MAGNETORESISTIVITY OF COPPER AND ALUMINUM AT CRYOGENIC TEMPERATURES†

F. R. Fickett
Cryogenics Division
National Bureau of Standards
Institute for Basic Standards
Boulder, Colorado 80302

Abstract

Results of recent measurements of the magnetoresistance of polycrystalline wires of aluminum and copper are presented. The measurements were made in the temperature range 4 K to 35 K and in magnetic fields to 100 kOe. The aluminum wires ranged in purity from RRR = 1000 - 30 000 and the copper wires from RRR = 200 - 7000. RRR = R(273 K)/R(4 K).

I. Introduction

The use of normal metals, primarily copper and aluminum, as stabilizing materials for superconductors is essentially universal now. In most applications it is desirable to know how the resistivity of the metal changes with increasing magnetic field and how the purity of the metal affects this change. Classically, one would expect the magnetoresistance to obey Kohler's rule, which says that the magnetoresistance, $R(H,T) - R(0, T)/R(0, T) = \Delta R/R_o$, plotted versus $H/R(0, T)$ should give a single curve for all transverse data for a given metal. We have measured the transverse magnetoresistance of both copper and aluminum, in the form of polycrystalline wires, over a wide range of temperature and purity and present here some of our data and the conclusions drawn from the experiments.

II. Specimens and Measurements

The aluminum wires varied in size from 0.9 mm to 1.5 mm. The copper wires were all 1.5 mm in diameter. The wires were swaged from stock materials of varying purity, etched and annealed. The highest purity copper wires were obtained by annealing in a reduced atmosphere of oxygen. The author has described this technique in detail elsewhere.[1]

The resistance of the aluminum specimens was measured in magnetic fields to 40 kOe, which is sufficiently high to determine the total behavior of the resistance versus field curve. The copper wires were measured to fields of 100 kOe. Measurements on aluminum were made at temperatures of 4, 15 and 20 K and on copper at 4, 15, 25 and 35 K.

At zero magnetic field, and at 4 K, high purity wires of the sizes used have a significant added resistance as a result of electron scattering from the surface, the dc size effect. The contribution may be as high as 30% of the bulk resistance. Most of the added resistance is removed by the magnetic field. In order to have the data representative of the metal, i.e. specimen independent, the zero field resistance values are corrected for size effect using Nordheim's rule[2] with $(\rho \ell)_{bulk} = 0.7 \times 10^{-11}\ \Omega\, cm^2$ for aluminum and $0.66 \times 10^{-11}\ \Omega\, cm^2$ for copper.

III. Results

Aluminum shows a magnetoresistance which rises rapidly in low fields and then becomes linear with increasing field. The slope of the linear region is low even for very high purity. Thus the magnetoresistance $\Delta R/R_o$ continues to be small even to high fields. The magnetoresistance of aluminum does not obey Kohler's rule. Figure 1 shows the magnetoresistive behavior of a number of specimens. It is possible to derive a predictive scheme for the magnetoresistance of aluminum such that, given RRR, one can determine $\Delta R/R_o$ at a given field. This scheme, which is too lengthy to present here, is described in detail in an earlier paper by the author.[3]

Copper obeys Kohler's rule with amazing consistency over the entire range of field, temperature and purity. Figure 2 shows a Kohler plot for some 200 data points taken on our copper wires. The maximum deviation of the actual data from the line is about 5%. An analytical expression for the line is presented in the original report [4] but the use of the plot itself is easier for determining values.

An important feature of the magneto-

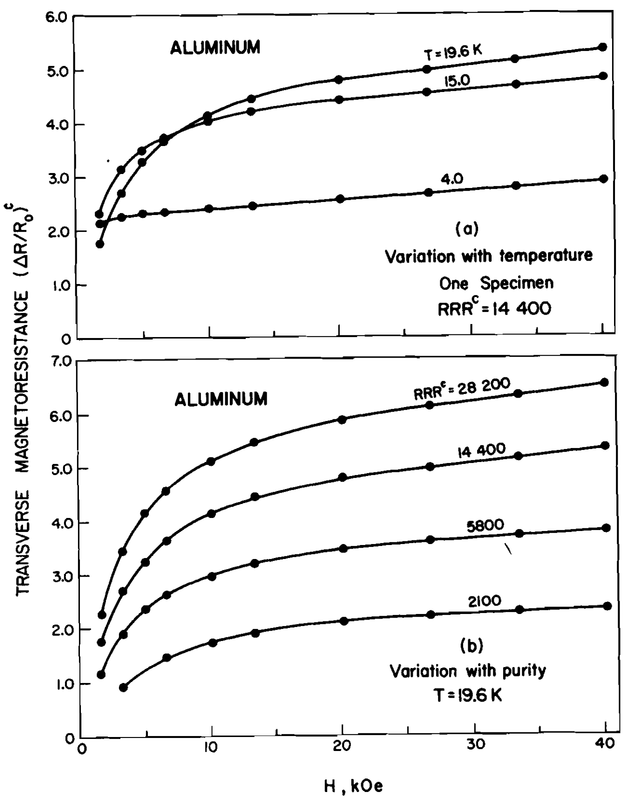

Fig. 1. Transverse magnetoresistance data for polycrystalline aluminum wires. The superscript c indicates that the zero field data have been corrected for size effect.

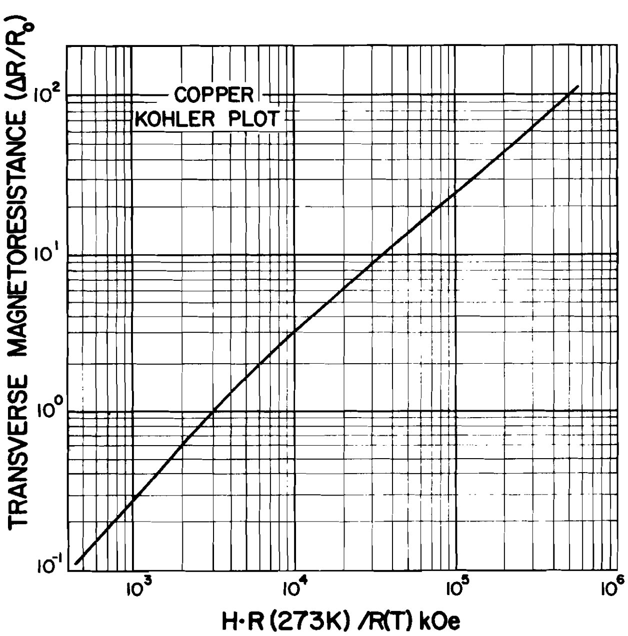

Fig. 2. Kohler plot for polycrystalline copper wires.

resistance is shown in Figs. 3 and 4 in which we present the variation of the bulk resistivity as a function of purity at a given field and at several temperatures. Figure 3 shows data for aluminum at 40 kOe and Fig. 4 presents data for copper at both 100 and 30 kOe. Note that, in both cases, the curves tend to level off after dropping rapidly. This occurs at RRR ≈ 15000 for aluminum and at RRR ≈ 2000 for copper. This implies that purification of the metal beyond these ratios is not of much value and probably not worth the added cost. Note also that, contrary to some opinions, the resistivity at a given field is always decreasing as the purity increases - even though, for copper, $\Delta R/R_0$ may reach values of 120.

It is important to stress that we are dealing here with the bulk resistivity. When the specimen sizes become on the order of the electronic mean free path, the problems become more complex. Although the standard size effect correction mentioned above is useful as a first approximation, much is yet to be learned about size effects in a magnetic field, the magnetomorphic effects. We are now studying just such effects in thin copper specimens of high purity.

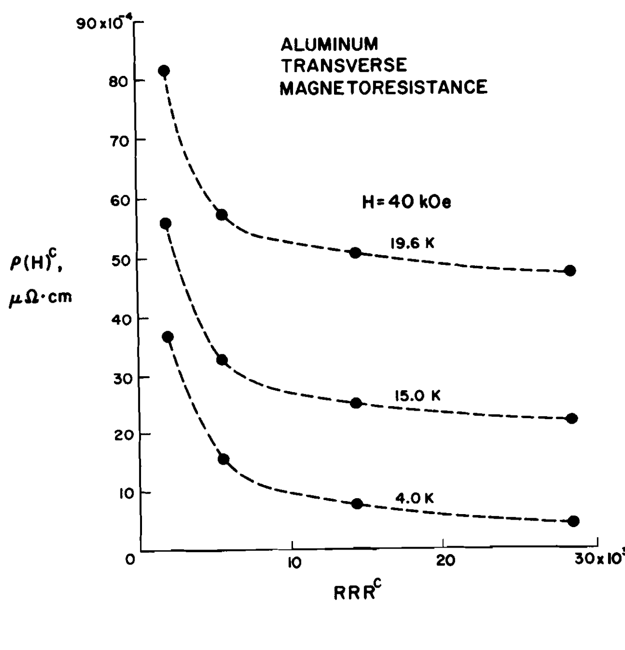

Fig. 3. Resistivity of aluminum specimens at 40 kOe. The superscript c indicates that the zero field data have been corrected for size effect.

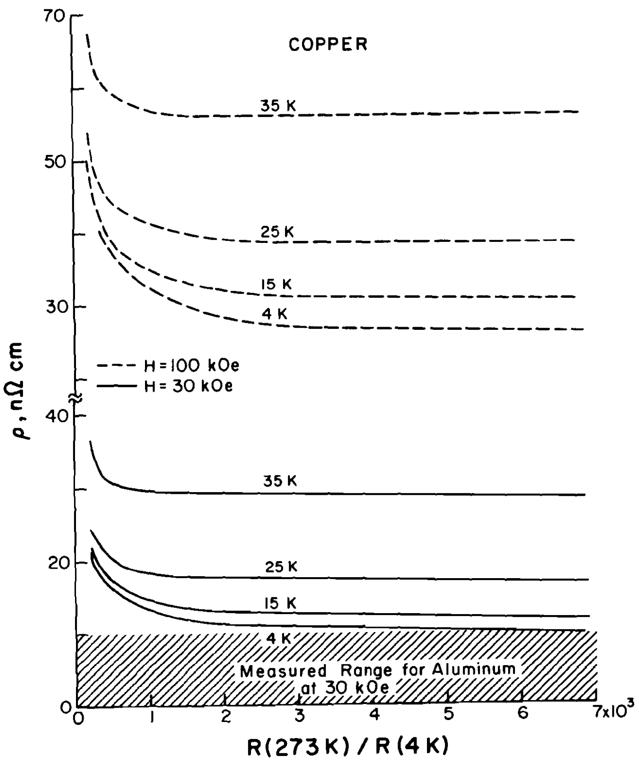

Fig. 4. Resistivity of copper specimens at 30 kOe and 100 kOe.

IV. References

† Copper research sponsored by the International Copper Research Association (INCRA) and aluminum research sponsored by U. S. Army Missile Command.

1. F. R. Fickett, Supplement to third quarterly report to INCRA (1972) (To be published).

2. G. Brandli and J. L. Olsen, Mater. Sci. Eng. 4, 61 (1969).

3. F. R. Fickett, Phys. Rev. B 3, 1941 (1971).

4. F. R. Fickett, Annual Report - INCRA Project No. 186 (To be published).