

minimum is reached at a rather higher pressure. Sodium and potassium behave rather differently from the others: for these two metals  $K$  increases rather slowly after the minimum has been reached. Nevertheless it seems that in all these metals we are seeing the effect on  $K$  of progressive distortion of the Fermi surface.

### Pressure Coefficients and Thermoelectric Power

At high temperatures (temperatures which are large as compared to the characteristic temperature of the lattice) the absolute thermoelectric power of a metal  $S$  is related to its resistivity by the following relationship (23):

$$S = -\frac{\pi^2 k^2 T}{3eE_F} \left( \frac{d \ln \rho(E)}{d \ln E} \right)_{E=E_F} \quad (9)$$

( $k$  is Boltzmann's constant and  $e$  is the electronic charge). This relationship (24) expresses the fact that the thermoelectric power of a metal depends on how the resistivity of the metal varies with its Fermi energy, and from the measured values of the thermoelectric power of a metal at high temperature it is thus possible to obtain a measure of this variation through the quantity

$$x = \left( \frac{d \ln \rho(E)}{d \ln E} \right)_{E=E_F}$$

One way of altering the Fermi energy of a metal is to compress it. Thus there should be some relationship between the volume coefficient of resistivity and the value of  $x$  for that metal. It is not to be expected that  $x$  will be related to the total change of resistance due to the volume change because this involves the change in the amplitude of the lattice vibrations, which has no counterpart in  $x$ . If, however, we eliminate the part due to changes in the lattice vibrations and consider  $d \ln K/d \ln V$ , we might expect that this would be related to  $x$ . In Table 2 a comparison of these quantities is made for the monovalent metals, and the ratios are listed (column 6). If the change in  $K$  with volume were due entirely to the

change in the Fermi energy  $E_F$  with volume and if the Fermi surface did not distort under pressure, this ratio would be simply  $d \ln E_F/d \ln V$ . For a spherical Fermi surface this has the value  $-2/3$ , since  $E_F$  is proportional to  $V^{-2/3}$ . It may be seen that for all the metals the value lies between  $-0.3$  and  $-0.8$ ; in particular for sodium and potassium, the two metals whose Fermi surfaces are most nearly spherical, the value of the ratio is quite close to  $-2/3$ .

If the interpretation given above of the minimum in the resistance-versus-pressure curve of cesium is correct, and if the thermoelectric power is intimately related to the quantity  $d \ln K/d \ln V$ , the thermoelectric power of cesium should be very sensitive to pressure and should in fact change sign at quite modest pressures (pressures similar to that required to reduce the resistance to its minimum value). Recent measurements on the thermoelectric power of cesium at  $0^\circ\text{C}$  (25) show that this change of sign does indeed occur and that the thermoelectric power of cesium is extremely sensitive to pressure; it changes by nearly 1/2 percent per atmosphere.

To sum up, we may say that the pressure coefficient of the ideal resistivity of a metal changes appreciably only at low temperatures ( $T < \theta/3$ ); moreover, experiments show that this change is related to the change in the temperature coefficient of resistivity in the way that theory predicts. There appears to be a close connection between the electronic contribution to the pressure coefficient of resistance on the one hand and the thermoelectric power of the metal on the other. When one comes to consider the magnitude of the pressure coefficient it is clear that in some metals, notably lithium, cesium, and the noble metals, this can only be understood in terms of the distortion of the Fermi surface of the metal. This distortion is also reflected in the temperature dependence and the magnitude of the resistivity. All this emphasizes how desirable it would be to obtain direct information about the shape of the Fermi surfaces in alkali metals (26).

### References and Notes

1. See, for example, the review by D. K. MacDonald in *Handbuch der Physik*, Flugge, Ed. (Springer, Berlin, 1956), vol. 1, p. 137.
2. P. W. Bridgman, *The Physics of High Pressure* (Bell, London, 1949).
3. G. N. Lewis, *Z. physik. Chem. (Leipzig)* 18, 532 (1927).
4. I remember hearing Professor Bridgman describe how he subjected a raw egg to high pressure. When he examined it afterward appeared as if it had been hard-boiled.
5. For a general account of the theory of electrical resistivity, see, for example, J. Ziman, *Electrons and Phonons* (Oxford Univ. Press, New York, 1960).
6. E. Grüneisen, *Ann. Physik.* 40, 543 (1941).
7. For a survey of recent high-pressure techniques and measurements see C. A. Swenson in *Solid State Physics*, F. Seitz and D. Turnbull, Eds. (Academic Press, New York, 1960), vol. 11, p. 41.
8. J. S. Dugdale and J. A. Hulbert, *Can. Phys.* 35, 720 (1957).
9. J. S. Dugdale and D. Gagan, *Proc. Roy. Soc. (London)* A241, 397 (1957).
10. J. Hatton, *Phys. Rev.* 100, 681 (1955).
11. C. A. Swenson, *ibid.* 99, 423 (1955).
12. J. S. Dugdale and F. E. Simon, *Proc. Roy. Soc. (London)* A218, 291 (1953).
13. J. S. Dugdale and D. Gagan, in preparation.
14.  $\theta_D$  is the Debye temperature which characterizes the temperature dependence of specific heat.
15. For simplicity the discussion is restricted to body-centered and face-centered cubic lattices which are Bravais lattices.
16. A. B. Pippard, *Phil. Trans. Roy. Soc. Lond.* A250, 325 (1957); D. Shoenberg, *Phil. Mag.* 5, 105 (1960); R. W. Morse and J. Gavenda, *Phys. Rev. Letters* 2, 250 (1959); R. W. Morse et al., *ibid.* 4, 605 (1960).
17. M. H. Cohen and V. Heine, *Advances in Physics (Phil. Mag. Suppl.)* 7, 395 (1959).
18. F. S. Ham, in *The Fermi Surface*, W. Harrison and M. B. Webb, Eds. (Wiley, New York, 1960).
19. J. Collins and J. M. Ziman, in preparation. J. Collins, in preparation. I am indebted Dr. Collins for information about this work before publication.
20.  $\theta_0$  is the limiting value of the Debye temperature at the absolute zero of temperature.
21. Even under compression the Fermi surface must continue to occupy the same proportion of the Brillouin zone (here, one-half); therefore, the shape of the surface does not change under compression, the geometry of  $k$ -space of the scattering processes is not changed.
22. P. W. Bridgman, *Proc. Am. Acad. Arts Sci.* 81, 169 (1952); 76, 55 (1948).
23. N. F. Mott and H. Jones, *The Theory of Properties of Metals and Alloys* (Oxford Univ. Press, New York, 1936).
24. This expression ignores any phonon effects.
25. J. S. Dugdale and J. N. Mundy, *Phil. Mag.* in press.
26. It is a pleasure to acknowledge the collaboration of Dr. D. Gagan in much of the experimental work described here. I am grateful to Dr. D. K. C. MacDonald for encouragement and interest at all times and wish to thank him and Dr. A. V. Gold for many valuable discussions and for reading the manuscript.
27. W. Meissner, in *Handbuch der Experimentalphysik*, W. Wien and F. Harms, Eds. (Akademische Verlagsgesellschaft, Leipzig, 1957), vol. 11, pt. 2, p. 1.

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