Heat Capacity Measurement using Calorimeter

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1 Introduction

1.1 Recall: Definitions

Heat capacity of a solid may be defined as

$$C = \Delta Q/\Delta T$$

where unlike fluids[1], we needn't mention whether it is done at constant volume or at constant pressure. Specific heat capacity is therefore accordingly defined as

$$c = C/m$$

1.2 Water Equivalent

Consider two object types A and B with specific heat capacities c_A and c_B. For a given temperature difference ΔT, the amount of heat absorbed ΔQ, by A (assuming appropriate signs) of mass m_a, will be given by

$$\Delta Q = c_a m_a \Delta T$$

Defn: B equivalent of A $\equiv$ The mass of B s.t. heat absorbed by B for a given temperature difference is the same as the heat absorbed by A

Consequently, if m_b is the B equivalent of A, then $c_b m_b = c_a m_a$, which yields

$$m_b = \frac{c_a m_a}{c_b}$$

1.3 The idea behind the measurement scheme

W Defn: Calorimeter $\equiv$ A vessel which can thermally isolate its contents $\doteq$A

Defn: Water $\equiv$ Water inside the calorimeter $\doteq$ W

Defn: Target Object $\equiv$ The object whose heat capacity is to be measured $\doteq$ C

I Defns: m_x, c_x, C_X

[1] The symbols have the usual meaning

The target object is heated to a known temperature T_A and then put in thermal contact with water and the calorimeter. The calorimeter and water initially are assumed to be at temperature $T_W = T_c = T$. After achievement of equilibrium (at which the temperature is say T_f), we have, heat lost by the target = heat gained by water and the calorimeter, viz.

$$-c_c m_c (T_f - T_A) = c_a m_a (T_f - T) + c_w m_w (T_f - T)$$

Assmptn: Water equiavlent of A = m_{wa}

$$\begin{aligned} \implies -c_c m_c (T_f - T_A) &= c_w (m_w + m_{wa})(T_f - T) \\ \implies c_c &= \frac{c_w (m_w + m_{wa})(T_f - T)}{m_c (T_a - T_f)} \end{aligned}$$

and it is physically plausible that $T_f > T$ and $T_a > T_f$ and therefore c_c is positive.

2 The experiment

2.1 Setup

The setup consists of two parts, the heating setup and the calorimeter. A weighing machine is also required (precision 0.1g). The target object is heated to $100\,^0C$ using steam. The calorimeter is used as described. The weighing machine is used to measure the mass (or strictly, the weight) of the target object and water.

2.1.1 Heating Setup

It consists of a round bottom flask, with its mouth air-sealed and connected to a pipe. The other end of the pipe is connected to a heating chamber which is essentially a cylinder with two chambers in thermal contact. Steam flows into one of the chambers and is taken out via another pipe (air tight connection) which drains the steam into a beaker. Note carefully that this implies that the target object must be a good conductor of heat. This is because the heating is taking place by conduction of heat from the surface of the chamber with the target object particles. The particles in contact with the chamber wall will heat up and then heat their neighbours and so on. If the conductivity is not good, there'd be a temperature gradient which hasn't been modeled. Therefore even if we're using a metal, we must make sure there's no impurity on the surface.

2.1.2 Calorimeter

We are given the water equivalent of the calorimeter. It has a stirer and a thermometer (precision $0.1\,^0C$). It pays to realize that instead of using a volumetric flask for measuring the volume of water, we may simply use the weighing machine to find the amount of water inside the calorimeter. Other than the simplicity, this has the advantage of (a) not requiring conversion to mass from volume and more importantly (b) not over estimating, unlike the volume flask where some of the water may not transfer off of its walls.

2.1.3 Formula

The final formula for the specific heat capacity is

$$c_c = \frac{4.186(m_w + 15.3)(T_f - T)}{m_c(100 - T_f)} Jg^{-1}K^{-1}$$

obtained by substituting for c_w, m_{wa} and T_a values off of the manual (and the boiling temperature of water). For ease of reference, T_f is the final equilibrium temperature and T is the initial temperature of water.

2.2 Procedure

The procedure given in the manual is rather obvious and has been omitted. All the important points have been listed before. However, as will be pointed out later, if we measure the initial temperature of the target object with a thermometer instead of assuming it to be 100 ^0C, the obtained specific heat capacity will be more reliable.

2.3 Observations

The experiment was performed for various solids, viz. glass, copper (twice), tin. The results have been tabulated below. Temperature's been measured in ^0C.

Glass		masses(grams)	specific heat capacity	product=m*c	initial temp	final temp	temp difference
	Water	50	4.19	209.5	18.3	29.6	11.3
	Calorimete	15.3	4.19	64.107	18.3	29.6	11.3
	material	61.9	0.709483565		100	29.6	70.4
Cu		masses(grams)	specific heat capacity	product=m*c	initial temp	final temp	temp difference
	Water	48.9	4.19	204.891	18.3	21.5	3.2
	Calorimete	15.3	4.19	64.107	18.3	21.5	3.2
	material	37.6	0.291636265		100	21.5	78.5
Cu		masses(grams)	specific heat capacity	product=m*c	initial temp	final temp	temp difference
	Water	50.1	4.19	209.919	16.3	18	1.7
	Calorimete	15.3	4.19	64.107	16.3	18	1.7
	material	54.5	0.104239024		100	18	82
tin		masses(grams)	specific heat capacity	product=m*c	initial temp	final temp	temp difference
	Water	53	4.19	222.07	15.8	20.1	4.3
	Calorimete	15.3	4.19	64.107	15.8	20.1	4.3
	material	96.5	0.222159033		77.5	20.1	57.4

3 Results and Discussion

The specific heat[2] of glass was found to be 0.70, while the quoted value is 0.84. Similarly for copper it was 0.29 (room temperature 18.3 ^0C) and 0.10 (room temperature 16.3 ^0C), while the quoted value again was higher; 0.34. It appears that the assumption that the initial temperature of the target object is 100 ^0C is becoming more inaccurate as the room temperature drops. Finally, for tin, the value was found to be 0.22 and the quoted value was 0.21, which is the closest. This maybe attributed to (a) the fact that it was obtained as stated before, by measuring the initial temperature of the target object and (b) absence of an oxide layer on the tin surface.

4 Suggestions

- A thermometer in the heating chamber could be used to obtain a more reliable initial temperature value
- Ethanol (99.9%) could be used as a fuel to ensure no soot is formed during the heating process
- The outlet pipe shouldn't touch the water in the beaker, else there're cases in which the water maybe sucked by the outlet pipe into the heating chamber.

[2]The units of all specific heats in this section are $Jg^{-1}K^{-1}$