How to solve Calorimetry problems.

There are only a few main types of thermochemistry problems to deal with, and keeping track of the types of problems will help when developing strategies to solve a particular problem. This guide is not meant to be a comprehensive explanation of how to solve problems, but rather a supplement that assumes familiarity with the language of thermochemistry. Reading the book and the Intro To Thermo prior to using this guide is essential.

Calorimetry problems (includes two subcategories).

Calorimetry problems involve measuring temperature changes due to either combining substances with different temperatures or conducting chemical reactions inside of a calorimeter. The energy changes occurring can be calculated with the formula $q = mass \times \Delta T \times C_s$. $\Delta T$ is defined as $T_{\text{final}} - T_{\text{initial}}$ and it is important to keep track of the + or – sign of $\Delta T$. Be aware of the sign of $q$, as it will help determine if the reaction or process is endothermic (+) or exothermic (–).

(a) Substances with different temperatures, no chemical reactions: This is applicable for situations where two substances, each at different temperatures, are combined in a calorimeter and the substances come to thermal equilibrium without dissolving or reacting. This could be a block of metal in a liquid or two liquids mixing together. Thermal equilibrium means that the temperature of the two substances will eventually equalize to a common value. It is possible to determine the amount of heat energy that the cooler substance ($q_{\text{cool}}$) requires to warm up separately from the amount of heat energy that the warmer substance ($q_{\text{warm}}$) releases as it cools. The values of $q_{\text{warm}}$ and $q_{\text{cool}}$ are theoretically equal but with opposite signs, due to the 1st law of thermo. Whatever heat energy the warm object releases will be absorbed by the cool object, so $q_{\text{warm}} = -q_{\text{cool}}$. The formula $q = mass \times \Delta T \times C_s$ can be used to calculate both $q_{\text{warm}}$ and $q_{\text{cool}}$ separately, using the specific heat, mass, and $\Delta T$ specific to what is warming up, or what is cooling off.

Here are some things to watch out for when solving these kinds of problems.

$\Delta T$: There are probably two values of $\Delta T$ for this type of problem, as the temperature changes (up and down) are not likely to be the same.

Mass: There are probably two values of $\Delta T$ for this type of problem, as each substance can have a mass independent of the other.

$C_s$: There are probably two values of $C_s$ for this type of problem, as each substance can have a mass independent of the other.

Example:

Calculate the specific heat of a metal if adding 100.0 g of the metal at 50.00 °C is added to 50.0 g of water at 20.00 °C results in a final temperature of 23.10 °C. The $C_s$ of water is 4.18 J/g∙°C.

**Solution:**

$q_{\text{metal}} = -q_{\text{water}}$ and $q_{\text{metal}} = m_{\text{metal}} \times \Delta T_{\text{metal}} \times C_{s(\text{metal})}$ and $q_{\text{water}} = m_{\text{water}} \times \Delta T_{\text{water}} \times C_{s(\text{water})}$

$100.0 \text{ g} \times 26.90 \text{ °C} \times C_{s(\text{metal})} = 50.0 \text{ g} \times 3.10 \text{ °C} \times 4.18 \text{ J/g·°C}$ or $C_{s(\text{metal})} = 0.241 \text{ J/g·°C}$

Great intro to specific heat capacity and heat exchange problems:
https://www.youtube.com/watch?v=eIBVimdYnDI

Background on heat energy for phase changes:
https://www.youtube.com/watch?v=0cUK4jcAEaU

Advanced calculation for combining two substances and calculating final temperature.
https://www.youtube.com/watch?v=lIsB017B0RI

(b) Substances combining in a calorimeter, causing a temperature change in the calorimeter due to a chemical reaction or change of state (dissolving): If solutions of chemical reactants are combined in a calorimeter, the reaction can cause the solvent to either increase or decrease in temperature. The same is true for adding a substance that changes state, for example a solid dissolving. There will be two different values of $q$ in this type of problem. One is $q_{\text{soln}}$, or the amount of heat energy absorbed or released by the solution. The other is $q_{\text{rxn}}$ or
the amount of heat energy absorbed or released by the solution. The $q_{\text{soln}}$ can be calculated using the mass, $C_s$, and temperature change that is measured in a calorimeter. Due to the first law of thermo, $q_{\text{rxn}} = -q_{\text{soln}}$. Watch out for the sign of $q$, as this will indicate whether the reaction is exothermic (–) or endothermic (+).

Here are some things to watch out for when solving these kinds of problems.

$\Delta T$: There is only one value for $\Delta T$ for this type of problem, as the mixture will be a homogeneous solutions and the temperature of the reactants and solvent are both either increasing or decreasing.

Mass: There is only one value for mass for this type of problem, as the combined mass of reactants and solvent must either increase or decrease in temperature. The *entire mass* of the solution, including dissolved compounds must be considered.

$C_s$: There is only one value for $C_s$ for this type of problem, as the substances form a mixture that can’t be separated into component parts. The $C_s$ will usually be that of water for aqueous solutions, since they are mostly water.

An example would be 50.0 mL of 1.00 M HCl being combined with 100.0 mL of 2.00 M KOH. The combined mass of the mixture must be known, the two solutions will mix completely so there is only one $\Delta T$ for the entire mixture, and the $C_s$ value would be that of water, assuming aqueous solutions, since the solutions are mostly water.

An extension of this type of problem is to calculate the $\Delta H$ per mole of reactant or product. To do this, the amount of the reactant consumed, or product formed, must be calculated via stoichiometry. Simply divide the value of $q$ for the reaction by the number of moles of the specified product or reactant. Make sure the sign of $\Delta H$ is consistent with the overall temperature change.

Example: 50.0 mL of 1.00 M HCl starting at 22.00 °C is combined with 30.0 mL of 1.00 M Sr(OH)$_2$ (also at 23.00 °C) in a calorimeter. The total mass of the final mixture is measured to be 82.0 g, and the final temperature is measured to be 31.32 °C. Assuming the calorimeter is perfectly insulated and the solutions have the same $C_s$ as water, calculate the following:

a. The amount of heat energy absorbed or released by the water, in J.

b. The amount of heat energy $\Delta H$ absorbed or released by the reaction, in J.

c. The $\Delta$, in kJ/mol of the limiting reactant.

The net ionic reaction is $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

* a. $q_{\text{soln}} = m_{\text{soln}} \times \Delta T_{\text{soln}} \times C_s(\text{soln}) \Rightarrow q_{\text{soln}} = 82.0 \, \text{g} \times 8.32 \, ^\circ \text{C} \times 4.18 \, \text{J/g} \cdot ^\circ \text{C} = 2852 \, \text{J}$
  (since $\Delta T$ is $+$, so temp goes up, $\Delta T$ is $+$)

* b. $q_{\text{rxn}} = -q_{\text{soln}} = -2852 \, \text{J}$

* c. Using a balanced chemical equation, we can see that there are 0.0500 mol $H^+$ and 0.0600 mol $OH^-$, so the $H^+$ is the LR. $-2852 \, \text{J}/0.0500 \, \text{mol HCl} = -57.0 \, \text{kJ/mol HCl}$

Here is a video describing a similar problem. It’s a bit shaky (literally), but the problem is worked out pretty well. OK, there is a sig fig issue towards the end, but you know how to deal with those.

https://www.youtube.com/watch?v=LRW8uFjxZGM