Thermal Conductivity of Solids at Low Temperatures

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Abstract

This report presents the methodology and results of an experiment conducted to measure the thermal conductivity of various solid materials at low temperatures. The results are analyzed, compared to literature values, and discussed in the context of thermal conduction principles.

1   Introduction and theory

The objective of this experiment is to measure the thermal conductivity of solid samples at low temperatures using the axial flow method. According to Fourier's law, the rate of heat transfer is proportional to the temperature gradient across the material, which allows for the determination of thermal conductivity, k. The experiment aims to investigate the temperature dependence of thermal conductivity for different materials, primarily nickel and glass, and to compare the experimental results to known literature values. (Doe, 2020).

Thermal conductivity describes a material's ability to conduct heat. It quantifies the rate at which thermal energy is transferred through a material due to a temperature gradient. A high thermal conductivity indicates that a material readily allows heat to flow through it, while a low thermal conductivity signifies that the material is a poor conductor of heat and acts as an insulator. Mathematically, this relationship is expressed by:

$$\frac{\mathrm{d}Q}{\mathrm{d}t} = -kA\frac{\mathrm{d}T}{\mathrm{d}x} \tag{1}$$

where $\vec{q}$ is the heat flux density (rate of heat transfer per unit area), k is the thermal conductivity of the material, and ∇T is the temperature gradient. The negative sign indicates that heat flows in the direction of decreasing temperature.

2   Apparatus and experimental methods

The experimental setup for measuring thermal conductivity involves using a Janis SuperVariTemp cryostat, which allows for precise temperature control from 80K to room temperature. The sample, either a nickel rod or a glass plate, is mounted onto a heater within the cryostat, ensuring that the heat flow is uniaxial through the sample to minimize radial losses. Two thermocouples are attached to either side of the sample to measure the temperature difference (ΔT), while the power input to the heater is recorded to calculate the heat flux. The experiment is conducted by cooling the system to thermal equilibrium, varying the temperature, and recording the necessary data at multiple points to analyze the thermal conductivity as a function of temperature.

3   Results and discussion

Based on the experimental data, the thermal conductivity of the nickel sample decreases from approximately $94.7\,\mathrm{W\,m^{-1}\,K^{-1}}$ at 80K to $54.4\,\mathrm{W\,m^{-1}\,K^{-1}}$ at 293K. This decreasing trend is consistent with the theoretical predictions on the k values of nickel, which suggests that k decreases with rising temperature. However, the deviation between the experimental data of k and the literature values lies in the magnitude of k. As shown by figure, the values of k are lower than literature at similar temperature. This discrepancy is possibly due to the composition of the samples, as the impurities in the sample can reduce its k values by

promoting electron scattering(Chen et al., 2021) and hence the heat transfer becomes less efficient.

Another possible source of the deviation is the error in experimental setup and procedure.

4   Discussion

Analyze the results and discuss their implications. Address any discrepancies or uncertainties and propose possible sources of error. Compare the experimental results with theoretical predictions if applicable.

5   Conclusion

Summarize the key findings of the experiment. Discuss whether the objectives of the experiment were achieved and suggest improvements for future experiments.

6   References

The references are formatted according to the APA citation style. All citations in the text should use the \autocite or \cite commands.

References

Chen, X., Li, C., Xu, Y., Dolocan, A., Seward, G., Van Roekeghem, A., Tian, F., Xing, J., Guo, S., Ni, N., et al. (2021). Effects of impurities on the thermal and electrical transport properties of cubic boron arsenide. *Chemistry of Materials*, *33*(17), 6974–6982.

Doe, J. (2020). *Physics principles*. Science Press.

A   Appendix: tables and figures

Include any additional material such as raw data, derivations, or supplementary information.

Variable	Measured Value	Uncertainty
x	10.5	± 0.2
y	15.3	± 0.1

Table 1: Sample data table.