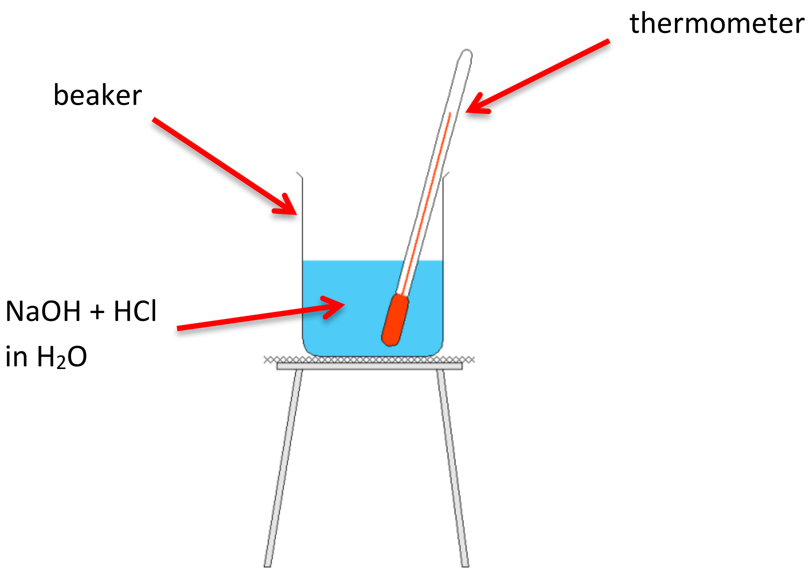
Calorimetry ($Q = mc\Delta T$)

Calorimetry is a way to measure the **heat change** of a chemical reaction.

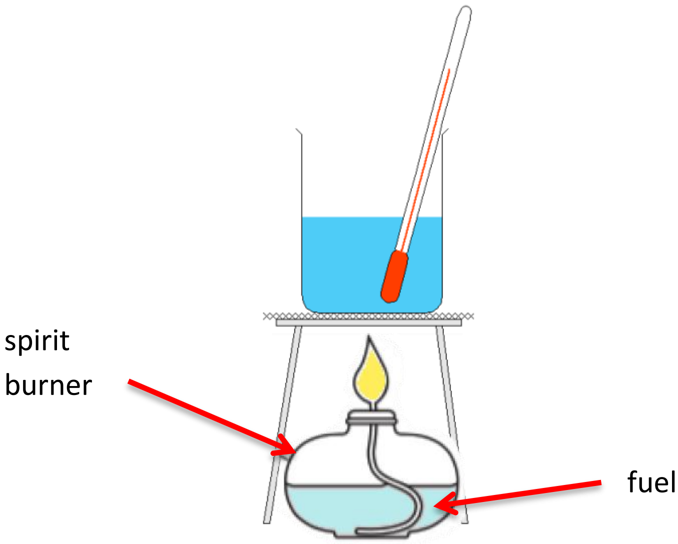
A very simple way to do this is shown below. For example, you could add HCl and NaOH to the beaker and measure the temperature change.



The big problem with this kind of basic set up is **heat loss**. A beaker is not an ideal container as it is glass and will conduct heat. Usually in schools they will use a polystyrene cup with a lid, which is a lot better at retaining the heat and minimising heat loss.

✓ **exothermic** reactions give a **temperature increase** and **endothermic** give a **temperature decrease**.

Another common experiment is to burn a fuel (combustion) as shown below. The fuel, for example ethanol, is placed and heated in a spirit burner. Again the temperature change of the water in the container is measured:



Experimentally all you are doing is heating up water and measuring the temperature change.

Calculations

The point of these experiments is usually to calculate the enthalpy change in **KJ mol^{-1}**. So you do the experiment to get the temperature change then you use the well-known equation:

$$Q = mc\Delta T$$

Q = heat change in **joules**

m = mass of **water** in grams

c = specific heat capacity of **water** (4.18 J g^{-1} K^{-1})

ΔT = temperature change measured

✓ temperature change units don't matter, when it is a **change** in temperature °C or K are the same value.

✓ the specific heat capacity is how much energy it takes to raise the temperature of 1 g of solution by 1 K.

These questions are always done in **3 steps**:

1. calculate **Q**
2. calculate the **moles**
3. **divide** Q/moles → enthalpy change

✓ Just remember **Q, moles, divide.**

Example

$$CaO + 2HCl \rightarrow CaCl_2 + H_2O$$

50 cm^3 of 2 mol dm^{-3} HCl (an excess) was added to a polystyrene cup. The initial temperature measured was 19.5 °C. 1.46 g of CaO was then added to the HCl solution. The mixture was stirred and the final temperature was 35.0 °C. Calculate the enthalpy change for the reaction.

✓ you will be given c = 4.18. But make sure you know the equation **Q = mcΔT**

step 1 use **Q = mcΔT**

You may notice that there is no mass of water given to use for m. HCl or any other acid or base are always aqueous solutions so you need to use the 50 cm^3 as the volume of water. It might seem strange to use a volume as the mass but….

the **density of water = 1**. This means cm^3 and grams are interchangeable i.e. 50 cm^3 = 50 g

✓ be careful here as a lot of students just pick the first number that has grams after it. It is tempting to pick 1.46 g for m. But remember it is the **mass of water**. 1.46 g is the mass of CaO. The mass of water will be a reasonably large number.

Q = 50 x 4.18 x 15.5

= 3239.5 J

Step 2 calculate the **number of moles**

The question tells us that **HCl is in excess** so we need to use the **moles of CaO**. The smaller number of moles is always used. If they didn't say which was in excess, you'd need to work out the moles of both then decide which is in excess.

Moles CaO = 1.46/56.1

= 0.026025

Step 3 calculate the **enthalpy change**

= 3239.5/0.026025

= - 124 470 J mol^{-1}

or **-124.47 KJ mol^{-1}**

✓ watch out for the sign at the end. As the **temperature has increased**, we know the reaction must be **exothermic**. Therefore we need the **negative sign for the enthalpy change**.

✓ step 1 only tells us how much heat is given out i.e. only **joules**. It gives us no idea as to how much we reacted or how much of a fuel was burned. We need to convert it to J or kJ **per mole** to give it context and that's why we divide Q/moles. Per mole allows you, for example, to compare the efficiency of fuels.

There have been other examples where they give you the enthalpy change and they want you to calculate the temperature change or how much of a solid was added. Stick to the three steps above, just do them in a slightly different order.

Experimental v Theoretical Value

Exam questions are very keen to ask why the experimental and theoretical values differ. The obvious and easiest answer is **heat loss**. As was mentioned above, if they do it in a beaker or if there is no lid, then lots of heat is lost. Even a polystyrene cup isn't going to be perfect.

But, they sometimes ask for answers **excluding** heat loss. So a few other less obvious factors to consider:

Incomplete combustion: like the fuel example with the spirit burner/fuel example earlier on.

Heat capacity: if an acid or base is in water to form an aqueous solution then it isn't pure water and therefore the heat capacity is likely not to be exactly 4.18.

Heating the surroundings: again with the fuel example. The flame is not heating only the bottom of the beaker. Some of the heat from the flame is heating the surroundings.

Evaporation: some of the fuel in the spirit burner could evaporate, therefore the number of moles burned is not accurate.

Impurities: if you are using a solid such as CaO above, then it might not be 100% pure.

Thermometer: depending on how accurate the thermometer is, there are likely to be small reading errors.

Volume: when adding a solid the volume might change slightly therefore be careful with the value of 'm'.

Experiments

If you get a question on experiments and it is connected to enthalpy then you have to be thinking of $Q = mc\Delta T$.

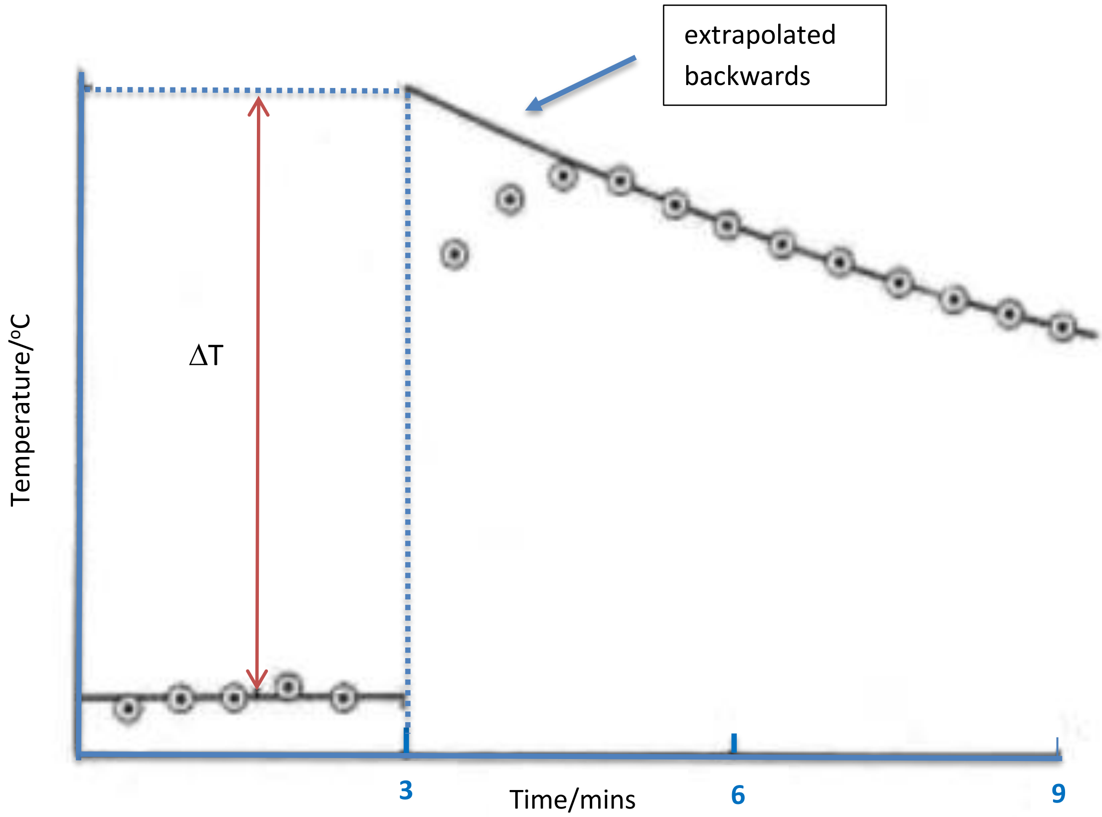
$Q = mc\Delta T$ is the **only** enthalpy experiment over the two A-level years.

One common method to take heat loss into account is to **plot a curve of temperature against time** as shown below.

Let's say we are doing a simple reaction such as NaOH being added to a beaker of HCl. All that you have to do is firstly measure the temperature of the solution **before** any NaOH is added. Then after a few minutes add the NaOH and take temperature readings at regular time intervals (the reaction will be exothermic so the temperature will increase).

After the curve is plotted, you draw a line of best fit and then **extrapolate** the line backwards. Also, draw a **vertical line** upwards from the time when the NaOH was added (in this example 3 minutes as indicated by the vertical dashed line). Finally draw a horizontal dashed line from where the vertical line and extrapolated line **intersect** to the y-axis.

The vertical distance as indicated on the diagram is the **"true" temperature change**. You can see that this temperature change is higher than the highest point plotted on the curve, therefore, indicating heat loss has been accounted for.



✓ You can get curves that are the mirror image of this. Above shows a temperature increase which is an exothermic reaction. So for an endothermic reaction it would be a **temperature decrease** i.e. the curve is like the mirror image of that above.