ULTRASONIC ATTENUATION STUDIES OF
THE ELECTRONIC STRUCTURE OF METALS

PROGRESS REPORT

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ALLAN R. HOFFMAN

University of Massachusetts

Amherst, Massachusetts 01002

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ABSTRACT

Measurement of the thermal conductivity (K) in two beryllium samples is proceeding. K has been accurately measured in the purer sample (residual resistivity ratio ~ 2000) from 1.5 to 40 K and the expected maximum in K variation with temperature was observed at 36K. Preliminary measurements of K as a function of magnetic fields up to 65 kOe were made at several temperatures ranging from 4 to 14K.

A review of the literature indicated a need for a measurement of electrical conductivity (σ) as a function of temperature in the same sample in which K is measured. For the purpose of measuring K and σ simultaneously and in order to resolve several experimental difficulties, the sample holder was redesigned. Construction of the new sample holder is nearly complete.

Progress Report:

a. niobium measurements:

A thorough analysis of the measurements of ultrasonic attenuation in the mixed state of two niobium single crystals has been completed, along with an associated Ph.D. thesis. The thesis was successfully defended in late February, and a long paper has been accepted for publication in the International Journal of the Physics and Chemistry of Solids (see attached manuscript).

b. beryllium measurements:

As part of our research effort on beryllium we conducted an extensive review of the literature on electronic transport behavior in metals. Several facts stood out:

- a) major areas of electrical and thermal transport properties in specific metals are not well documented, especially for the case of high purity, single crystal samples.⁽¹⁾
- b) much effort has been devoted to separating and understanding the temperature independent scattering mechanisms contributing to the electrical and thermal resistivities,⁽²⁾ and the availability of reliable transport data for these two cases from very pure, single crystal specimens is crucial to this area of investigation.
- c) our present theoretical understanding of the basic features of the electronic conductivities and specific heats in metals accounts for most observed behavior. However, measured specific heats of beryllium for samples of different purities are in serious disagreement with expected behavior.⁽³⁾ [Note: our exploratory measurements of thermal conductivity in two beryllium samples also revealed features that support this observation.]

In response to the above, we decided to include electrical conductivity (σ) along with thermal conductivity (K) as parameters to be measured for each of our two high purity, single crystal beryllium samples (see report C00-3331-4 for specimen details). The majority of the accumulated beryllium data at present are for alloyed or polycrystalline (usually sintered) specimens, or in a few instances for relatively low purity single crystals. To our knowledge, the only measurements of K for high purity single crystal beryllium samples are those of Grüneisen and Adenstedt.⁽¹⁾ It is of particular interest to obtain measurements of $K(T)$ and $\sigma(T)$ for the same single crystal sample, as well as for samples of varying purity, since different impurities affect these two transport processes in significantly different ways. In the low temperature regime, scattering of carriers is usually assumed to arise predominantly from temperature independent sources (e.g., chemical impurities, point defects, dislocations, grain boundaries, etc.), and the generally accepted measure of impurity content has been the residual resistivity ratio (RRR). In beryllium, our measurements to date, as well as those of others on less pure samples, indicate that the extent to which one may successfully depend on the RRR as an indicator of overall purity must be carefully examined. Fickett⁽²⁾ has also suggested that a careful study of the magnetic field dependence of the Lorentz number L ($\equiv K/\sigma T$) would be of use to theoreticians. We propose to include such measurements in our program of study.

Measurements completed during the current renewal period with the apparatus described in report C00-3331-4 include:

- a) $K(T)$ for beryllium sample #1 ($RRR \sim 2000$) over the range 1.5 to 40K.

This region includes the K maximum, at approximately 36K (see Fig. 1).

In the course of these measurements, the computer programs used to determine temperature from carbon resistance thermometers were significantly improved. Relative temperatures are now determined to better than 1 mK below 15K and to better than 5 mK at 40K.

- b) $K(H)$ for beryllium sample #1 and an OFHC copper "dummy" sample were measured for $0 < H < 65,000$ oersteds in the temperature range 4-14K. $\vec{H}$ was aligned along the heat current direction.

[Note: the carbon resistance thermometers were found to track to within 0.25 mK over the full magnetic field range.] The copper sample exhibited zero field thermal conductivity behavior consistent with published results,⁽⁵⁾ and a positive magnetothermal resistance, as expected. The beryllium sample, on the other hand, exhibited an unexpected increase in K with increasing field (i.e., a negative magnetothermal resistance). Two effects which might produce spurious results of the type observed in a beryllium #1 are a) non-uniform injection of heat, and b) the phenomenon of "current jetting," first proposed by A. B. Pippard.⁽⁶⁾ He has suggested that this effect may be responsible for anomalous electrical conductivity results that have led some investigators to announce the discovery of normal metals that become superconducting in high magnetic fields. A similar effect is possible in thermal transport processes as well, but has not yet been observed to our knowledge.

A new conductivity measuring apparatus has also been designed, to incorporate many of the changes suggested in the above discussion (see Fig. 2) Construction of this apparatus is nearly complete, as of the time of this writing. Modifications include silver caps "wetted" to the samples with indium-tin eutectic to insure more uniform heat injection (as compared to winding a wire heater directly on the sample), and the addition of evaporated gold contacts on the samples to allow simultaneous measurement of electrical and thermal conductivities. Not shown are two additional carbon resistance thermometers to test for current jetting.

Note: we are grateful to Professor A. B. Pippard of Cambridge, University, who visited our laboratory during completion of the preliminary magnetothermal conductivity measurements. He participated in many useful discussions and provided several suggestions for improvement of the apparatus.

c. other measurements:

Due to the time spent completing the niobium analysis and related Ph.D. thesis, along with the demands of the beryllium conductivity measurements, it was decided not to pursue the other proposed measurements mentioned in renewal proposal COO-3331-5.

Personnel:

Two graduate students, one postdoctoral research associate, and the author of this progress report (principal investigator) have been involved in the research program during the current renewal period. One graduate student has completed the requirements for the Ph.D. degree, and the other should complete his requirements within one more renewal period.

References and Footnotes

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Also see Fickett.⁽²⁾
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3. G. Ahlers, Phys. Rev. 145, 419 (1966)
4. E. Grüneisen and H. Adenstedt, Ann.d. Phys. 31, 714 (1938)
5. Purdue Thermophysical Properties Research Center Report, Vol. 1
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6. J. A. Delaney and A.B. Pippard, Rep. Prog. Phys. 35, 677 (1972)

Figure 1

THERMAL CONDUCTIVITY (K) MEASURED IN Be 1
AS A FUNCTION OF TEMPERATURE

Figure 2 MODIFIED SAMPLE HOLDER FOR THERMAL AND
ELECTRICAL CONDUCTIVITY MEASUREMENTS