

$$\frac{d^2 A(x)}{dx^2} = \frac{2\beta}{x_1} \int_0^d k\left(\frac{x-y}{\xi}\right) A(y) dy, \quad (2)$$

$$\beta = \frac{3\sqrt{3}x_1}{16\pi\lambda_\infty^3} = \frac{3x_1}{8\xi_0\lambda_L^2}$$

$\lambda_\infty$  has been introduced because, according to Pippard, it has closer correlation with the measured penetration depth than  $\lambda_L$ . A solution of this equation is obtained through an iterative method. The function  $k((x-y)/\xi)$  is developed in terms of increasing order in  $x/\xi$ ,  $d/\xi$ . By inserting  $A^{(1)} = H_1(\frac{1}{2}x_1 + x)$  into (2), we obtain  $d^2 A^{(4)}/dx^2$ , and so forth. We obtain:

$$\frac{H^{(5)}}{H_1} = 1 + \beta d^2 \left\{ \frac{x}{d} \left( 0.423 + \frac{d}{\xi} - 0.335 \frac{d^2}{\xi^2} \right) + \frac{x^2}{d\xi} \left( -1 + 0.502 \frac{d}{\xi} \right) + \frac{x^3}{d^2\xi} \left( \frac{2}{3} - 0.335 \frac{d}{\xi} \right) + \left( \frac{1}{2} - \frac{x^2}{24\xi^2} \right) \frac{x^2}{d^2} \ln\left(\frac{\xi}{x}\right) + \left( \frac{1}{2} - \frac{(d-x)^2}{24\xi^2} \right) \frac{(d-x)^2}{d^2} \ln\left(\frac{d-x}{\xi}\right) + \left( \frac{1}{2} - \frac{d^2}{24\xi^2} \right) \ln\left(\frac{\xi}{d}\right) \right\}.$$

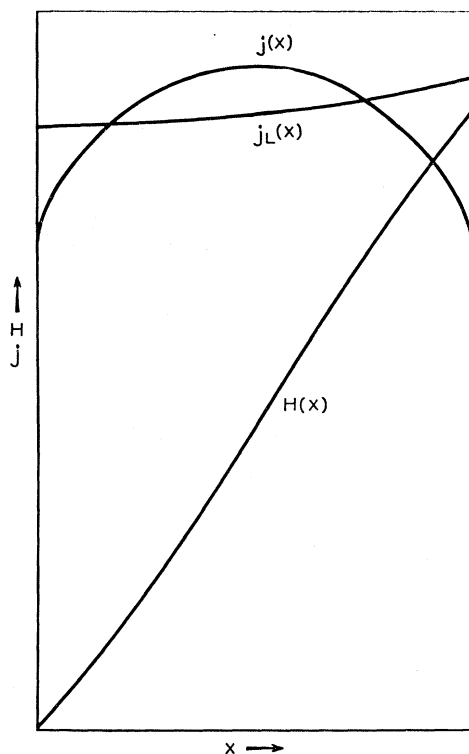


FIG. 1. Penetration of magnetic field difference  $H(x)$  and current  $j(x)$  through superconducting film according to Pippard's equation.  $H(x) = [H^{(5)}(x) - H_1]/\beta d^2$  and  $j(x) = j^{(5)}(x)/\beta d$  are plotted in arbitrary units;  $j_L(x)$  is the current according to the London theory, given in the same units as  $j(x)$ .

The fields and currents are finite everywhere. The iterative procedure is found to improve the expression for the field penetration by three orders of magnitude in  $d/\lambda_\infty$  in each step. If  $d/\lambda_\infty$  becomes too large, a solution can be obtained by approximating (2) by a system of linear equations.

Figure 1 shows  $[H^{(5)}(x) - H_1]/\beta d^2$  and  $j^{(5)}(x)/\beta d$  for  $d/\xi = 0.2$ . For comparison, the current which would result from the London theory,  $j_L(x)$ , has also been plotted. For larger values of  $d/\xi$ ,  $j(x)$  is of course no longer symmetrical about the film center.

The author wishes to thank A. L. Schawlow for suggesting this problem, and D. E. Eastwood, M. Tinkham, and L. R. Walker for discussions.

<sup>1</sup> Bardeen, Cooper, and Schrieffer, Phys. Rev. **108**, 1175 (1957).

<sup>2</sup> A. B. Pippard, Proc. Roy. Soc. (London) **A216**, 547 (1953).

<sup>3</sup> A. L. Schawlow, Phys. Rev. **109**, 1856 (1958), preceding Letter.

<sup>4</sup> R. E. Glover, III, and M. Tinkham [Phys. Rev. **108**, 243 (1957)] have used this geometry. In our case, the substratum is very thin compared with  $L$ ; however, our film is not very thin compared with  $\lambda$ .

<sup>5</sup> Because of the formal analogy of Pippard's and Sondheimer's equations, the calculations also apply to the anomalous skin effect in normal conducting films.

### Lack of Metallic Transition in LiH and LiAlH<sub>4</sub> under Static Pressure\*†

D. T. GRIGGS, W. G. McMILLAN, E. D. MICHAEL,  
AND C. P. NASH

University of California, Los Angeles, California

(Received January 15, 1958)

ALDER and Christian<sup>1,2</sup> have reported that the resistivities of LiAlH<sub>4</sub>, I<sub>2</sub>, and several alkali halides of large atomic number decrease by factors of about 10<sup>6</sup> under shock pressures ranging from 50 to 280 kilobars. Of the ionic substances, LiAlH<sub>4</sub> exhibited the effect at the lowest pressure (50 kilobars).

Somewhat earlier we had examined the pressure dependence of the conductivity of LiH in a primitive apparatus patterned after that of Bridgman.<sup>3</sup> The sample in powder form was compressed between two Carboly pistons in the form of truncated cones between which the resistance was measured. The resistivity of LiH was sensibly unchanged to 80 kilobars. At higher pressures a drop in resistance by 10<sup>9</sup> was observed. Subsequent experiments showed that the pistons had shorted, so the observed drop in resistance was spurious. These early experiments thus provided only a negative result to 80 kilobars for LiH.

After Alder and Christian's work, it seemed most desirable to do static experiments on LiAlH<sub>4</sub> and to extend the range of pressure for LiH. New apparatus<sup>4</sup> of the same general type was employed in this second series of experiments. This incorporated provision for raising the temperature while at high pressure. The samples were prepared in a nitrogen atmosphere in a dry box by weighing an appropriate amount of material

on a microbalance, then pressing this into a coherent pellet in a pill press at 5 kilobars pressure. The pellet was then assembled between the pistons with an airtight plastic closure to prevent reaction with water in the atmosphere. The sample was surrounded by a pipestone ring to act as a mechanical constraint and insulator at low pressures. In the room temperature experiments at the highest pressures (>150 kilobars) the pipe stone was extruded, but no shorting of the pistons occurred. The upper piston was made of grade 905 or 999 Carboloy with a truncated 140° cone, pressed against a flat of K-6 Kennametal. Very small permanent deformation of the pistons was observed, even at 240 kilobars pressure. The pressure was calculated as the force applied divided by the area of the piston measured after the run. Since no other element of the apparatus supports any of this force, the maximum pressure is slightly higher than this calculated mean value. Calibrations by Bridgman and in our Laboratory show that the difference is probably less than 5%. Resistance is measured between the two pistons. The shape of the sample changes in an unknown way during the experiments, so that accurate measurements of resistivity are not possible. The specific resistivity is approximately 30 times the measured resistance, and is so plotted.

Figure 1 shows the resistivity of LiH and LiAlH<sub>4</sub> at room temperature. The LiAlH<sub>4</sub> does not show the large drop in resistance observed by Alder and Christian. Two possible explanations were considered: (1) Their samples were shock-heated, so that the drop in re-

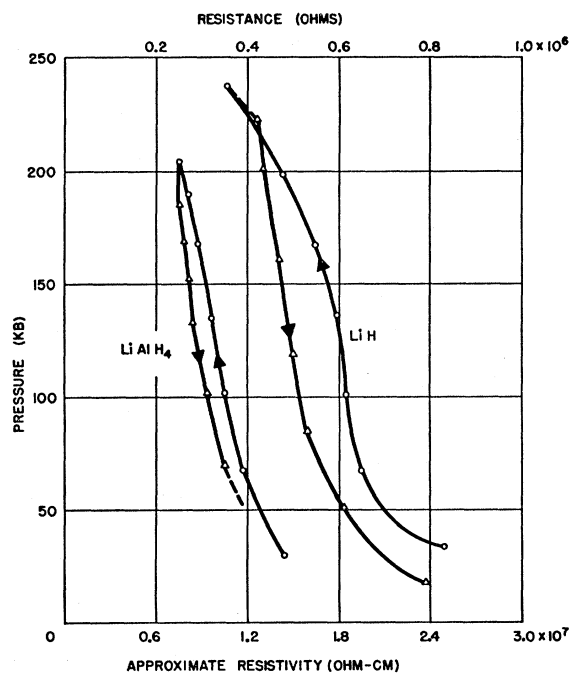


FIG. 1. Approximate resistivity of LiH and LiAlH<sub>4</sub> vs pressure at room temperature.

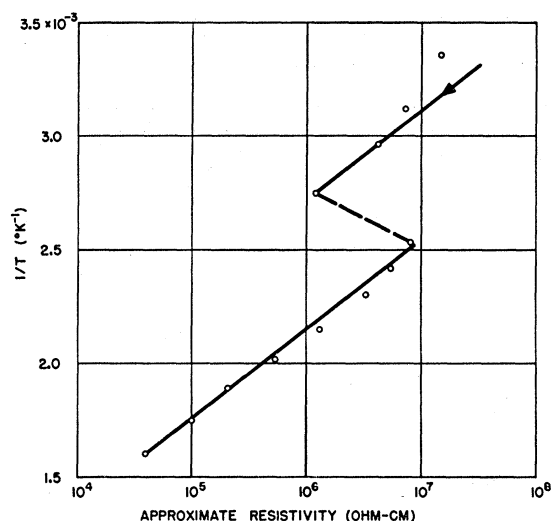


FIG. 2. Approximate resistivity of LiAlH<sub>4</sub> vs reciprocal temperature at 70 kilobars. Activation energy corresponding to solid curve is 12 kcal/mole.

sistance observed by them might have been due to the elevated temperature. (2) Their LiAlH<sub>4</sub> contained some metallic impurity, which was not present in our material. The LiAlH<sub>4</sub> which we used was prepared at the University of California Radiation Laboratory, Livermore, with great attention to purity, and was kindly provided us by Alder and Christian.

The temperature rise in their 50-kilobar experiment is believed to be less than 100°C. Accordingly, we investigated the resistivity of LiAlH<sub>4</sub> at elevated temperature. Figure 2 shows the apparent resistivity versus  $1/T$  at 70-kilobars pressure to 350°C. The break in the curve is typical of these experiments, but is not understood. The activation energy derived from the slope of the curve is 12 kcal/mole. In this, and other experiments at elevated temperature, the LiAlH<sub>4</sub> was surrounded by a narrow pipestone ring. These measurements do not distinguish between the conductivity of the sample and that of the pipestone ring. One can only be sure that the resistivity of the LiAlH<sub>4</sub> was not less than these values.

Thus, we have found no metallic conductivity in LiH to 240 kilobars at room temperature, in LiAlH<sub>4</sub> to 200 kilobars at room temperature, or in LiAlH<sub>4</sub> at 70 kilobars to 350°C.

We wish to thank Dr. Alder and Dr. Christian for making available their data prior to publication and for providing the LiAlH<sub>4</sub>. Thanks are also due Dr. Edward Teller for his interest.

\* Publication No. 95, Institute of Geophysics, University of California at Los Angeles, California.

† This work was supported by the Office of Ordnance Research.

<sup>1</sup> B. J. Alder and R. H. Christian, Phys. Rev. **104**, 550 (1956).

<sup>2</sup> B. J. Alder and R. H. Christian, Discussions Faraday Soc. **22**, 44 (1956).

<sup>3</sup> P. W. Bridgman, Proc. Am. Acad. Arts Sci. **81**, 169 (1952).

<sup>4</sup> D. T. Griggs and G. C. Kennedy, Am. J. Sci. **254**, 722 (1956).