/46.0 = 0.010217391\text{mol}$

1 mole produced: $-8400/0.010217391 = -822127.6841\text{J} = -822.1276841\text{kJ/mol}$

Enthalpy change of combustion = **-822.1276841kJ/mol**

Propanol

Average mass difference: 0.39g

Mr of Propanol: 60.0g

Moles used: $0.39/60.0 = 0.0065\text{mol}$

1 mole produced: $-8400/0.0065 = -1292307.692 = -1292.307692\text{kJ/mol}$

Enthalpy change of combustion = **-1292.307692kJ/mol**

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Butanol

Average mass difference: 0.33g

Mr of Butanol: 74.0g

Moles used: $0.33/74.0 = 0.004459459\text{mol}$

1 mole produced: $-8400/0.004459459 = -1883636.558 = -1883.636558\text{kJ/mol}$

Enthalpy change of combustion = **-1883.636558kJ/mol**

Analysis

The evidence I have gathered shows me that the enthalpy change of combustion becomes more negative as the molecular mass of the alcohols increases.

When existing bonds in an alcohol and oxygen are broken, it requires energy. Also when new bonds are formed from the products of the reaction, the energy is given out. The enthalpy change of combustion of the reaction is measured by adding the energy taken in and given out by the reaction.

Looking at my results, I could roughly predict the enthalpy change of the next few straight chain alcohols, however I cannot be sure about them, since my results are not very accurate. I researched the enthalpy changes of the alcohols I investigated and compared those results with mine in the table below:

Alcohol	Enthalpy change calculated by myself(rounded to 1 decimal place)(kJ)	Actual enthalpy change(kJ)	ERROR (kJ)
Methanol	-768.0	-726.0	42
Ethanol	-822.1	-1367.3	545.2
Propanol	-1292.3	-2021.0	728.7
Butanol	-1883.6	-2005.8	122.2

This table shows that my results are definitely not accurate, even though some are more inaccurate than others. This is probably because as the molecular mass went up, there was more heat lost to the surroundings because more energy was given out per unit of time (this is untrue for Butanol probably because I took extra care during the investigation). Even though all these errors were observed, a pattern can be seen from my results that supports my prediction.

Results like the one of ethanol are significantly smaller than those in a text book, which might suggest that the alcohol did not combust completely and instead of producing carbon dioxide and water, also formed carbon deposit at the bottom of calorimeter which is considered a product of incomplete combustion.

When an alcohol is oxidised, the bonds between the molecules are broken. In an alcohol which chains are longer, the bonds are easier to break resulting in less energy being required to break the bonds which means more energy will be released during the making of carbon dioxide and water bonds, which will be weak since the substances are formed in their gaseous states. However carbon formed is a solid, meaning that it has to form stronger bonds requiring more energy. That means less energy will be transferred into the water in a calorimeter.

From my graph it can be seen that the result for ethanol does not fit in with the line of best fit like the rest of the results. That has probably occurred due to faults in my equipment. However the overall trend on my graph supports my prediction. The results I have researched are 650kJ/mol on average away from each other. My results show the following:

Methanol to Ethanol: 54kJ/mol

Ethanol to Propanol: 470kJ/mol

Propanol to Butanol: 591kJ/mol

Looking at those, I can conclude that there is no trend like in the researched results within my results.

Percentage error:

$$\% \text{ error} = \frac{\text{Error}}{\text{Expected Result}} \times 100$$

Methanol: $42/726.0 = 0.057851239 \times 100 = 5.78 \%$

Ethanol: $545.2/1367.3 = 0.398742046 \times 100 = 39.87\%$

Propanol: $728.7/2021.0 = 0.360564077 \times 100 = 36.05\%$

Butanol: $2005.8/122.2 = 16.41407529 \times 100 = 1641.40\%$

EVALUATION

Looking at my investigation, I identified a number of limitations that could have led to the errors shown in my results.

- Heat could have been lost to the surroundings since there was nothing around the apparatus, where draft excluders could have been placed to prevent that loss.
- Since some of the alcohols have toxic fumes, the room had to be well ventilated for our safety; that could have resulted in heat loss also.

- The thermometer was left for me to read which means there could have been a slight human error. An electric thermometer could have been used; which could record the peak temperature, so no errors would be made during the reading taking.
- The soot at the bottom of the calorimeter could have been acting as an insulator and stopping the efficient energy transfer.
- A conclusion cannot be drawn about every alcohol because none of the isomers were used.
- If I was to do this investigation again, I would take into account all the factors mentioned above and also to extend it, I would use a wider variety of alcohols(e.g. up to hexanol) and also try and do it with some isomers(e.g. Propan-2-ol).