

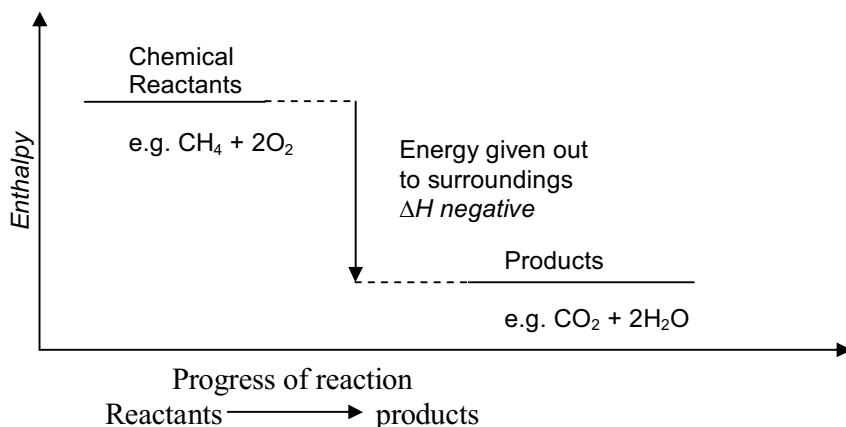
## Comparing The Enthalpy Changes of Combustion of Different Alcohols

### Aim

I am going to investigate the difference in enthalpy of combustion for a number of different alcohols. My aim is to find out how the hydrocarbon carbon chain length affects the enthalpy change that occurs during the combustion of alcohols. The enthalpy change of combustion of a fuel is a measure of the energy transferred when one mole of the fuel burns completely in oxygen. I will be able to calculate a value for enthalpy change by burning different fuels to heat a specific amount of water using the fact that 4.2J of energy are required to raise the temperature of 1g of water by 1°C. I will produce a wide range of results and will be able to compare them, calculate their enthalpy change of combustion and effectively find out which alcohol has the highest enthalpy change.

### Hypothesis

Many chemical reactions give out energy and a few take in energy. A reaction that gives out energy and heats the surroundings is described as an exothermic reaction. Endothermic is a reaction that takes energy in and cools the surroundings. The alcohols that I am using, all have an exothermic reaction when burnt in air. We use exothermic reactions to heat our surroundings by the chemical reactants losing energy. The energy transferred to and from the surroundings can be measured as enthalpy change. This is where the products end up with less energy than the reactants however, the surroundings end up with more energy and so it gets hotter. We can show enthalpy change as an enthalpy level diagram



In an exothermic reaction, the bonds that form the molecular structure of the compound break, to form new bonds. In order for the bonds to break, energy is required for the reaction to commence. When new bonds are formed, energy is then released and our products are then formed. If the hydrocarbon chain has more bonds to break, then more energy is then lost to the

surroundings. Therefore fewer moles of fuel will be used to achieve the specified temperature rise of  $10^{\circ}\text{C}$ . As Hexane has the largest hydrocarbon chain then I predict that Hexane will give off the highest enthalpy change of combustion.

### **Null Hypothesis**

There will be no relationship found between the length of the hydrocarbon chain and the enthalpy change of combustion.

### **Background**

The enthalpy change of combustion of a fuel is a measure of energy transferred when one mole of the fuel burns completely. A value for the enthalpy change can be obtained by using the burning fuel to heat water and using fact that 4.2J of energy are required to raise the temperature of 1g of water by  $1^{\circ}\text{C}$ . I can use this information to work the enthalpy change of combustion of each alcohol and come to a fair and accurate conclusion.

**Variables**

Independent variable: – Is the fuel that I'm using or the chemical structure of the fuel I'm using

Dependant variable: –The change in weight of fuel

Control Variables: – Below is a table of my control variables and how I will be keeping them the same. Plus what effect that it has on the experiment.

<u>Variable</u>	<u>How to control it</u>	<u>Effect</u>
Heat loss	Put things like heatproof mats surrounding the fuel burner & cork plug in the calorimeter to reduce heat loss	This will give me more accurate results and when calculating the enthalpy changes the energy transfer will be closer to the standard
Wick length	Keep the wick at a standard length of 1 cm. For all fuels	This should keep the size of the flame similar to each other. Then this can't be unfair to the other fuels. Because is one flame was bigger than the other it may heat up the fuel faster than others. It could be the nature of the fuel that makes the difference in the size of flame but I can't control this.
Height from top of wick to bottom of calorimeter	I will keep the height from the wick to the bottom of calorimeter at 10 cm throughout the experiment.	This will make sure that every fuel is the same distance from the calorimeter so one fuel doest heat up the water faster than the other
Amount of water in the calorimeter	I will put 100 cm <sup>3</sup> of water in to the calorimeter each time for each different fuel	Now each fuel will have the same amount of water to heat up, and this will make it fair.
Plentiful supply of oxygen.	Make sure that the flame is not sealed completely.	It will cause the flame to burn in complete combustion and no soot will be formed.
Temperature rise	Let the temperature rise by 10°C	This will make all my results fair. I am letting it rise by 10°C because the more a substance has to rise in temperature the faster the heat is lost from the water. So if it was raised by 20°C the heat from the water that the flame had already heated is being lost to the air so low temperatures reduces the time it takes to heat the water.

**Method**

Before attempting any practical work I must identify any hazards, assess the risks from these hazards, and then decide appropriate control measures to reduce these risks. This is so I can reduce the risk of anyone getting hurt and knowing what to do if such an event would happen.

**Risk Assessment**

<b><u>Fuel</u></b>	<b><u>Principle Hazards</u></b>	<b><u>Safe Handling</u></b>	<b><u>Emergency</u></b>	<b><u>Disposal</u></b>
Methanol – C1 H3 OH	Methanol is toxic. If ingested or inhaled it can cause a wide range of harmful effects, from sickness, heart and liver damage to reproductive harm, blindness or death. Methanol is very flammable. The pure liquid catches fire easily and aqueous solutions containing a significant amount of methanol can also catch fire.	Always wear safety glasses. Remove any source of ignition from the working area. You should not breathe in the vapour, so use a fume cupboard if available. If this is not possible, ensure that the area in which you work is very well ventilated. If spilt, turn off all sources of ignition and the spillage must be cleaned immediately in the appropriate way. Always burn small volumes of the alcohol using a spirit burner.	<b><i>Eye contact:</i></b> Immediately flush the eye with plenty of water. Continue for several minutes and call for medical help. <b><i>Skin contact:</i></b> A person whose clothes are soaked in methanol will be at serious risk from fire, so immediately remove any contaminated clothing and store well away from a source of ignition (preferably outside). Wash exposed skin with soap and water. If the skin reddens or appears damaged, or if methanol may have been swallowed, call for medical aid. <b><i>If swallowed:</i></b> Call for immediate medical help; if the quantity swallowed is significant urgent medical action is vital.	Trace amounts of methanol can be flushed down a sink with a large quantity of water, unless local rules prohibit this. Larger amounts should be collected in a non-chlorinated waste solvent container for disposal.

<p><u>Ethanol – C<sub>2</sub>H<sub>4</sub>OH</u></p>	<p>Contact with the eyes can cause considerable irritation. Consumption of small amounts of ethanol is not likely to be harmful, but consumption of large amounts can be fatal. Chronic ingestion of ethanol may lead to damage to a variety of organs, such as the liver, and may increase the risk of cancer. Ethanol is very flammable, so forms a fire risk. The Flashpoint of Ethanol is 13 C at which it is the lowest point it can burn.</p>	<p>Wear safety glasses. Ensure that no sources of ignition, such as a gas flame, hot plate or hot air gun, are present in the working area. Check that ventilation is good; use a fume cupboard if possible. If spilt, turn off all sources of ignition and the spillage must be cleaned immediately in the appropriate way. Always burn small volumes of the alcohol using a spirit burner.</p>	<p><b>Eye contact:</b> Flush the eye with plenty of water. If irritation persists, call for medical help. <b>Skin contact:</b> Wash off with water. <b>If swallowed:</b> Seek medical attention immediately especially if victim shows signs of intoxication.</p>	<p>Dilute to a 5% solution before pouring down a foul water drain.</p>
<p><u>Propan-1-ol – C<sub>3</sub>H<sub>7</sub>OH</u></p>	<p>Propan-1-ol is very flammable. It evaporates readily, so it is possible for dangerous levels of vapour to build up and cause a high risk of explosion if an ignition is present. A high risk of blindness if in contact with eyes. Can easily be absorbed through the skin. The Flashpoint of Propan-1-ol is 15 C</p>	<p>Wear safety glasses. Ensure that there is no sources of ignition, such as a Bunsen burner, hot plate or hot air gun, near the working area. Good ventilation is essential; use of a fume cupboard is desirable. If spilt, turn off all sources of ignition and the spillage must be cleaned immediately in the appropriate way.. Always burn small volumes of the alcohol using a spirit burner.</p>	<p><b>Eye contact:</b> Immediately flush the eye with plenty of water. If irritation persists, call for medical help. <b>Skin contact:</b> Wash off with water. Remove any contaminated clothing. Note that clothing soaked in propanol will present a significant fire risk, so should be removed immediately and placed in a safe location outside the building or in a fume cupboard. <b>If swallowed:</b> Call for medical help.</p>	<p>Prepare a 15% solution before pouring down a foul water drain.</p>

<p><u>Butanol – C4 H9 OH</u></p>	<p>Butanol is harmful if you swallow or inhale it. This material is very flammable. The Flashpoint of Butanol is 29 C</p>	<p>Wear safety glasses. Ensure adequate ventilation. Do not work near a source of ignition. May be ignited by contact with a hot plate or even a hot water pipe - a naked flame is not required. If spilt, turn off all sources of ignition and the spillage must be cleaned immediately in the appropriate way. Always burn small volumes of the alcohol using a spirit burner.</p>	<p><b>Eye contact:</b> Immediately flush the eye with plenty of water. If irritation persists, call for medical help. <b>Skin contact:</b> Wash off with water. Remove any contaminated clothing. If the skin reddens or appears damaged, call for medical aid. Be aware that clothes soaked in butanol present a serious fire risk, so ensure that clothes (and anybody in them!) are kept well away from sources of ignition. <b>If swallowed:</b> Wash out the mouth with water if the person is conscious. If a significant quantity has been swallowed, call for immediate medical help.</p>	<p>Dilute these alcohols to less than 10% before pouring down a foul water drain</p>
<p><u>Hexane – C6 H14</u></p>	<p>Hexane is very flammable. Because it is highly volatile, dangerous concentrations can develop in ambient air, creating a possible explosion risk. May cause impaired fertility. Harmful by inhalation. Irritant. Prolonged exposure may cause serious health damage. The Flashpoint of Hexane is 59 C</p>	<p>Always wear safety glasses. Do not work in an area in which sources of ignition, such as a Bunsen burner or hot air gun, are used. Ensure good ventilation at all times - use a fume cupboard for your work if possible. If spilt, turn off all sources of ignition and the spillage must be cleaned immediately in the appropriate way. Always burn small volumes of the alcohol using a spirit burner.</p>	<p><b>Eye contact:</b> Immediately flush the eye with plenty of water. If irritation persists, call for medical help. <b>Skin contact:</b> Wash off with plenty of water. Remove any contaminated clothing immediately. Note that clothes soaked in hexane will present an extreme fire risk, so rapid action is essential. Place clothes in a safe location, such as outside the building (and do not forget to deal with them subsequently!). If the skin reddens or appears damaged, call for medical aid. <b>If swallowed:</b> Call for immediate medical help.</p>	<p>Burn small volumes of the alcohol using a spirit burner in a fume cupboard</p>

As part of my risk assessment I need to assess how likely this could occur and what impact it could have. To show this I have devised a risk assessment matrix shown below. This enables me to think about the likelihood, hazard and impact of a particular risk.

	Low	Medium	High
Low	1	2	3
Medium	2	4	6
High	3	6	9

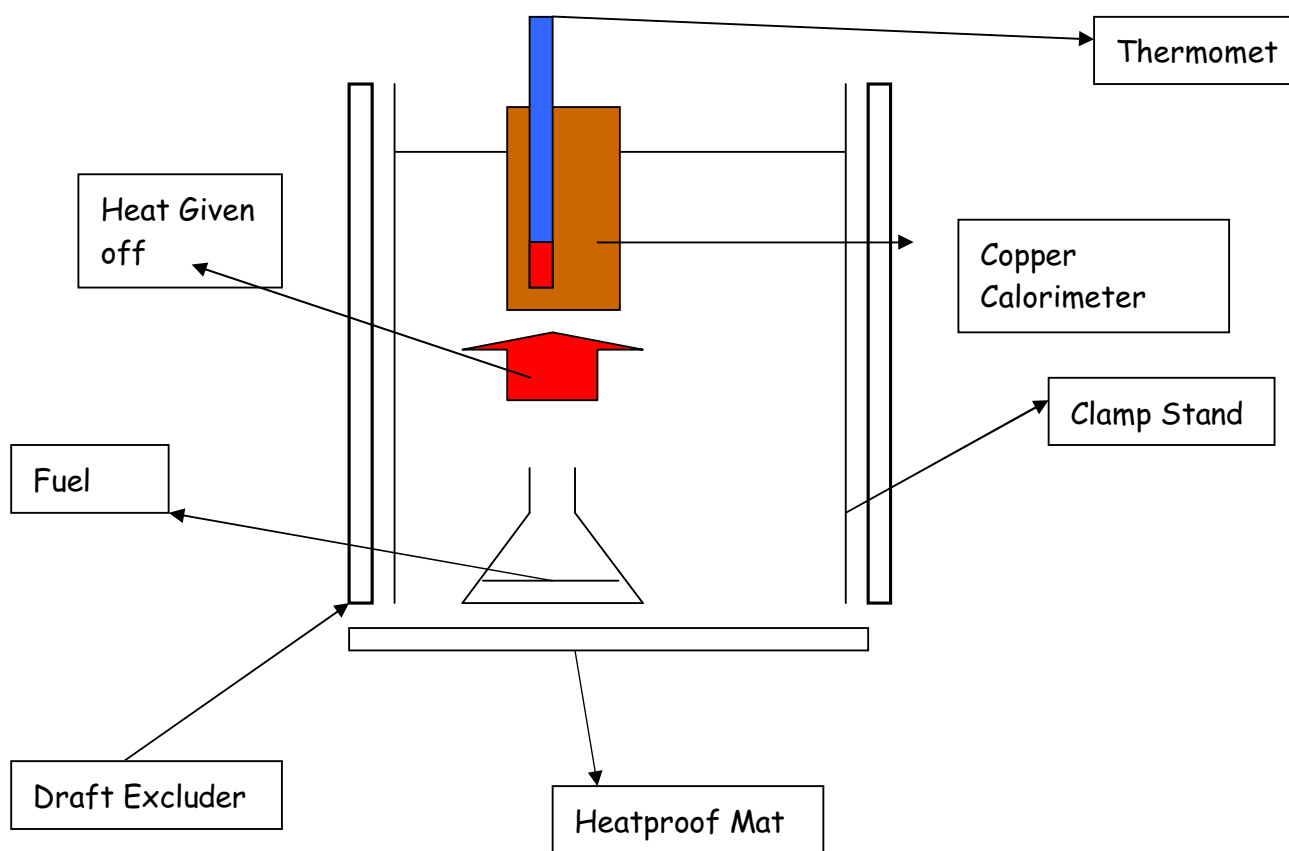
<u>Risk</u>	<u>Likelihood</u>	<u>Hazard</u>	<u>Impact</u>
<i>Spillage</i>	4	4	3
<i>Swallowing</i>	1	3	6
<i>Contact with eye</i>	2	4	6
<i>Contact with skin</i>	6	3	3

For this experiment, the alcohols that I will be using are Me thanol, Ethanol, Propan-1-ol, Butanol and Hexane.

### Equipment list

In this experiment I will be using the following equipment:

- Copper Calorimeter (I will use copper because copper is a good thermal conductor)
- Thermometer
- Clamp stand
- Boss
- Clamp
- 4x heatproof mats
- 5x fuels
- Balance
- Matches

Diagram of the ApparatusSet up and procedure: -

1. Set up the clamp stand, boss and clamp
2. Attach the copper calorimeter to the clamp
3. Adjust the height of the calorimeter so it is 10cm above the fuel wick.
4. Weigh the alcohol (Methanol) with the lid on and record the weight.
5. Pour in  $100\text{cm}^3$  water into the copper calorimeter and record the temperature.
6. Place the heatproof mat underneath the fuel bottle and set up the draft excluder.
7. Remove the lid from the alcohol bottle and light the wick using the matches.



8. Stir the water with the thermometer being careful not to touch the bottom or the sides of the calorimeter, so the water is heated evenly. Let the water heat up  $10^{\circ}\text{C}$
9. Extinguish the flame by snuffing it with the lid of the alcohol bottle.
10. Weigh the alcohol bottle and record the weight.
11. Repeat this method a further 2 times for methanol.
12. Follow this method for all the alcohols, making sure that every stage is done carefully and accurately.

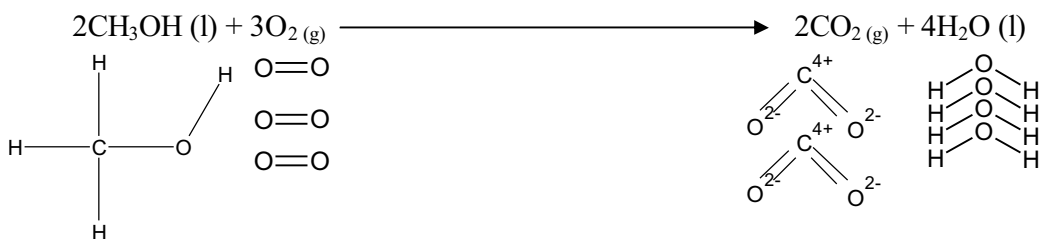


## Analysis

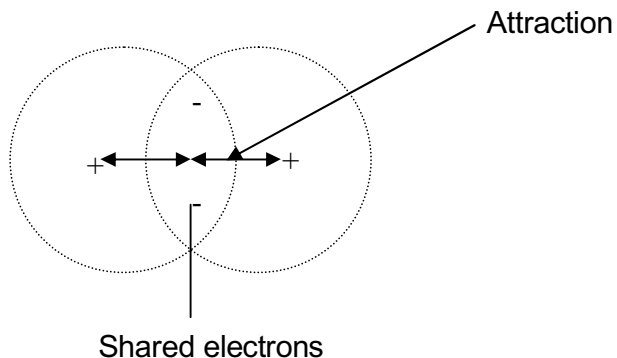
Standard enthalpy change of combustion  $\Delta H_{c, 298}^{\ominus}$  is the enthalpy change that occurs when 1 mole of fuel is burned completely in oxygen, where 298 is the standard temperature in K (25 °C). If  $\Delta H$  refers to these standard conditions it is written as  $\Delta H_{c, 298}^{\ominus}$ . When an exothermic reaction occurs, the enthalpy change is a negative number. This is because during combustion the reactants lose energy to their surroundings

The enthalpy change of combustion of a fuel depends on two things. First, there is the number of bonds to be broken and made. This will depend on the size of the molecule involved, the longer the hydrocarbon chain the higher the number of bonds. The  $\Delta H_{c}^{\ominus}$  also depends on the type of bonds involved i.e. double bonds or single bonds etc.

### Example of combustion



From the figure above we can see which bonds are going to break in the reaction. The bonds that break are 3 C-H bonds 3O=O bonds 4C=O bonds 9 H-O bonds 1 C-O bonds.



When a bond like the one above forms, the atoms move together because of the attractive forces between nuclei and electrons. But there are also repulsive forces, between the nuclei of the two atoms because of two positive charges, and so these get bigger as the atoms get closer until the atoms stop moving together. The distance between them is now the equilibrium bond length. The shorter the bond length the stronger the attraction between the atoms, thus the harder it is to break them apart.

Enthalpy change is measured in kilojoules per mole. So for every mole of a substance that reacts with oxygen,  $n$  kJ of energy is transferred to heat the

surroundings. If we have 2 moles of substance reacting with oxygen then we simply multiply  $n$  by 2.

If we measure the temperature change of water, and if we know its mass and specific heating capacity, we can then work out how much energy was transferred to the water during the chemical reaction. We can use the relationship:

$$\text{Energy transferred} = cm\Delta T$$

Where  $c$  is the specific heating capacity of water =  $4.17 \text{ J g}^{-1} \text{ K}^{-1}$

$m$  is the mass of water, in g

$\Delta T$  is the change in temperature of the water.

If we take Ethanol for example,

The molecular mass = 46,

$$\Delta \text{ Fuel burned} = 1.26 \text{ J} \quad \Delta T = 10 \text{ }^\circ\text{C} \quad \text{mass of water} = 0.096 \text{ Kg}$$

$$\Delta H = cm\Delta T$$

$$\Delta H = 4.17 \times 0.096 \times 10 = -4.0032 \text{ kJ}$$

We can use  $\Delta$  Fuel burned to work out the Enthalpy change of combustion of Ethanol

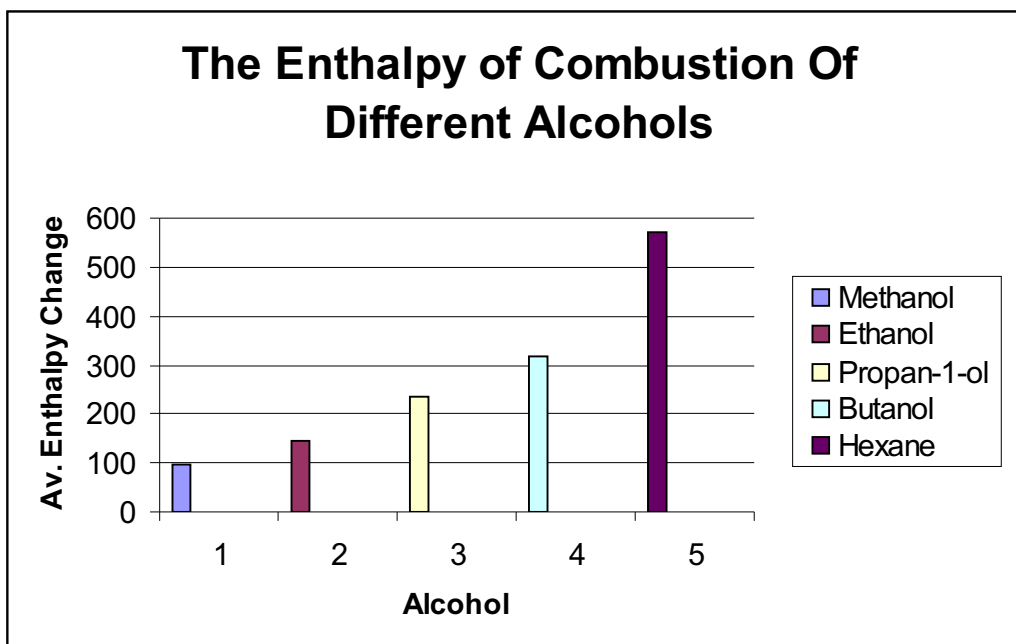
$$\text{Enthalpy change of combustion of Ethanol} = \frac{-4.0032}{1.26} \times 46$$

$$= -148.93 \text{ kJ mol}^{-1}$$

Below is a table of enthalpy changes that I calculated for all the alcohols using the above method. Highlighted in red is any anomalous result that may have occurred.

Fuel	Methanol (CH <sub>3</sub> OH)			Ethanol (C <sub>2</sub> H <sub>5</sub> OH)			Propan-1-ol (C <sub>3</sub> H <sub>7</sub> OH)			Butanol (C <sub>4</sub> H <sub>9</sub> OH)			Hexane (C <sub>6</sub> H <sub>14</sub> )		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Enthalpy Changes (kJ mol <sup>-1</sup> )	-80.422	-111.7	-98.1	-148.93	-144.89	-187.03	-225.87	-232.32	-246.4	-317.63	-379.96	-250.96	-309.41	-549.41	-592.65
Average Enthalpy Changes (kJ mol <sup>-1</sup> )	-96.741			-146.91			-234.863			-316.183			-571.03		
Spread sheet Enthalpy Changes (kJ mol <sup>-1</sup> )	-820			-1437			-2054			-2671			-3905		
Data Table Enthalpy Changes (kJ mol <sup>-1</sup> )	-726.3			-1366.7			-2017.3			-2674.9			-4194.7		

Below is a graph of the average enthalpy combustion of the alcohols that I have tested.



Fuel	Av. Enthalpy changes released during the reaction kJ/mol
Methanol	-96.741
Ethanol	-146.910
Propan-1-ol	-234.863
Butanol	-316.183
Hexane	-571.030

From the table opposite, we can see that there is a noticeable pattern between the number of carbon atoms in each fuel and the average enthalpy change. All the alcohols have a steady increase of enthalpy change as the number of Carbon atoms increase as we go down the table. Hexane however, has a much larger increase in enthalpy change. We can expect this because Hexane is not an alcohol but an alkane. During the exothermic reaction, all the alcohols have

an oxygen atom, unlike Hexane. As the energy release during combustion comes from making bonds to oxygen, all the alcohols are partly oxidised so less energy is needed for them to become fully oxidised. Hexane doesn't have any oxygen atoms; so more energy is needed to break the bonds to form bonds with oxygen in the air, resulting in more energy being released.

If I compare my results to the standard enthalpy change of combustion table

below, I can see that there are similarities. Although the figures of the enthalpy change are quite different, the pattern of which the enthalpy change increases is similar. This proves my point, that as the number of carbon atoms increase; the enthalpy change of combustion also increases.

I can also refer to my graph on the previous page, where it shows a positive correlation, showing that there is an increase of energy being released as the number of carbon atoms increase in each fuel.

Fuel	Standard enthalpy changes kJ/mol
Methanol	-726.0
Ethanol	-1367.3
Propan-1-ol	-2021.0
Butanol	-2674.9
Hexane	-4163.0

#### Reference

I got these results from the – Book of data, 1984, longman group.

I expected my results to be different from the 'true' values because there is severe heat loss even with the precautions I took. The only way that I could have eliminated this heat loss completely was if I used a bomb calorimeter This would eliminate heat loss by sealing the fuel in a container and fuel ignited with remote ignition so all energy is transferred to the water.

Whilst conducting the experiment, a huge amount of heat loss would have occurred due to the flame of the spirit burner being susceptible to drafts even with the draft excluder being in place. This would have caused the energy to be released to the surroundings instead heating the water. We also have to consider that incomplete combustion would have occurred. After the experiment, the copper calorimeter had a sufficient amount of carbon on the bottom. This proves that incomplete combustion has occurred. The draft excluder would have increased the possibility of incomplete combustion occurring. Heating the copper of the copper calorimeter would have affected my results, as the energy from the fuel would have been used to heat the metal before heating the water inside. Preheating the calorimeter would improve this, but making sure that the water and calorimeter were at the

exactly the same temperature for each trial of each fuel would prove to be very difficult. When conducting the experiment with Hexane, I noticed that the flame was considerably larger compared to the other fuels. The flame was lapping over the sides of the calorimeter wasting vast amounts of energy, again causing a considerable decrease in values. I could resolve this if I was to do it again by adjusting the height of the calorimeter so that the very top point of the flame was just below the calorimeter for all the fuels. These are just a few possibilities to explain why my enthalpy changes are a lot lower compared to the standard enthalpy change figures.

Another thing to consider is the percentage of error in the equipment that I used to conduct the investigation.

The thermometer has a percentage of error. Its range is  $\pm 0.5\text{ }^{\circ}\text{C}$  and to work out percentage of error I can divide range by how much your measuring. For instance, if the thermometer was measuring  $20\text{ }^{\circ}\text{C}$ , there is a possibility that it could be reading either 19.5 or 20.5 so,

$$\text{Percentage error} = \frac{0.005}{\text{Actual weight}} \times 100$$

Below is a table with the calculations of the percentage error.

Fuel	Weight of Copper Calorimeter	Weight of Copper Calorimeter with water	Weight of water	Start water temperature	Finish water temperature	Height above wick	Fuel weight at start	Finish fuel weight
Methanol	0.0070721%	0.00300341%	0.0052224%	0.0025%	0.0016%	0.005%	0.002606%	0.002628%
Ethanol	0.0070721%	0.00300341%	0.0052224%	0.0025%	0.0016%	0.005%	0.002482%	0.002498%
Propan-1-ol	0.0070721%	0.00300341%	0.0052224%	0.0025%	0.0016%	0.005%	0.002601%	0.002616%
Butanol	0.0070721%	0.00300341%	0.0052224%	0.0025%	0.0016%	0.005%	0.002493%	0.002506%
Hexane	0.0070721%	0.00300341%	0.0052224%	0.0025%	0.0016%	0.005%	0.003193%	0.003216%

From the data above I can say that my experiment was very susceptible to error, perhaps this would have contributed to so much heat loss during the experiment. If I had to repeat this experiment again I would use equipment that had a considerably lower percentage of error. This would involve working to more decimal places, as the error is caused through rounding the figures. If I worked with precision, meaning working with more decimal places then work reduce my percentage of error. However, using equipment that produced very accurate results, like the bomb calorimeter, would save time and work.

The results that I was getting from the experiment were quite repeatable as they followed the same trend as the standard enthalpy change data. However, my results also showed heat loss. My method of extinguishing the flame after the water had risen by the 10°C could be improved. The time spent between the water reaching its 10 C rise and extinguishing the flame was very long, due to the removal of the draft excluders to get to the spirit burner. I am not sure how accurate these results are compared to the true values.

Keeping the room temperature, the amount of temperature rise, the volume of water used and the structure of the draft excluder was important as this would have helped to keep the experiment a fair one. If I didn't keep these the same for each of my experiments this could have dramatically changed my results.

The equipment used proved to be inadequate for this type of experiment as this involves sophisticated apparatus being used to get accurate and reliable data. Heat energy can be very easily lost and so using equipment that is very accurate is vital. However, taking the appropriate precautions to help minimise heat loss like using a draft excluder, helped to an extent to which I was able to make a comparison between fuels and the enthalpy change of combustion.



References:

- Chemical Ideas, Second Edition By Salters Advanced Chemistry. Put together by George Burton, John Holman, John Lazonby, Gwen Pilling, and David Waddington. Published by Heinemann Educational Publishers.
- Chemical Storylines, Second Edition By Salters Advanced Chemistry. Put together by George Burton, John Holman, John Lazonby, Gwen Pilling, and David Waddington. Published by Heinemann Educational Publishers.
- Experimental Measurement of Enthalpy Change:  
[http://www.webchem.net/notes/how\\_far/enthalpy/measurement\\_of\\_enthalpy.htm](http://www.webchem.net/notes/how_far/enthalpy/measurement_of_enthalpy.htm)
- Chemical Hazard Cards