

Marc Duxbury

## Comparing the Enthalpy changes of combustion of different alcohols

### Aim:

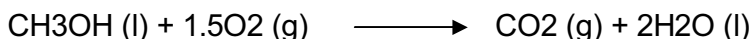
The aim of this experiment is to find out how the enthalpy change (total energy released when the alcohols are completely combusted in a plentiful supply of air) for 5 different alcohols is affected by the number of carbon atoms in the alcohol and other factors contributing to the molecular structure.

### Prediction:

I predict that as the amount of carbon atoms in the alcohol increases, the higher the enthalpy of combustion will be. I have made this prediction, using the values for the enthalpy change of combustion for each alcohol, calculated using bond enthalpies and Hess' law.

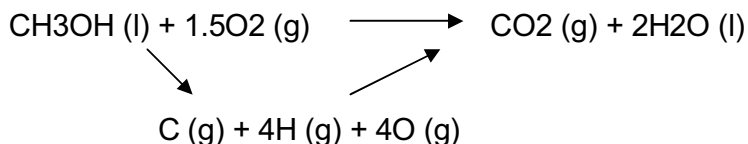
Methanol's molecular formula is CH<sub>3</sub>OH. This is the basic structure for all the alcohols, then to make the larger ones an extra carbon is added to the existing carbon each time and the oxygen-hydrogen molecule gets added to the atoms added to the new carbon atom

When methanol combusts in air, it reacts with oxygen molecules to form water and carbon dioxide. The balanced equation for this is:



This means that the bonds broken are; 3 carbon - hydrogen, 1 carbon-oxygen, 1 oxygen-hydrogen and 1.5 oxygen - oxygen (double bond) and the bonds broken are; 2 carbon - oxygen (double bond) and 4 oxygen -hydrogen.

Constructing a Hess' law cycle will show how these are linked together:



N.B. bond enthalpies are for elements in their gaseous states

If a calculation for the amount of energy needed to break the bonds is made and then the amount of energy given out from bond formation, the resultant energy difference (negative because the reaction is exothermic) is the enthalpy change of combustion.

Average bond enthalpies for elements in their gaseous states (kJmol<sup>-1</sup>):

Carbon – Carbon (C-C) = +347

Carbon – Hydrogen (C-H) = +413

Oxygen – Hydrogen (O-H) = +464

Carbon – Oxygen (C-O) = +358

Carbon – Oxygen double bond (C=O) = +805

Oxygen – Oxygen double bond (O=O) = +498

Energy absorbed when bonds are broken (positive): (E=Energy)

$$= E \text{ 3(C-H)} + E \text{ (C-O)} + E \text{ (O-H)} + E \text{ 1.5(O=O)}$$

$$= 3(413) + 358 + 464 + 1.5(498)$$

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= 2808kJmol<sup>-1</sup>

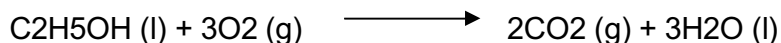
Energy given out when bonds are made (negative): (E=Energy)

$$\begin{aligned} &= E\ 2(\text{C}=\text{O}) + E\ 4(\text{O}-\text{H}) \\ &= 2(805) + 4(464) \\ &= -3466\text{kJmol}^{-1} \end{aligned}$$

$$\begin{aligned} \text{Enthalpy change of combustion} &= \text{Energy absorbed} + \text{energy given out} \\ &= 2808 + -3466 \\ &= -658\text{kJmol}^{-1} \end{aligned}$$

The combustion of methanol gives out  $-658\text{kJ}$  of energy for every mole of fuel burnt. This is only an approximate result and the actual value in my experiment may be different because, firstly the bond enthalpies are an average and they may vary in different molecules and secondly because the values are worked out assuming that the reactants and products are in a gaseous state, when in practice the water and alcohol are liquids. This means that my values for enthalpy change of combustion are likely to be different, but as long as the same method is used for each alcohol the pattern can be seen. I will now use the same bond enthalpy values to work out the estimation of enthalpy change of combustion for each alcohol.

Ethanol:



Energy absorbed when bonds are broken (positive): (E=Energy)

$$\begin{aligned} &= E\ 5(\text{C}-\text{H}) + E\ (\text{C}-\text{C}) + E\ (\text{C}-\text{O}) + E\ (\text{O}-\text{H}) + E\ 3(\text{O}=\text{O}) \\ &= 5(413) + 347 + 358 + 464 + 3(498) \\ &= 4728\text{kJmol}^{-1} \end{aligned}$$

Energy given out when bonds are made (negative): (E=Energy)

$$\begin{aligned} &= E\ 4(\text{C}=\text{O}) + E\ 6(\text{O}-\text{H}) \\ &= 4(805) + 6(464) \\ &= -6004\text{kJmol}^{-1} \end{aligned}$$

$$\begin{aligned} \text{Enthalpy change of combustion} &= \text{Energy absorbed} + \text{energy given out} \\ &= 4728 + -6004 \\ &= -1276\text{kJmol}^{-1} \end{aligned}$$

Propan1-ol:



Energy absorbed when bonds are broken (positive): (E=Energy)

$$\begin{aligned} &= E\ 7(\text{C}-\text{H}) + E\ 2(\text{C}-\text{C}) + E\ (\text{C}-\text{O}) + E\ (\text{O}-\text{H}) + E\ 4.5(\text{O}=\text{O}) \\ &= 7(413) + 2(347) + 358 + 464 + 4.5(498) \\ &= 6648\text{kJmol}^{-1} \end{aligned}$$

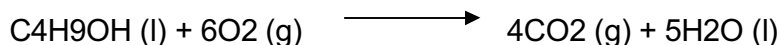
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Energy given out when bonds are made (negative): (E=Energy)

$$\begin{aligned} &= E\ 6(\text{C}=\text{O}) + E\ 8(\text{O}-\text{H}) \\ &= 6(805) + 8(464) \\ &= -8542\text{kJmol}^{-1} \end{aligned}$$

$$\begin{aligned} \text{Enthalpy change of combustion} &= \text{Energy absorbed} + \text{energy given out} \\ &= 6648 + -8542 \\ &= -1894\text{kJmol}^{-1} \end{aligned}$$

### Butan1-ol:



Energy absorbed when bonds are broken (positive): (E=Energy)

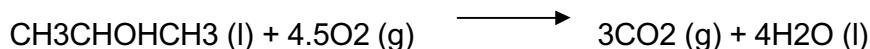
$$\begin{aligned} &= E\ 9(\text{C}-\text{H}) + E\ 3(\text{C}-\text{C}) + E\ (\text{C}-\text{O}) + E\ (\text{O}-\text{H}) + E\ 6(\text{O}=\text{O}) \\ &= 9(413) + 3(347) + 358 + 464 + 6(498) \\ &= 8568\text{kJmol}^{-1} \end{aligned}$$

Energy given out when bonds are made (negative): (E=Energy)

$$\begin{aligned} &= E\ 8(\text{C}=\text{O}) + E\ 10(\text{O}-\text{H}) \\ &= 8(805) + 10(464) \\ &= -11080\text{kJmol}^{-1} \end{aligned}$$

$$\begin{aligned} \text{Enthalpy change of combustion} &= \text{Energy absorbed} + \text{energy given out} \\ &= 8568 + -11080 \\ &= -2512\text{kJmol}^{-1} \end{aligned}$$

### Propan2-ol:



Energy absorbed when bonds are broken (positive): (E=Energy)

$$\begin{aligned} &= E\ 7(\text{C}-\text{H}) + E\ 2(\text{C}-\text{C}) + E\ (\text{C}-\text{O}) + E\ (\text{O}-\text{H}) + E\ 4.5(\text{O}=\text{O}) \\ &= 7(413) + 2(347) + 358 + 464 + 4.5(498) \\ &= 6648\text{kJmol}^{-1} \end{aligned}$$

Energy given out when bonds are made (negative): (E=Energy)

$$\begin{aligned} &= E\ 6(\text{C}=\text{O}) + E\ 8(\text{O}-\text{H}) \\ &= 6(805) + 8(464) \\ &= -8542\text{kJmol}^{-1} \end{aligned}$$

$$\begin{aligned} \text{Enthalpy change of combustion} &= \text{Energy absorbed} + \text{energy given out} \\ &= 6648 + -8542 \\ &= -1894\text{kJmol}^{-1} \end{aligned}$$

Alcohol (carbon atoms)	Enthalpy change of Combustion (kJmol <sup>-1</sup> )
Methanol (1)	-658
Ethanol (2)	-1276

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Propan1-ol (3)	-1894
Butan1-ol (4)	-2512
Propan2-ol (3)	-1894

As you can see, as the number of carbon atoms (the larger the molecule) in the molecule increase, the enthalpy change of combustion (energy given out) increases. This is because there are more higher value bond enthalpies made, giving out more energy. The increase is a constant  $618\text{kJmol}^{-1}$  per carbon atom or for every 2 hydrogen atoms, so the structure of the alcohol proportionally affects the enthalpy change of combustion. So the larger alcohols will give out more heat energy per mole and the temperature of the water will rise more while less of the fuel is burnt leading to a higher enthalpy change of combustion.

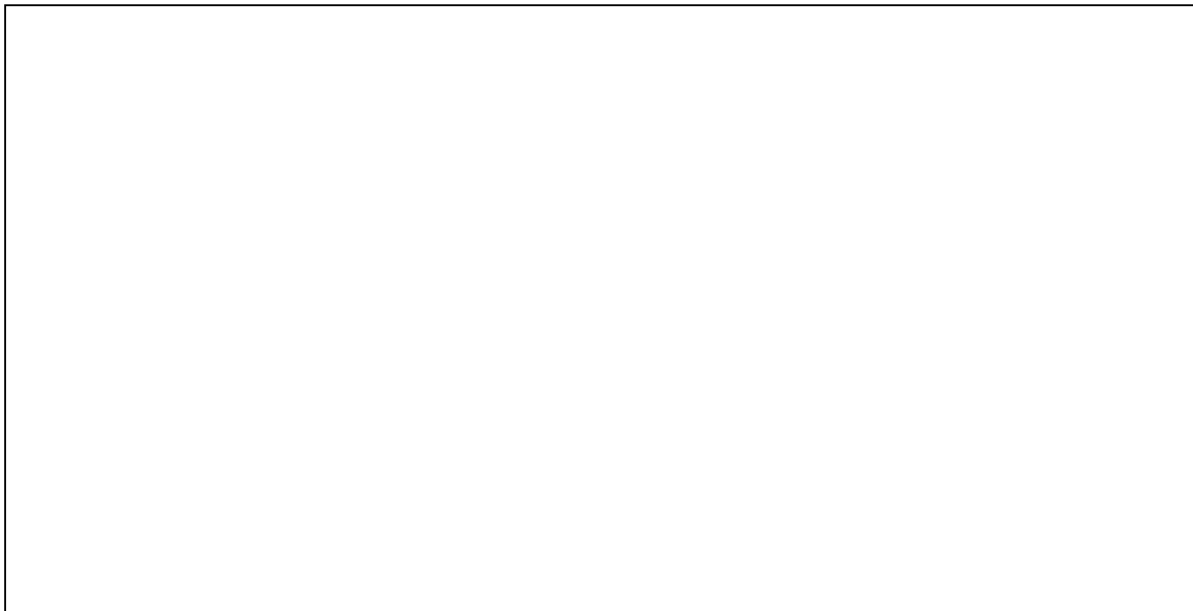
My other aim was to find out if the position of the OH group will affect the enthalpy change. Propan1-ol has the OH group on the last carbon in the chain, whereas Propan2-ol has the OH group on the middle carbon. I am aware that this could very well affect the enthalpy change of combustion because the bond enthalpies vary depending on the molecule they're in, but using my predicting method above, the enthalpy change of combustion is not affected by the position of the OH group in the molecule. My experiment may prove otherwise.

### **Equipment list:**

- Small copper calorimeter with a lid
- Spirit burners with methanol, ethanol, propan1-ol, butan1-ol and propan2-ol in them
- Clamp Stand and clamp
- Thermometer (0-100°C)
- Balance
- Safety mat
- 100cm<sup>3</sup> measuring cylinder
- Glass rod as a stirrer
- Draught shields
- Bunsen burner or matches

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**Diagram:**



**Method:**

I am going to conduct this experiment to find out if the length of an alcohol molecule and the position of the OH group affect the enthalpy change of combustion. I will work out the enthalpy change by using the fact that it takes 4.2J of energy to raise the temperature of 1g of water by 1°C and assuming that 1ml of water weighs 1g. I will use a 100cm<sup>3</sup>-measuring cylinder to measure out 100cm<sup>3</sup> of cold tap water. This has sufficient measuring accuracy, as the amount of water is quite high, so using a more accurate measuring device will not significantly increase the accuracy of my experiment. I have used 100cm<sup>3</sup> of water because it is enough to have a low percentage error when it is measured, but it will reach the temperature rise quicker than a larger amount of water, leading to a lower amount of burning time, which means less heat energy is lost to the surroundings and a more precise result is achieved.

I will then pour the water into a small copper calorimeter. I am using a copper calorimeter because copper is a good conductor of heat, so a higher percentage of the heat from the burning fuel will be transferred to the water to be measured. It is small to reduce the amount of energy that the calorimeter absorbs itself. I shall then set up the apparatus as shown in the diagram, with a safety mat, the calorimeter held by a clamp stand, with the thermometer inside and draught shields set up all around the experiment. The draught shields have reflective surfaces and so will reduce the amount of energy lost to the surroundings by convection and radiation by reflecting the heat back in on the experiment.

I will make sure that the spirit burner is filled with methanol to start off and that the wick is about 1cm long so that for each experiment the flame will be about the same height, leading to more precise results. The wicks will also be of the same thickness, so that the alcohols have the same surface area to burn from so that the experiment is fair. I will make sure the lid is on the spirit burner and I will measure the weight of the burner and alcohol on a set of accurate scales (electronic). This will give me an accurate measurement of the amount of alcohol, which will be quite small, so it keeps the error in my calculations down. The lid is kept on to avoid any evaporation, affecting the weight of the alcohol.

Using the thermometer I will measure the temperature of the water before the experiment, so I can check the temperature change in °C. The thermometer is also accurate enough to keep the percentage errors in my calculations down enough to be accurate. I will leave the thermometer in for 3 minutes so the actual temperature can be found. I will then place the spirit burner under the calorimeter in the centre and make sure

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that the calorimeter is about 2 or 3cm above the burner. Leaving the thermometer in the water, I will remove the lid of the burner and using a match light the wick. I will move the calorimeter so it is 1cm above the flame, so as much of the energy as possible is transferred to the water and so that my experiment is fair each time. I will put a lid on the calorimeter, as best as I can to reduce the amount of energy lost through convection and radiation from the water so the thermometer reading is accurate.

I will wait until the temperature of the water has risen by 20°C because this is enough to lower the percentage error when reading the thermometer and also it won't take long for the water to achieve this temperature, reducing the experiment time and so reducing the amount of time for heat loss. Throughout the experiment I will stir the water so that the heat is evenly distributed throughout the water. I will then put the lid on the spirit burner and re-weigh the burner on the scales. This will limit the amount of alcohol that evaporates after the experiment finishes so I can attain an accurate amount of fuel burnt. I will use the glass stirrer (glass doesn't conduct heat very well) to stir the water. The glass stirrer will make sure that the heat is evenly distributed throughout the water i.e. to eliminate hot spots, so that a more precise average temperature of the water mass can be found. I will do this for a couple of minutes and check the thermometer temperature until the maximum temperature has been reached. This ensures that as much of the energy that was given out by the fuel is measured as heat energy in the water. The temperature range should not therefore, be much more than 20-25°C

I will record the temperature change (°C) and mass of alcohol burned (g) for methanol in a table. I will then repeat the experiment once more for the same alcohol (methanol), again recording these two measurements. This will ensure that I get a more accurate result. I will then wait for the apparatus to cool down so that it is a fair test. I will repeat the same experiment for ethanol and take two sets of results for it to get an average. The conditions will be the same for each test, e.g. the same environment and same equipment so that it is a fair test and errors are kept down to a minimum so more accurate results are gained. This all applies to the next 3 alcohols so that the experiment is fair for all three sets of results.

I will test, propan-1-ol, butan-1-ol and then propan-2-ol as my last three alcohols. I am using these the first four alcohols (methanol, ethanol, propan-1-ol and butan-1-ol) because I need to test how the length of the molecule (amount of carbon atoms) affects the enthalpy change of combustion and each of those alcohols has the same structure but each one as an extra carbon and two hydrogen atoms so this will help answer this aim. They are also the four smallest alcohols because there are less isomers of these alcohols that are possible. Methanol and ethanol both have the OH group on the last carbon on the chain and I wanted to keep the structure as similar as possible because it is a variable that might affect enthalpy of combustion. If less isomers are possible then propan-1-ol and butan-1-ol are the closest representatives that I can get of propanol and butanol helping to keep this variable unchanged. They also release the least energy, so I can keep control over the temperature much easier than with other, larger alcohols. 4 alcohols is a large enough range to draw conclusions about the general trend. I have also used propan-2-ol, which has its OH group on the middle carbon so that I can investigate if and how the position of the OH group on the molecule affects the enthalpy change of combustion because I can compare it to propan-1-ol.

Once I have the temperature change and amount of fuel burned I can calculate the enthalpy change of combustion. The amount of energy given out by the fuel in joules is defined as; mass of water(g)\*specific heat capacity of water(J)\*temperature change(°C), where the s.p.c of water is 4.2J. So taking an average of the temperature change I can multiply 100 by 4.2 and then by the temperature change to give the amount of energy given out. This is because it takes 4.2J of energy to raise the temperature of 1g of water by 1°C. I can then work out how many moles of the fuel was burnt by dividing the average mass of fuel burnt (g) by the molar mass of the alcohol, given by adding up all the relative masses

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of the elements in the molecule e.g. molar mass of methanol =  $12 + 16 + 4(1) = 32$ . I can then work out the amount of energy given out per mole of fuel burnt by dividing the energy given out by the amount of moles burnt. I will then divide this by 1000 to change the final units to  $\text{kJmol}^{-1}$  and I will have the enthalpy change of combustion for the fuel. I will do this for each alcohol and record the results in a table and display them as a graph, ready for analysis.

### **Safety-Hazard assessment:**

These are the safety considerations I will take into account when doing my experiments -

- The alcohols are flammable, so they need to be handled carefully and never exposed to a naked flame
- The experiment produces heat, so I need to take care when handling hot equipment i.e. wait until they've cooled down
- Alcohol vapours can catch fire at very low temperatures, so whenever possible keep the lid on the spirit burners and re-fill them in a fume cupboard
- The fumes have a toxic effect if inhaled -make sure the room is well ventilated. Seek medical attention if they are inhaled
- They are irritating to skin so if split on skin or eyes, rinse with water and seek medical attention
- If there are any spillages, I will clear them up as I go to avoid any fire hazard, and will remove any clothes that have spillages
- I will wear safety goggles at all times to protect my eyes and will cover my skin where possible
- I will take care with other people's experiments as well, trying not to expose their alcohols to a naked flame

### **Sources used in plan:**

Chemical Ideas – Salters advanced chemistry  
Activity book – Developing fuels