Comment on "Model for the analysis of the magnetoresistance in potassium" and "High- and low-field limits for the Hall coefficient of potassium"*

J. C. Garland
Department of Physics, Ohio State University, Columbus, Ohio 43210

B. W. Maxfield
Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, New York 14850

P. A. Penz
Advanced Technology Laboratory, Texas Instruments, Incorporated, Dallas, Texas 75222

H. Taub
Department of Physics, New York University, New York, New York 10003

D. K. Wagner
Laboratory of Atomic and Solid State Physics, Cornell University, Ithaca, New York 14850

(Received 23 August 1973)

Comments are offered on two papers by Babiskin and Siebenmann, and it is suggested that additional experimental evidence is needed to justify the conclusions of the papers.

Two letters[1,2] have been recently published by Babiskin and Siebenmann (B and S) on the magnetoresistance and Hall effect in potassium. These two letters account for the puzzling linear magnetoresistance of potassium in terms of macroscopic inhomogeneities present in the potassium specimens. We have serious reservations about the validity of this explanation, and wish to comment here on the B and S letters in the light of presently published experimental results on potassium. First, however, it is useful to discuss the broad context of this work.

The galvanomagnetic properties of the alkali metals have been studied for several decades.[3–13] The electronic structure of these metals is widely thought to be exceptionally simple. In the case of potassium, de Haas–van Alphen measurements have shown the Fermi surface to be spherical to about 0.1%.[14] Thus, the alkali metals, and potassium in particular, should be natural systems in which to test the electron theory of metals. The conventional semiclassical treatment of electron transport in homogeneous metals[15] makes unambiguous predictions about the transport coefficients for metals having a closed Fermi surface, such as potassium. In strong magnetic fields, the magnetoresistance is predicted to saturate and the Hall coefficient is predicted to have the isotropic value $1/ne$ (in mksa units, where n is the electron density).

In contrast to these predictions, the general experimental observation is that the resistance increases linearly with magnetic field in the high-field regime. Some experiments show the Hall coefficient decreasing at high fields, while others show little, if any, change. Clearly, there is a disagreement between the predictions of transport theory and the magnetoresistance measurements, and some confusion as regards the Hall-coefficient measurements. A number of suggestions[16] concerning the origin of the linear magnetoresistance have been made, but many of these have not proved to be completely satisfactory, and others must stand the test of further experiments. With these remarks of introduction, we turn to the two letters of B and S.

In the first letter,[1] data for the magnetoresistance of five polycrystalline potassium wires are presented. In addition, a model for the magnetoresistance of potassium is advanced for which it is stated that "*all* the qualitative features of the experimental results can be consistently explained. . . ." According to this model the magnetoresistance of potassium is composed of contributions from several sources, all of which except one "saturate" or become field independent at strong magnetic fields. The remaining anomalous term increases as a linear function of magnetic field even to $\omega_c \tau$ values of several hundred (ω_c is the cyclotron frequency and τ is the electron relaxation time). In their letter, B and S conclude that this linear magnetoresistance results from the presence of "macroscopic spatial inhomogeneities" in their samples, according to a model first proposed by Herring[17] in 1960. This conclusion is based primarily on their observation that the observed slope of the linear magnetoresistance is strongly dependent on the details of sample preparation, an observation also made by other workers.

In the second letter,[2] S and B make use of their model for the linear magnetoresistance to analyze a related problem, the field dependence of the Hall coefficient of potassium. After examining three specimens, S and B present data on one of them which show a field-independent Hall coefficient and a very small linear magnetoresistance. Drawing on the conclusion from their first paper, S and B infer from the small linear term that their samples are homogeneous and that the observed field dependence of the Hall coefficient seen by other workers therefore arises from sample inhomogeneities.

There are several observations which we wish to make, both about this work and about the general problems inherent in galvanomagnetic studies of the alkali metals.

(i) We do not believe that sufficient evidence has been presented by B and S to support their assertion that the linear magnetoresistance arises specifically from macroscopic sample inhomogeneities. On the other hand, if one regards their description of the source of the linear term as conjecture, then we do not take issue with them; several of us, in fact, have considered this mechanism in the past.[7,12] In our judgment the only way to demonstrate experimentally the applicability of the Herring theory to potassium is to show a direct correlation of the slope of the linear magnetoresistance with an independently determined quantitative measure of sample inhomogeneity. To our knowledge this has not yet been done.

(ii) The main conclusion of the second letter by S and B—that the anomalous Hall coefficient of potassium arises from macroscopic sample inhomogeneities—is entirely dependent on the validity of the model proposed in the first letter. As stated before, we do not regard this first model as having been adequately tested by experiment, so that we must at this point regard the conclusion of the second letter as merely an interesting conjecture. In this regard, and in view of some evidence to the contrary,[7] we feel that the claim by S and B[2] that "the anomalous behaviors of the Hall coefficient and magnetoresistance can be systematically correlated with each other and with the presence of many sources for macroscopic inhomogeneities..." cannot yet be generally accepted until publication of additional corroborating data.

(iii) As a more general comment, we would like to stress the importance of describing fully the details of sample preparation and handling when reporting result in this subject. For example, in the case of samples made by drawing molten potassium into plastic tubing (this is the method used by B and S), questions arise concerning the relative thermal contraction rates of potassium and plastic, and the annealing history of these samples. These questions are very significant because it has been shown that the magnitude of the linear magnetoresistance can be influenced by strain and the state of anneal.[7,12]

Inasmuch as it has been demonstrated repeatedly that the high-field galvanomagnetic coefficients of potassium (and the other simple metals as well) can be greatly affected by sample-handling techniques, it is impossible to assess the significance of any experimental results unless full experimental details are given. Because of the mandatory size restriction it would appear to us that letters do not represent the most desirable format for reporting research in this subject.

In conclusion, we find that the existing experimental evidence is not sufficient to justify the conclusion of B and S that the linear magnetoresistance in potassium is caused by the presence of macroscopic inhomogeneities. Additional experimental work will be necessary to clarify this problem.

---

*Work supported in part by the National Science Foundation, Grant No. GH-33385A1, and by the Atomic Energy Commission, Contract No. AT (11-1)-3150, technical report No. COO-3150-17.

[1]J. Babiskin and P. G. Siebenmann, Phys. Rev. Lett. 27, 1361 (1971).

[2]P. G. Siebenmann and J. Babiskin, Phys. Rev. Lett. 30, 380 (1973).

[3]P. Kapitza, Proc. Roy. Soc. A 123, 292 (1929).

[4]E. Justi, Ann. Phys. 3, 183 (1948).

[5]D. K. C. MacDonald, in *Handbuch der Physik* (Springer Verlag, Berlin, 1956), Vol. 14, p. 137.

[6]F. E. Rose, Ph.D. thesis (Cornell University, 1964) (unpublished).

[7]P. A. Penz and R. Bowers, Phys. Rev. 172, 991 (1968).

[8]B. K. Jones, Phys. Rev. 179, 637 (1969).

[9]J. Babiskin and P. G. Siebenmann, Phys. Kondens. Mater. 9, 119 (1969).

[10]J. C. Garland and R. Bowers, Phys. Rev. 188, 1121 (1969).

[11]J. S. Lass, J. Phys. C 3 1926 (1970).

[12]H. Taub, R. L. Schmidt, B. W. Maxfield, and R. Bowers, Phys. Rev. B 4 1134 (1971).

[13]D. E. Chimenti and B. W. Maxfield, Phys. Rev. B 7, 3501 (1973).

[14]D. Schoenberg and P. J. Stiles, Proc. Roy. Soc. A 281, 62 (1964).

[15]I. M. Lifshitz, M. Ya. Azbel and M. I. Kaganov, Zh. Eksp. Teor. Fiz. 31, 63 (1956) [Soviet Phys.-JETP 4, 41 (1957)].

[16]For a useful summary of the various explanations of the linear magnetoresistence have been proposed, see L. M. Falicov and H. Smith, Phys. Rev. Lett. 29, 124 (1972).

[17]C. Herring, J. Appl. Phys. 31, 1939 (1960).