V47

Molar Heat of Copper

Fritz Agildere
fritz.agildere@udo.edu

Amelie Strathmann
amelie.strathmann@udo.edu

Experiment: May 13, 2024
Submission: May 13, 2024

TU Dortmund – Department of Physics

Contents

1 Objective

By investigating the molar heat capacity of copper, we test some of the most prominent models for their validity and determine select characteristic quantities of solids.

2 Theory [1]

In the description of condensed matter, tools from classical thermodynamics and statistical physics as well as quantum mechanical considerations need to be applied. Throughout the following paragraphs, we explore some of the more well known models in the subfield of thermal properties, specifically for the explanation of the heat capacity in solids.

2.1 Heat Capacity

The heat capacity of any material is defined via

$$C \equiv \frac{\Delta Q}{\Delta T}$$

as the amount of heat ΔQ corresponding to a unit change ΔT in temperature. This is clearly dependent on the amount of matter, so to allow for comparisons between different materials we can normalize with volume V or mass M to obtain a specific heat capacity.

2.1.1 Molar Heat

In our case, we are interested in the heat capacity per number of particles making up a sample. This leads to

$$c \equiv \frac{\Delta Q}{n \Delta T}$$

for the molar heat capacity, where n is the number of mol contained in the substance. To determine n one can use readily available values of the molar mass m or molar volume v for the given experimental parameters.

2.1.2 Measurement

During the measuring process, it is necessary to constrain certain parameters. To understand the resulting relations, we examine the first law of thermodynamics

$$\mathrm{d}U = \delta Q - \delta W = T\mathrm{d}S - P\mathrm{d}V$$

where U is the internal energy, Q and W are heat and work, T stands for temperature, S for entropy, P for pressure and V for volume. The symbols d and δ denote exact and inexact differentials, respectively.

From this relation, we identify $\delta Q = T\mathrm{d}S$ and thereby

$$C = T\frac{\partial S}{\partial T}$$

when translating the defining statement to infinitesimal notation.

2.1.2.1 Isochoric Case

At fixed volume, all units of heat result in temperature changes exclusively. The isochoric heat capacity can be written as

$$C_V = T\left.\frac{\partial S}{\partial T}\right|_V$$

and constitutes an interesting quantity to study the behaviour of materials due to the isolation of otherwise connected effects.

2.1.2.2 Isobaric Case

When the pressure is kept constant instead, some of the heat exchange also results in expansion or contraction of the sample and therefore reduces the total temperature difference. Intuition therefore tells us that $C_P > C_V$ where we write

$$C_P = T\left.\frac{\partial S}{\partial T}\right|_P$$

for the isobaric heat capacity. This situation is more easily realizable in experiments but comes at the cost of no longer separating different mechanisms affecting the substance.

2.1.2.3 Connection

In order to convert between C_P and C_V we need some generally applicable relationship between the two quantities.

2.2 Models

2.2.1 Classical Physics

2.2.2 Quantum Mechanics

2.2.2.1 Phonons

2.2.2.2 Einstein

2.2.2.3 Debye

2.2.2.4 Electrons

3 Setup
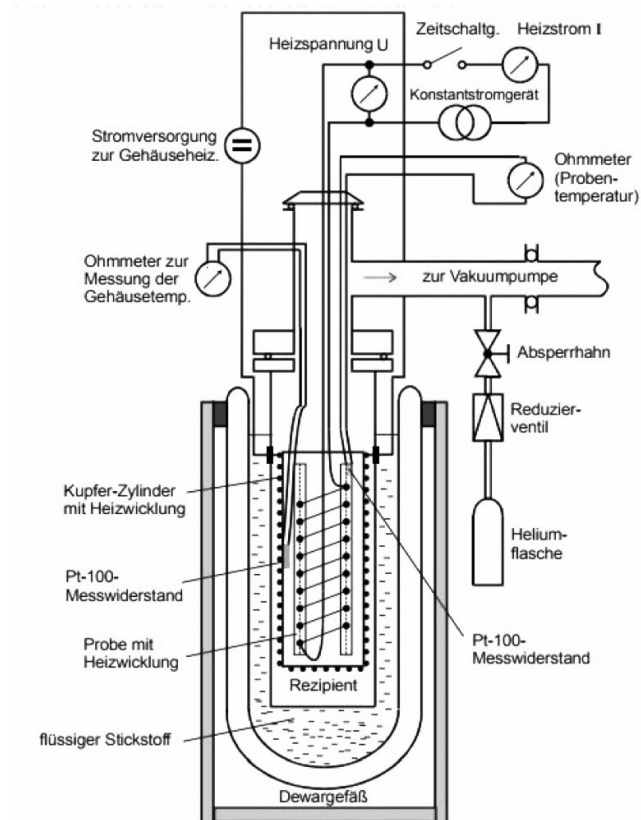
Figure 1: [2]

4 Procedure

5 Results

T[°C]	-200	-190	-180	-170	-160	-150	-140	-130	-120
R[Ω]	18,44	22,71	27,03	31,28	35,48	39,65	43,80	47,93	52,04
T[°C]	-110	-100	-90	-80	-70	-60	-50	-40	-30
R[Ω]	56,13	60,20	64,25	68,28	72,29	76,28	80,25	84,21	88,17
T[°C]	-20	-10	0	+10	+20	+30	+40		
R[Ω]	92,13	96,07	100	103,90	107,79	111,67	115,54		

Figure 2: [2]

T [K]	70	80	90	100	110	120	130	140
α [10^{-6} grd^{-1}]	7,00	8,50	9,75	10,70	11,50	12,10	12,65	13,15
T [K]	150	160	170	180	190	200	210	220
α [10^{-6} grd^{-1}]	13,60	13,90	14,25	14,50	14,75	14,95	15,20	15,40
T [K]	230	240	250	260	270	280	290	300
α [10^{-6} grd^{-1}]	15,60	15,75	15,90	16,10	16,25	16,35	16,50	16,65

Figure 3: [2]

θ_D/T	0	1	2	3	4	5	6	7	8	9
0	24,9430	24,9310	24,8930	24,8310	24,7450	24,6340	24,5000	24,3430	24,1630	23,9610
1	23,7390	23,4970	23,2360	22,9560	22,6600	22,3480	22,0210	21,6800	21,3270	20,9630
2	20,5880	20,2050	19,8140	19,4160	19,0120	18,6040	18,1920	17,7780	17,3630	16,9470
3	16,5310	16,1170	15,7040	15,2940	14,8870	14,4840	14,0860	13,6930	13,3050	12,9230
4	12,5480	12,1790	11,8170	11,4620	11,1150	10,7750	10,4440	10,1190	9,8030	9,4950
5	9,1950	8,9030	8,6190	8,3420	8,0740	7,8140	7,5610	7,3160	7,0780	6,8480
6	6,6250	6,4090	6,2000	5,9980	5,8030	5,6140	5,4310	5,2550	5,0840	4,9195
7	4,7606	4,6071	4,4590	4,3160	4,1781	4,0450	3,9166	3,7927	3,6732	3,5580
8	3,4468	3,3396	3,2362	3,1365	3,0403	2,9476	2,8581	2,7718	2,6886	2,6083
9	2,5309	2,4562	2,3841	2,3146	2,2475	2,1828	2,1203	2,0599	2,0017	1,9455
10	1,8912	1,8388	1,7882	1,7393	1,6920	1,6464	1,6022	1,5596	1,5184	1,4785
11	1,4400	1,4027	1,3667	1,3318	1,2980	1,2654	1,2337	1,2031	1,1735	1,1448
12	1,1170	1,0900	1,0639	1,0386	1,0141	0,9903	0,9672	0,9449	0,9232	0,9021
13	0,8817	0,8618	0,8426	0,8239	0,8058	0,7881	0,7710	0,7544	0,7382	0,7225
14	0,7072	0,6923	0,6779	0,6638	0,6502	0,6368	0,6239	0,6113	0,5990	0,5871
15	0,5755	0,5641	0,5531	0,5424	0,5319	0,5210	0,5117	0,5020	0,4926	0,4834

Figure 4: [2]

6 Discussion

References

[1] Rudolf Gross and Achim Marx. *Festkörperphysik*. Berlin, Boston: De Gruyter Old-enbourg, 2022. ISBN: 9783110782394. DOI: doi:10.1515/9783110782394. URL: https://doi.org/10.1515/9783110782394.

[2] *Manual for Experiment 47, Molar Heat of Copper*. TU Dortmund, Department of Physics. 2024.

Appendix