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Strain-Dependent Magnetoresistance of Sodium and Potassium

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The longitudinal magnetoresistance of sodium and potassium has been measured by a four-terminal method. The results are similar to those for the transverse magnetoresistance. The strain dependence is found to differ from other measurements.

1. INTRODUCTION

THE magnetoresistance ($\Delta\rho/\rho$) of sodium and potassium is anomalous in that it is large and linear in all magnetic fields, rather than small and constant in large fields ($\omega_c\tau \gg 1$, where $\omega_c\tau$ is the product of the electron cyclotron frequency and relaxation time) as predicted by all applicable accepted theories. The recent study by Penz and Bowers[1,2] has provided a summary of the present conflict between theory and experiment. Here we present a brief report of some related experiments to show that this is a real problem and is not caused by the particular form of the experiment.[3] As well as confirming these results, we emphasize a difference in the measured strain dependence in the hope that this may help to reveal the cause of the anomaly.

2. LONGITUDINAL MAGNETORESISTANCE

Because of the high symmetry, longitudinal magnetoresistance ($\mathbf{H}\|\mathbf{j}$) measurements can be more convenient than transverse ($\mathbf{H}\perp\mathbf{j}$) measurements. Experimentally there are fewer possible sources of difficulty such as unwanted Hall effect voltages and current flow nonuniformity. The theory is also simpler when applied to the longitudinal configuration.

The experiments were performed by a conventional four-terminal method in magnetic fields up to 60 kG. The specimens were polycrystalline and a very wide range of possible experimental variables chosen; magnetic field, temperature, specimen current, specimen purity, specimen diameter and length, potential probe separation and depth of penetration, sample straightness and constraints, annealing and cooling procedure, grain size, surface oxidation, etc.

The results showed a linear variation of the resistance with field with a slope $S \equiv \{[\rho(H)-\rho(0)]/\rho(0)\} \times (1/\omega_c\tau)$ of about 2–5% for both Na and K with no systematic variations with the above variables. This slope is larger than that observed by the helicon method[1] but is about the same as for the transverse magnetoresistance (also measured here but with fewer samples). The most noticeable feature is that there was a large ($\sim$50%) nonsystematic irreproducibility between the slopes (S) for nominally the same specimens. This is about the same as observed by other workers.

In these materials there seems to be a real, anomalous effect which has a magnitude dependent on some uncontrolled parameter. Strain measurements on these specimens showed a distinct difference between these two methods.

3. STRAIN DEPENDENCE

Measurements were made on the high-field magnetoresistance of clean, annealed, unconstrained wires strained at 4.2°K. The apparatus was similar to that used for measurements on Li[4] and applied a longitudinal strain to the wires. The changes in dimensions were allowed for by assuming a constant density.

The residual resistance ratio (s) decreased linearly by 4.5% per percent strain for Na and 1.3% per percent for K. These values compare reasonably with 8% per percent for Li[4] since the amount of phase conversion and hence extra electron scattering is larger in Li than Na and there is no phase change in K. The result for K is almost exactly that obtained by Penz and Bowers.[1]

The magnetoresistance remained linear but the slope S decreased linearly by 2.0% per percent strain for Na and 3.3% for percent per K, although it initially decreased more rapidly for Na (see Fig. 1). A maximum strain of 5.5% for K and 18% for Na were obtained

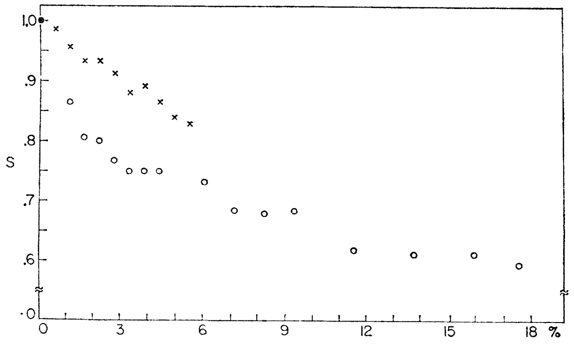

FIG. 1. Strain dependence of the slopes S of the linear magnetoresistance normalized to the zero-strain value (○ Na, × K). The residual resistance ratios (s) are 7000 for Na and 2840 for K. The zero-strain magnetoresistance S is 4.24% per $\omega_c\tau$ for Na and 6.8% per $\omega_c\tau$ for K.

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[2] P. A. Penz, Phys. Rev. Letters **20**, 725 (1968).

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before breaking. In comparison, the change in magnetoresistance for Li is less than 0.5% per percent strain after the phase transformation has been completed. No linear magnetoresistance has been observed in Li. The results were repeatable.

These results differ from those of Penz and Bowers[1] for K in sign, although the magnitude is about the same.

There are several differences between the experiments which may account for the result. It is unlikely that the sample geometry or the method of measurement seriously affects the result in view of the consistency of the unstrained data. The (initially) single crystals of Ref. 1 were almost certainly polycrystalline after the initial strain. The helicon method measures the averaged transverse magnetoresistance rather than the longitudinal effect.

The helicon method of straining is compressional rather than extensional, and the geometry is such that during the strain the ends of the flat plate are relatively constrained; thus the flow may be rather complex, whereas for the wire the sides are unconstrained. The strains were performed at 77°K for the helicon method and at 4.2°K for the wires. There is evidence for annealing at very low temperatures for the alkali metals.[5]

By comparing the effects in Na, K, and Li, we conclude that Na and K have an extra contribution to the magnetoresistance which is linear in magnetic field and is affected by strain. The sign of the strain dependence depends on the nature of the strain. A relatively indirect mechanism may be the explanation.[6]

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Studies of the Mean Displacement of Surface Atoms in the (100) and (110) Faces of Silver Single Crystals at Low Temperatures*

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The intensities of back-diffracted low-energy (10–300-eV) electrons have been measured as a function of temperature for the (110) and (100) faces of single-crystal silver in the temperature range −195 to 85°C. From these data, the rms displacements $\langle u_\perp \rangle$ of surface atoms perpendicular to the surface planes have been calculated and the magnitudes of the parallel components $\langle u_\parallel \rangle$ estimated. The perpendicular components of the surface rms displacements on silver (110) and (100) surfaces are 60 and 100% larger than those of bulk atoms. There is little difference in magnitude between the parallel and perpendicular components for these faces, as has also been reported for the (111) face. The parallel components of the rms displacements did not exhibit anisotropy within the accuracy of the measurements, and the physical adsorption of several noble gases had no effect on any of these measurements. The surface rms displacement for silver and those other fcc metals studied are larger than predicted by theory, which assumes bulk force constants for the surface atoms. This suggests that force constants for surface atoms are smaller than those of bulk atoms.

I. INTRODUCTION

It has long been recognized that the rms displacements of surface atoms should be different from those of bulk atoms.[1] Theoretical calculations which predict the magnitude of this difference have been reported for cubic metals,[2] ionic,[3] and molecular solids.[4] The calculations for the face-centered cubic metals indicate[5] a larger ($\approx\sqrt{2}$) rms displacement perpendicular to the surface plane ($\langle u_\perp \rangle$). The rms displacements in the surface plane ($\langle u_\parallel \rangle$) have also been calculated and found to be a function of crystal orientation. In general, these computations[2,5] make use of (a) the harmonic approximation and (b) force constants for surface atoms which are identical to those in the bulk. The larger surface rms displacements are primarily due to the change in the number of nearest neighbors for surface atoms. The rms displacements of surface atoms are measurable by low-energy electron diffraction (LEED) from the single-crystal surface. The temperature dependence of the different diffracted electron beam intensities $[(I_{hkl})$ minus the background $(I_0)]$ at the beam

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