Enthalpy of combustion planning

Aim: To work out the enthalpy change of combustion of alcohols

To work out the enthalpy change of combustion of the alcohols, the energy output must be measured. This simplest way of doing this accurately is to use the thermal energy of combustion to raise the temperature of a substance with a known specific heat capacity.
The rise in temperature of this substance can then used to work out the thermal energy used to do this work.

Basic plan

Apparatus

Metal calorimeter
Thermometer measures to 0.1 ^{o}c
Clamp stand
Alcohol with spirit burner
Heat proof mat
Scales that measure to two decimal places
Wooden splint

100cm3 measuring cylinder that measures 1cm3
For safety
To begin with prepare a table remove all items of stationary from the surface and place them in bags, leaving only the paper and pen that are to be used to record the results. Remove bags from under the desks and place them in the designated positions.
With the exception of the scales collect all the apparatus above, and place them on the prepared table. To ensure the weights recorded on the scales are reliable.
Switch the scales on, wait until the balance has settled, once the balance has settled press the tare button to ensure that the balance reads 0.00 and the balance registers the entire weight of the spirit burner alcohol. Weigh the alcohol in the burner to two decimal places with burner lid on. This weight should be recorded straight away in the table below, to ensure that a simple mistake in the recall of a figure weight doesn't corrupt the reliability of the final findings.
The weighed alcohol should be placed with the equipment on the prepared desk.
Next 100cm3 should be carefully measured out ensuring the bottom of the meniscus rests on the 100cm3 line.
This water should then be carefully poured into the calorimeter, (no water should be present before hand and if the calorimeter has been previously used it should be dried with a cloth as it could affect the results) The lid should be placed on to prevent any water being lost through evaporation before and after the heating.

The equipment should then be set up as seen in figure 1. However before the draught shield is put in place calorimeter should be positioned exactly 10cm above the flame.
This is to ensure that the same distance is present between each of the alcohols and the water that it is heating. Keeping this constant between different fuels ensures that the same amount of energy will be lost to the surroundings for each fuel.
(Because the specific heat capacity is a single value, if the volume of air in between the flame and the calorimeter is kept the same, then the same amount of energy is needed to heat the surrounding air. Hence since this energy loss is constant for all the fuels it can be disregarded to a certain extent)
Once the distance between the top of the lid and the bottom of the calorimeter has been set at 10cm, the procedure can begin.
Reading the thermometer accurately to 0.05 degrees Celsius, and recording it on the prepared table below.

Table1 figure2

Before the fires are lit to avoid potential hazards due to open flames jackets should be removed, lab coats should be put safety goggles should be put on hair should be tied back.

Next light a splint, hold it in one hand, remove the lid and light the spirit burner, place the draught shield around the clamp stand and spirit burner. The draught shield is simply to ensure that the heat loss to the surroundings is minimal to ensure that the worked values for enthalpy of combustion are as accurate as the equipment in of an A level class room will allow.

The equipment should now be exactly as seen in figure 1.

The water's temperature will rise quickly. I have decided to have a change in temperature of 20°c.

As the water is being heated the thermometer should be used to stir the water. This to ensure that the temperature registering on the thermometer is uniform through out the water and will not rise or fall as the water settles once the heating stops. This is to ensure the temperature recorded in the temperature will be accurate.

The room temperature in the classroom is usually 21°c. To ensure that the water rises by 20°c only, I will remove the draught shield and place the lid on the spirit burner 2°c -3°c before the water reaches 41°c. The number of degrees in advance of the desired 10°c rise that I will place the lid on the spirit burner depends on the amount how fast the temperature is rising. If it appears to be rising rapidly then the lid will be placed on more degrees in advance, if it is rising slower then of course the lid will be placed on fewer degrees in advance.

Even after the flame has been extinguished the thermometer should still be used to stir the water.

The final temperature is the maximum temperature that the water reaches. This is to be recorded in the table above.

The burner should be weighed with the lid on; the same procedure should be followed after heating, as before, the balance must settle before the tare button is pressed.

The weight as before should be recorded straight away.

The water should then be poured into a clean dry $100cm^{3}$-measuring cylinder; the volume of the water should be recorded in to the table above. Assuming that $1cm^{3}$ of water has a mass of 1g I will then know how much water was lost through evaporation.

This process should be repeated to more times with the same alcohol, so that average values can be obtained.

In between repeats new portions of cold water should be measured out and poured in to dry calorimeters to ensure that the temperature rises all take place in the same conditions. As water behaves differently as it approaches boiling temperature, it absorbs more energy with a lower change in temperature in order to break intermolecular attractive forces to become a gas. Also while the water is in the calorimeter there is no way of knowing the mass of water being heated, if it is not refreshed between repeats then the water definitely going to evaporate.

This whole process including the two repeats for each of the other alcohols.

I have chosen to compare the enthalpy change of combustion of consecutive straight chain alcohols. Firstly because I already understand that the physical properties of alcohols like hydrocarbons change

as the relative molecular increases. By investigating consecutive straight chain alcohols I should be able to observe trends, which should make my analysis more interesting

I also know that the trends in properties that can be seen in alcohols are interfered with by the OH bond, because of hydroxyl groups polarising properties, it tends make the properties of the lower alcohols the exception from the trend. By observing trends in the lower alcohols I intend to determine whether the hydroxyl groups effect on physical properties extends to enthalpy change of combustion.

Alcohol	Temperature/°c		Mass of alcohol/g		Mass of water/g	
	Start	End	Start	End	Start	End
Methanol	22	32	207.90	207.52	100	99
	22	32	207.52	207.01	100	100
	23	33	207.01	206.70	100	99
Ethanol	22	32	189.98	189.68	100	100
	23	33	189.68	189.23	100	99
	22	32	188.23	188.83	100	100
Propan-1-ol	23	33	205.60	205.00	100	100
	23	33	205.00	204.50	100	100
	22	32	204.00	204.10	100	100
Butan-1-ol	22	32	192.40	192.20	100	100
	22	32	192.20	191.90	100	100
	23	33	191.90	191.70	100	100

Analysis
Methanol

Attempt number	Temperature/ oc		Mass of alcohol/g		Mass of water/g	
	Start	End	Start	End	Start	End
1	22	32	207.90	207.52	100	99
2	22	32	207.52	207.01	100	100
3	23	33	207.01	206.70	100	99
Average	22.33	32.33	207.48	207.08	100.00	99.33

Average change in temperature recorded over the three attempts is worked out by subtracting the average start temperature from the average end temp.

$\Delta T = \overline{End} - \overline{Start}$

(The line above end represents end bar, as in $\bar{x}$ the accepted mathematical symbol for mean average)

32.33 - 22.33 = 10 °c
ΔMass if alcohol used to obtain this 10 °c is
207.48-207.08= 0.4g

The average mass of water used is obtained by taking an average, of the average start and end volumes. To obtain a mass half way between the two values is the mass to use as the average mass used.

100 +99.33 =99.67g

Ethanol

Attempt number	Temperature/ oc		Mass of alcohol/g		Mass of water/g	
	Start	End	Start	End	Start	End
1	22	32	189.98	189.68	100	100
2	23	33	189.68	189.23	100	99
3	22	32	189.23	188.83	100	100
Average	22.33	32.33	189.63	189.25	100.00	99.67

ΔT 22.33 - 32.33 = 10 ^{o}c
ΔMass if alcohol used to obtain this 10 ^{o}c is
189.30-189.25=0.38 g

Estimated average mass of water used
100.00 + 99.67=99.84
　　　2

Propan-1-ol

Attempt number	Temperature/ oc		Mass of alcohol/g		Mass of water/g	
	Start	End	Start	End	Start	End
1	23	33	205.60	205.00	100	100
2	23	33	205.00	204.50	100	100
3	22	32	204.00	204.10	100	100
Average	22.67	32.67	204.87	204.53	100.00	100.00

ΔT 22.67 - 32.67 = 10 ^{o}c
ΔMass if alcohol used to obtain this 10 ^{o}c is

204.87-204.53=0.34g

100 +100　　　= 100g
　　3

Attempt number	Temperature/ oc		Mass of alcohol/g		Mass of water/g	
	Start	End	Start	End	Start	End
1	22	32	192.40	192.20	100	100
2	22	32	192.20	191.90	100	100
3	23	33	191.90	191.70	100	100
Average	22.33	32.33	192.17	191.93	100.00	100.00

ΔT 22.33 - 32.33 = 10 ^{o}c

ΔMass if alcohol used to obtain this 10 ^{o}c is
192.17 –191.93=0.24 g

100 +100　　　= 100g
　　2

Alcohol	Average change in temperature/°c	Average change in mass of alcohol/g	Estimated average mass of water heated/g
Methanol	10	0.4	99.67
Ethanol	10	0.38	99.84
Propan-1-ol	10	0.34	100.00
Butan-1-ol	10	0.24	100.00

From the table containing the average changes that I observed in the combustion alcohols, I can clearly see a trend in the change in mass of fuel, burnt in order to raise the temperature of approximately 100cm^3 of water by 10°c

As the length of the chain increases, (the table is ordered by number of carbons in a chain increasing by one each row) mass of alcohol used to give out the energy required to raise the temperature 10°c decreases.

As the temperature change is kept constant the amount of energy that each alcohol is required to give out is constant. This suggests that energy is contained in a smaller volume. Which means that there are more covalent bonds being broken per cm^3 of liquid. Manifestly there most be an increase in the density of the alcohol as the length of the chain increases.

Calculation of the enthalpy of combustion

Assumptions made to make this calculation 1cm^3 of water has a mass of 1g
The average mass of water used is exactly half way between the start and end mass
The specific heat capacity of water is 4.2J/g/K

Methanol

$q = cm\Delta T$

q represents the quantity of energy used to obtain the rise in temperature of water
c represents the specific heat capacity, (the amount of energy needed to raise 1 gram of a substance's temperature by 1 °K
m represents mass of the substance being heated
ΔT represents the temperature change observed in the substance being heated

q=4.2J/g/K x 99.67gx10°K

Note the intervals in the Kelvin scale are the same as the intervals of the Celsius scale therefore a change of 10°c is the same as change of 10 °K
q= 4186.14J
The average heat energy absorbed by water from the combustion of methanol was 4190J
To the enthalpy of combustion is energy given out (thermal) when one mole of a fuel is combusted
I have worked out how much thermal energy 0.4g of methanol has given out

There fore to work out the amount of energy one mole would give out, I need to work out the number of moles used to give out 4190J of thermal energy.
Then divide the quantity of energy by this number

The formula of the fuel is CH_3OH
To work out the number of moles used I need to work out the mass of one mole of the methanol
The relative molecular mass of the formula above is 12 + 3 + 16+1=32

One mole of CH_3OH weighs 32g
To calculate the number of moles used I will need to divide the mass used by the mass of one mole
To work out the number of moles used to raise the water's temperature by 10 °K
Mass used = no. mol
Mr

$\dfrac{0.4g}{32g} = 0.0125 \text{moles}$

0.0125moles of methage my result is out is

=46.14%

726

100-46.14 =53.86

out

ty is 0.51%

Ethanol

sures to 0.1 oc is 0.05

centage uncertainty in reading the thermometer ianol is combusted is 4190J

The molecular formula of ethanol is C_2H_5OH
One mole of ethanol has a mass of 24+5+16+1=46g

The number of moles used is mass used
                                Molar mass

$\dfrac{0.38}{46} = 8.26 \times 10^{-3}$

Therefore the thermal energy that the combustion of one mole of ethanol would give out is

$\dfrac{4190 \text{ J}}{8.26 \times 10^{-3} \text{moles}}$ $= 5.07 \times 10^{3}$

The enthalpy of combustion of ethanol is 507kJ/mol

Propan-1-ol

$q = 4.2J/g/K \times 100.00g \times 10\,^{\circ}K$
$q=4200J$

The thermal energy absorbed by water from the combustion of 0.34g of propan-1-ol is 4200J

The molecular formula of propan-1-ol is C_3H_7OH
One mole of ethanol has a mass of 36+7+16+1=60g

The number of moles used is mass used
                                Molar mass

$\dfrac{0.34g}{60} = 5.67 \times 10^{-3}$

Therefore the energy that the combustion of one mole of propan-1-ol would give out is

$\dfrac{4200}{5.67 \times 10^{-3}}$ $= 7.41 \times 10^{6}$

The enthalpy of combustion of propan-1-ol is 741kJ/mol

Butan-1-ol

$q = 4.2J/g/K \times 100.00g \times 10\,^{\circ}K$
$q=4200J$

The thermal energy absorbed by the water in the combustion of 0.24g of Butan-1ol is 4200J
The molecular formula of Butan-1-ol is C4H9OH
One mole of Butan-1-ol has a mass of 48+9+16+1=74g

The number of moles is used is mass used
                                Molar mass

$\dfrac{0.24}{74} = 3.24 \times 10^{-3}$

Therefore the thermal energy that one mole of butan-1-ol would give out is

$$\frac{4200}{3.24 \times 10^{-3}} = 1.30 \times 10^{6}$$

The enthalpy change of combustion of one mole of butan-1-ol is 1300kJ/mol

The enthalpy change of combustion of alcohols increases as the length of the chain increases.

The chain length increases with an addition of a CH2 group

When the alcohol is combusted what actually happens is the covalent bonds are broken, and new bond are formed.
More energy is released from the formation of bonds then is absorbed to break the bonds of the alcohol.
Subsequently the more atoms in the alcohol, more bonds are broken, and more bonds are formed.
The enthalpy change of this.
Because in the combustion of alcohols C-H and C-C bonds more energy is released then absorbed, the more carbons to from CO_2 and the more hydrogen to form H_2O the more energy is given out.
Hence the rise in enthalpy change as the chains length increases

Evaluation
The value that I worked out for the enthalpy change of combustion of methanol is 335kJ/mol.
The actual value is 726kJmol; I realised that my result would not be the same as the actual results as when I placed the lid on the fuel I could feel the air inside the draught shield had warmed significantly. Which meant that the heat energy had not gone straight to the water and that some may not have actually reached it at all. However I did not expect my register less then half the enthalpy change.

I repeated the procedure twice giving me three results to obtain an average, I observed no clear anomalous results, they appeared to support each other, which, suggests that any error was a procedural error and not just a random mistake.
Note the discrepancy between my worked value for the enthalpy of combustion of alcohol and the actual value was not isolated to Methanol

My worked Enthalpy change of combustion   Actual value of enthalpy change of combustion

Ethanol 507kJ/mol   1367kJ/mol

Propan-1-ol 741kJ/mol   2021kJ/mol
Butan-1ol 1300kJ/mol   2676kJ/mol

I believe that most of the main source of error came from the heat loss to air and heat loss to apparatus. Furthermore my metal calorimeter was orange when I begun the heating process, however by the end its was black, it appeared to be covered in a black film of soot which is a clear sign of incomplete combustion.

To check how much of the error should be attributed to procedural error I shall work out how percentage uncertainty in reading instruments.

Methanol
The uncertainty in reading a thermometer that measures to 0.1 ^{o}c is 0.05
Therefore the percentage uncertainty in reading the thermometer is the uncertainty divided by average temperature change of water being heated by the combustion of methanol

$\frac{0.05}{10}$ x100 = 0.5%

The uncertainty in reading the 100cm^{-3} measuring cylinder that measures to 1cm^{-3} is 0.005
The average value of water recorded was 99.67cm^3
$\frac{0.005}{99.67}$ x 100 = 5.02x 10^{-3}%

The uncertainty in reading a balance that meat measure to 2 decimal places it 0.005 the average mass recorded is the average (start mass + average end mass)/2
$\frac{207.48 + 207.08}{2}$ =207.28g

$\frac{0.005}{207.28}$ x100 = 2.41 x 10^{-3}%

The percentage my result is out is

$\frac{335}{726}$ x100=46.14%
100-46.14 =53.86
My result is 53.86% out
My total percentage uncertainty is 0.51%

Ethanol
The uncertainty in reading a thermometer that measures to 0.1 ^{o}c is 0.05
Therefore the percentage uncertainty in reading the thermometer is the uncertainty divided by average temperature change of water being heated by the combustion of ethanol

$\frac{0.05}{10}$ x100 = 0.5%

The uncertainty in reading the 100cm^{-3} measuring cylinder that measures to 1cm^{-3} is 0.005
The average value of water recorded was 99.84cm^3
$\frac{0.005}{99.84}$ x 100 = 5.01x 10^{-3}%

The uncertainty in reading a balance that meat measure to 2 decimal places it 0.005 the average mass recorded is the average (start mass + average end mass)/2

$\frac{189.63 + 189.25}{2}$ = 189.43g

2

$\dfrac{0.005}{189.43} \times 100 = 0.0264\%$

The percentage out my result is

$\dfrac{507}{1367} \times 100 = 37.1\%$

My result is
$37.1 - 100 = -62.9\%$ of the actual result

My total percentage uncertainty in working out the enthalpy change of combustion of ethanol is 0.53%

Propan-1-ol
The uncertainty in reading a thermometer that measures to 0.1 $^{\circ}$c is 0.05
Therefore the percentage uncertainty in reading the thermometer is the uncertainty divided by average temperature change of water being heated by the combustion of propan-1-ol

$\dfrac{0.05}{10} \times 100 = 0.5\%$

The uncertainty in reading the 100cm^{-3} measuring cylinder that measures to 1cm^{-3} is 0.005
The average value of water recorded was 100.00cm^3
$\dfrac{0.005}{100} \times 100 = 5.00 \times 10^{-3}\%$

The uncertainty in reading a balance that meat measure to 2 decimal places it 0.005 the average mass recorded is the average (start mass + average end mass)/2

$\dfrac{204.87 + 204.53}{2} = 204.7$

$\dfrac{0.005}{204.7} \times 100 = 2.44 \times 10^{-3}\%$

The percentage my result is out is

$\dfrac{741}{2021} \times 100 = 36.7\%$

It is unsettling to see that my result is just over 1/3 of the actual result
$36.7 - 100 = -63.3\%$ from the actual enthalpy change of combustion of propan-1-ol
My total percentage uncertainty is 0.51%
Butan-1-ol
The uncertainty in reading a thermometer that measures to 0.1 $^{\circ}$c is 0.05
Therefore the percentage uncertainty in reading the thermometer is the uncertainty divided by average temperature change of water being heated by the combustion of butan-1-ol

$\dfrac{0.05}{10} \times 100 = 0.5\%$

The uncertainty in reading the 100cm^{-3} measuring cylinder that measures to 1cm^{-3} is 0.005
The average value of water recorded was 100.00cm^3
$\dfrac{0.005}{100} \times 100 = 5.00 \times 10^{-3}\%$

The uncertainty in reading a balance that meat measure to 2 decimal places it 0.005 the average mass recorded is the average (start mass + average end mass)/2
$\dfrac{192.17 + 191.93}{2} = 192.05$

$\dfrac{0.005}{1920.05}$ x 100=2.60 x 10^{-3}%

The percentage my result is out is

$\dfrac{1300}{2676}$ x 100=48.6%

48.6-100= -51.4% from the actual enthalpy change of combustion of butan-1-ol
My total percentage uncertainty is 0.51/%

As I have established that the percentage uncertainty hasn't had a considerable effect on my experiment the only way I can think of improving my procedure is eradicate some of the procedural errors.

The easiest error to remove, is the incomplete combustion of the alcohol, The experiment simply has to take place in an oxygen rich atmosphere to ensure that there is oxygen way in excess of quantity needed for the complete combustion of the alcohols.
Also if I could redesign the procedure to remove the space between the burner and the calorimeter, and introduced oxygen feed to ensure enough oxygen is supplied I believe that it is quite possible to cut my percentage out from 2/3 to 1/3.

The reason why incomplete combustion could have a drastic effect on the worked enthalpy of combustion is the fact that the products release less energy then the products of complete combustion. My investigation is based on the premises that complete combustion has occurred, and even if I did manage to collect all of the soot weigh it and work out how many moles of carbon is present, there is no way of getting it all. Therefore there is no way of working out the ratio of complete combustion to incomplete. Hence unless I get rid of the incomplete combustion there is no way gaining an accurate result.

Reducing the distance between the burner, to a minimal will maximise the efficiency of the heat transfer from flame to the water