Lab6
Specific Heat of Solids Revisited
Physics 132

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0.1 Purpose

The purpose of this experiment is to test three different well known models of specific heat capacitance over the temeprature range of approximately 200k to 350k for two different solid materials(Chromium and Copper[Cu]). We will measure the $C_v(T)$ of two different solids by preparing a series of temperature baths, and fit $C_v(T)$ to the three models below, and analyze the results.

$$Dulong - Petit : c_v = 3R = 3N_A k_b \tag{1}$$

$$Einstein - Solid : c_v = 3R\frac{(\frac{T_E}{T})^2 e^{\frac{T_E}{T}}}{(e^{\frac{T_E}{T}} - 1)^2} \tag{2}$$

$$Debye - Model : c_v = \frac{12\pi^4}{5} R \frac{T^3}{T_D^3} \tag{3}$$

Where the gas constant is $R = 8.314 J \cdot K^{-1} \cdot Mol^{-1}$

0.2 Materials and resources

Data Studio, Water, Salt, Hot water, Dry Ice, Thermometers, Pressure meter, copper, chromium, Love.

0.3 Procedure

Create a series of hot and cold temperature baths to measure the specific heat of two solids. This lab will be divided into two parts, so it is highly recommended to complete Part I for both samples first, and complete Part II for both samples last.

Part I: Use hot and cold water for:

$$5°C < T < 80°C$$

Part II: Use ethanol and dry ice for

$$-70°C < T < 5°C$$

Collect at least 10 $C_v(T)$ data points for each sample, approximately 5 $C_v(T)$ data points or more in each Part. The data points should be spaced by approximately $15°C$ To do this, keep $T_H \sim T_C + 15°C$ so that the cold baths have the following temperatures (or similar temperatures):

$$T_c(°C) = 65, 50, 35, 20, 5, 0, -10, -25, -40, -55, -70$$

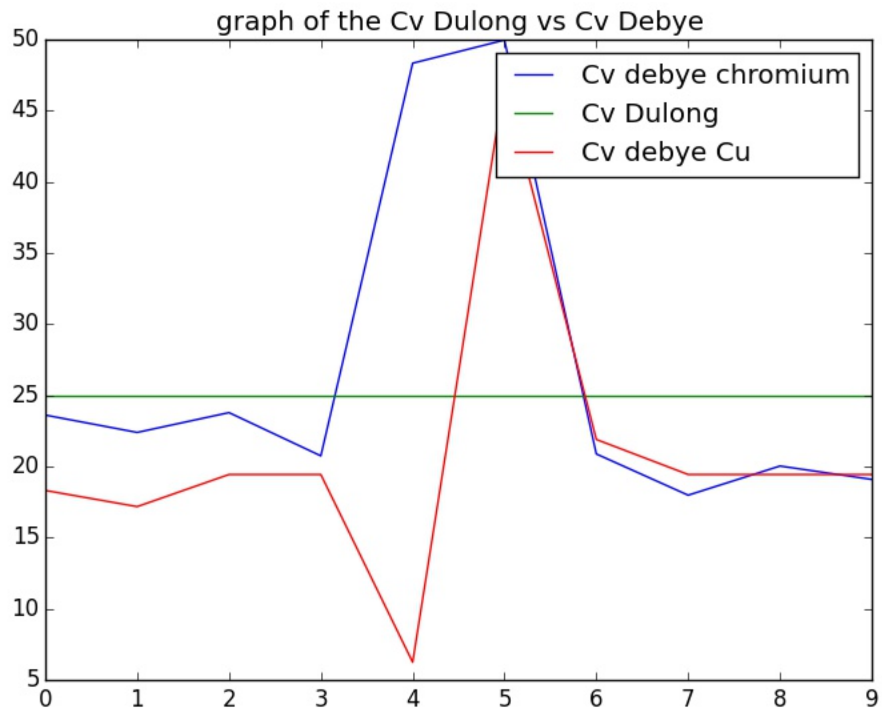
- Increase precision (significant figures) of temperature sensor to highest accuracy when collecting data
- If the cold water bath temperature does not change significantly, consider:
  - Decreasing amount of water in cold bath
  - Increasing difference between T_H and T_C
- It is possible to increase the experimental accuracy by repeating measurements and taking the average value, which may be considered if time permits

0.4 Data Analysis

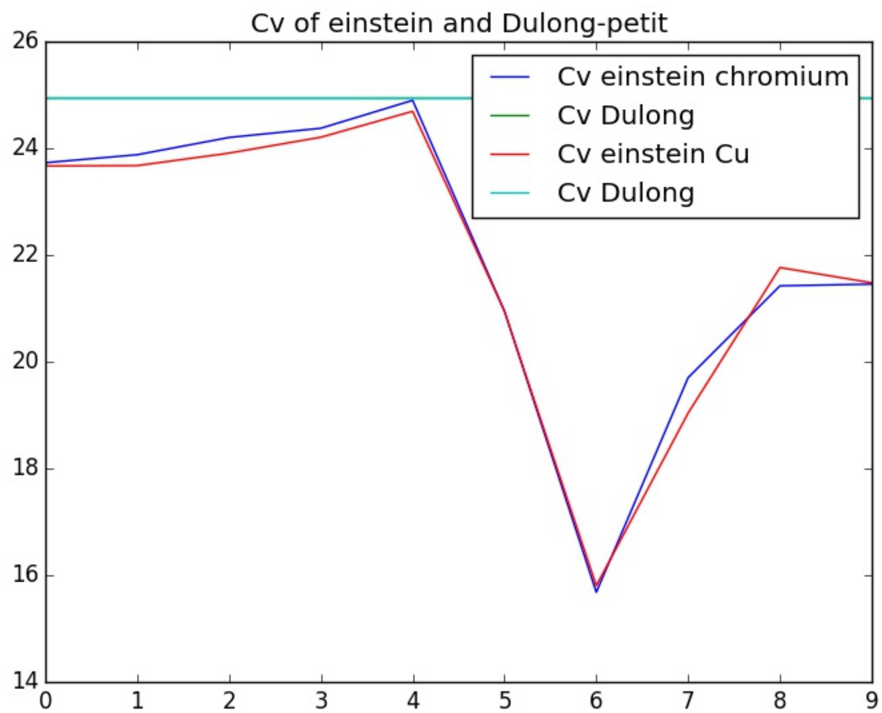
From our Data in **Part I** it appears that our mass and change in temperature appears to have changed in a somewhat linear fashion until we reached the very low temperatures. (Below $0°C$). However, when measuring the weight, we had an error of ± 0.07, skewing our accuracy for the weight of the samples.

When measuring the temperature, we had an error from outside heat sources. This is because our thermometer was exposed to not only the liquid we were dipping it in, but at the same time was exposed to air. This would have resulted in our temperature readings being off by about $\pm 2°C$. This is because the temperature of the air could have been significantly higher than our liquid. And thus forcing us to having to wait a while until our systema and the thermometer to reach equilibrium.

From **Part II** of our experiment, we saw that we had lost mass at constant rates when we used the Ethanol Alcohol and the dry ice. For the most part, this part of the experiment went well except for when we transferred our sample from the warmer bath to the colder bath. We could have, and most likely have, lost some heat due to the temperature of the air outside of the baths. For that, we can safely assume that the error of the sample temperature would be $\pm 2°C$.



Graph of the Chromium and Cu Debye model for C_v compared to the Dulong-Petit model.



Graph of the C_v of Chromium and Cu for the Einstein solid compared to the Dulong-Petit Model.

0.5 Questions

1. Scientific measurements involve error, including systematic, resolution and random error. Comment on the systematic errors present when obtaining heat Q_{sample}, and identify as many forms of systematic error as possible.

2. How can this experiment be improved? Consider how it may be improved without much effort (i.e. low budget), and how it may be improved while affording a large budget for laboratory equipment (i.e. using expensive equipment such as highly accurate temperature probes).

3. The Dulong and Petit model predicts $c_v = 3R = 24.9J \cdot mol^{-1} \cdot K^{-1}$ for all solids, however, experimentally solids have been shown to have

different heat capacities from this value. Why does this occur?

4. How did Debyes model for specific heat improve upon the Einstein Solid?

5. At extremely low temperatures, even the Debye model has been shown to break down. Why does this occur?

0.6 Answers to questions

1. Discussed in **Data Analysis**

2. This experiment can be improved by using a larger bath for our temperatures. This is because the larger the bath, our error caused by the temperature of the air would have been around 0. This is because the air temperature would be around the temperature of the baths. This is for if we had a low budget. However, if we had a large budget and were being funded in a laboratory environment. We would be able to actually create the equipment necessary to cool our baths to certain temperatures with almost perfect accuracy.

3. This occurs because we have different formations in the structures of our objects. Some parts of our objects may have a certain element that the other does not which effects the way energy is transferred. Gold for example has a high heat capacity, while regular plastic does not. Why is that? That's because of the structure of object and the amout of energy it takes to excite these atoms. Each atom is different (if they aren't of the same element) and that means that different energies is needed to change the phase-state of the object.

4. "Thus, the second model to test is the Einstein Solid model, which quantizes lattice vibrations as phonons and assumes an ensemble of N quantum harmonic oscillators, each oscillator with three degrees of freedom, so that all 3N normal modes of oscillation have frequency v_E. Above some temperature T_E, where $T_E = \frac{h}{k_B}$, Einsteins model returns its value to the high temperature limit of Dulong and Petit." This was basically explained in question 3. A summary of what was said is that we have degrees of freedoms to take into account now, thanks for the improvement by the Einstein Solid.

5. This occurs because at extremely low temperatures, it will take very little energy needed to excit our atoms and to cause heat to be transferred. Therefore, it's extremely easy to transfer heat at low temperatures thus showing that extremely low temperatures, the Debye Model breaks down.

0.7 Conclusion

We can conclude that our experiment was a success due to the small amount of errors that we had measured. We thus proved that solids have different heat capacities and how these heat capacities are affected at extremely low temperatures. At moderate temperatures, we saw that these heat capacities remain at a near constant. Showing to us how heat is lose when it is transferred from different objects.

0.8 Data

Part I, chromium

$T_H(C)$	$T_C(C)$	$T_F(C)$	$M_{Total}(g)$	$m_{H_2O}(g)$	$m_{cup}(g)$	$m_{chromium}(g)$
77.0	63.7	59.7	145.73	136.22	2.00	7.51
65.7	49.9	47.6	125.88	115.37	–	–
52.5	33.8	31.6	125.76	116.25	–	–
34.6	18.6	18.2	126.42	116.91	–	–
21.4	4.2	3.1	122.34	112.83	–	–

Part I, Copper

$T_H(C)$	$T_C(C)$	$T_F(C)$	$M_{Total}(g)$	$m_{H_2O}(g)$	$m_{cup}(g)$	$m_{Cu}(g)$
77.0	60.0	61.2	142.00	100.00	2.00	40.00
65.7	50.0	52.1	148.00	106.00	–	–
48.6	34.7	34.7	153.30	113.30	–	–
35.0	21.0	21.0	134.43	92.43	–	–
21.0	5.0	7.3	95.7	53.7	–	–

Part II, Chromium

$T_H(C)$	$T_C(C)$	$T_F(C)$	$M_{Total}(g)$	$m_{eth}(g)$	$m_{cup}(g)$	$m_{chromium}(g)$	$\frac{\partial m}{\partial t}$	$\Delta t(s)$
5.0	−10.0	−7.3	40.2	10.0	2.0	7.51	0.02	7
−10.11	−25	−24.41	38.5	–	–	–	0.01	8
−24.12	−40.0	−41.05	40.5	–	–	–	0.03	3
−40.00	−55.0	−54.45	44.6	–	–	–	0.02	5
−55.7	−75.0	−74.45	38.2	–	–	–	0.08	13

Part II, Copper

$T_H(C)$	$T_C(C)$	$T_F(C)$	$M_{Total}(g)$	$m_{eth}(g)$	$m_{cup}(g)$	$m_{Cu}(g)$	$\frac{\partial m}{\partial t}$	$\Delta t(s)$
5.0	−9.8	−7.3	40.2	10.0	2.0	40.0	0.13	10
−10.2	−25.4	−24.41	38.5	–	–	–	0.15	9
−22.5	−39.9	−41.05	40.5	–	–	–	0.09	9
−42.3	−56.2	−54.45	44.6	–	–	–	0.15	11
−55.2	−75.5	−74.48	38.2	–	–	–	0.07	13