Table I. Values of $J(0)$ (in eV) obtained in the RPt_2 and RPt_5 intermetallics from the various experimental data.

		From ^{195}Pt Knight shift				
		Ce	Pr	Nd	From Gd^{3+} g shift	From θ_P data
RPt_2		0.30	0.35	0.16	−0.45 0.05[a]	±0.2
RPt_5	Pt_I	0.10	0.22	0.16	0.20[b]	±0.4
	Pt_{II}	0.36	0.21	0.24		

[a]See Ref. 6. [b]See Ref. 7.

nature of the polarization they were dealing with. They then resorted to other models with interior cutoffs, etc., and at least obtained the correct signs of $J(0)$. Part of the difficulty is that Eq. (1) is an extremely poorly convergent series, violently sensitive to errors in either F or setting $J(q) = J(0)$. Evaluation of the conduction-electron polarization in various RE alloys using more rigorous procedures[8] is currently underway.

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[1]V. Jaccarino, B. T. Matthias, M. Peter, H. Suhl, J. H. Wernick, Phys. Rev. Letters 5, 251 (1960); V. Udaya Shankar Rao and R. Vijayaraghavan, Phys. Letters 19, 168 (1965); F. Borsa, R. G. Barnes, and R. A. Reese, Phys. Status Solidi 19, 359 (1966).

[2]M. Peter, D. Shaltiel, J. H. Wernick, H. J. Williams, J. B. Mock, and R. C. Sherwood, Phys. Rev. 126, 1395 (1962).

[3]D. Bosch, F. Pobell, and P. Kienle, Phys. Letters 22, 262 (1966).

[4]K. Yosida, Phys. Rev. 106, 893 (1957).

[5]R. G. Barnes and E. D. Jones, Solid State Commun. 5, 285 (1967), and the first two papers of Ref. 1.

[6]D. Shaltiel, J. H. Wernick, and V. Jaccarino, J. Appl. Phys. 35, 978 (1964).

[7]D. Shaltiel, J. H. Wernick, H. J. Williams, and M. Peter, Phys. Rev. 135, A1346 (1964).

[8]R. E. Watson and A. J. Freeman, Phys. Rev. 152, A566 (1966).

[9]P. G. de Gennes, J. Phys. Radium 23, 510 (1962).

[10]A. M. Clogston, V. Jaccarino, and Y. Yafet, Phys. Rev. 134, A650 (1964); S. S. Dharmatti, V. Udaya Shankar Rao, and R. Vijayaraghavan, in Proceedings of the International Conference on Magnetism, Nottingham, England, 1964 (The Institute of Physics and the Physical Society, London, England, 1965), p. 393.

[11]R. E. Watson, S. Koide, M. Peter, and A. J. Freeman, Phys. Rev. 139, A137 (1965).

[12]M. Peter, D. Shaltiel, J. H. Wernick, H. J. Williams, J. B. Mock, and R. C. Sherwood, Phys. Rev. Letters 9, 50 (1962).

[13]B. Giovannini, M. Peter, and J. R. Schrieffer, Phys. Rev. Letters 12, 736 (1964).

SIZE EFFECTS IN THE ELECTRONIC THERMAL CONDUCTIVITY OF GALLIUM SINGLE CRYSTALS*

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Recent work[1,2] on the electrical conductivity of 99.9999% gallium single crystals has shown that the ideal resistivity ρ_i varies as the square of the absolute temperature between 1.1 and 4.2°K. This variation may be caused either by collisions between electrons from different branches of the Fermi surface or by electron-phonon Umklapp processes. In a specimen of 0.95-cm diam, Newbower and Neighbor[1] also found a small peak in the resistance temperature curve at about 1.7°K; the exact temperature depended on the measuring current and on the earth's magnetic field. Specific-heat measurements on the same material by Shiffman and Neighbor[3] showed no corresponding effect, and this suggests that the resistance peak is not a property of the bulk metal, but may be due to the onset of boundary scattering for a particular group of electrons. (The average mean free path of electrons for

this material is >1 cm at 1°K.[2])

In an attempt to determine the reasons for the T^2 dependence of ρ_i and for the anomalous resistance peak, we have measured the thermal conductivity of gallium single-crystal rods of the same purity between 1.4 and 4.2°K as a function of size and crystal orientation, using the standard two-thermometers, one-heater technique. For a pure metal at low temperatures, neglecting lattice conduction, the thermal resistivity is normally given by $W = \alpha/T + \beta T^2$, where α/T and βT^2 represent scattering by impurities and phonons, respectively. If electron interactions are dominant, the ideal thermal resistivity $W_i = \beta T^2$ must be replaced by $\beta' T$. On the other hand, if the T^2 term in ρ is caused by electron-phonon Umklapp processes, then W_i should remain proportional to T^2, since thermal, unlike electrical, conduction cannot distinguish between small- and large-angle scattering.[4] Hence WT is a linear function of either T^2 or T^3. If the resistance peak is due to boundary scattering, a corresponding effect is likely to appear in thermal resistance as well. In the electrical case the problem of boundary scattering is complicated by the fact that the magnetic field generated by the measuring current alters the effective mean free path. It is presumably for this reason that an increase in the measuring current moves the peak to a lower temperature. Since a thermal current produces no magnetic field, this complication does not arise when heat is conducted by electrons.

The results of our measurements are summarized in Table I. For all the three principal axes, the conductivity K initially increases with the lowering of temperature until it reaches a maximum just below 2°K. The maximum values of K for the A, B, and C axes are 300, 845, and 76 W cm^{-1} °K^{-1}, at 1.84, 1.77 and 1.98°K, respectively. (As far as we know, 845 W cm^{-1} °K^{-1} is the highest recorded value of K for a solid.) None of the measured specimens gave a linear dependence of WT on T^2, even in a limited temperature region, and this indicates the absence of electron collisions. On the other hand, the graph of WT against T^3 was linear except for a limited region in the middle of the range. Figure 1 shows WT against T^3 for three A-axis specimens of different sizes. In each case there exist values $T = T_1$, T_2 depending on the specimen, such that the graph has the form $WT = \alpha + \beta T^3$ for $T \geq T_1$, $WT = \alpha + \beta T^3 + \varphi(T^3)$ for $T_2 < T \leq T_1$, and $WT = \alpha + \varphi(T_2^3) + \beta T^3$ for $T \leq T_2$; here $\varphi(T^3)$ is a decreasing function of T^3 with $\varphi(T_1^3) = 0$, and φ depends on the specimen. To within the accuracy of our experiments, which is about 1%, the constants α and β are the same for each specimen. The smaller the specimen the higher are the values of T_1, T_2 and $\varphi(T_2^3)$. We interpret these results as follows. The ideal thermal resistivity in gallium is mainly governed by electron-phonon collisions. In the range $T_2 \leq T \leq T_1$, boundary scattering of electrons provides an additional resistive mechanism. If l_{ep} denotes the electron-phonon mean free path of a small group of electrons and d the diameter of the specimen, then T_1 and T_2 correspond to $l_{ep} \approx d$ and $l_{ep} \gg d$, respectively. Below T_2, d itself becomes the effective mean free path for this group and φ does not increase any further. Since l_{ep} is inversely proportional to T^3, the last assertions require that $T_1^3 d$ and $T_2^3 d$ should each be the same for all specimens: the values obtained are 114.2, 114.3, and 119.1 for $T_1^3 d$ and 42.8, 41.3, and 43.6 for $T_2^3 d$.

The ratio T_1^3/T_2^3 for each specimen is approximately 2.7 and it is hard to understand how an increase by such a small factor can represent the entire range $l_{ep} \approx d$ to $l_{ep} \gg d$. However, if boundary scattering is confined

Table I. Thermal-conductivity and boundary-scattering data for three principal axes of gallium.

Orientation axis	Diameter (mm)	Bulk K_{max} (W cm^{-1} °K^{-1})	Temperature for K_{max} (°K)	T_1^3	T_2^3	$T_1^3 d$	$T_2^3 d$
A	3.97	300	1.84	30	11	119	43.6
A	3.175			36	13	114	41.3
A	2.38			48	18	114	42.8
B	3.175	845	1.77	40	21	127	66.7
C	3.175	76	1.98	45	12	143	38.1

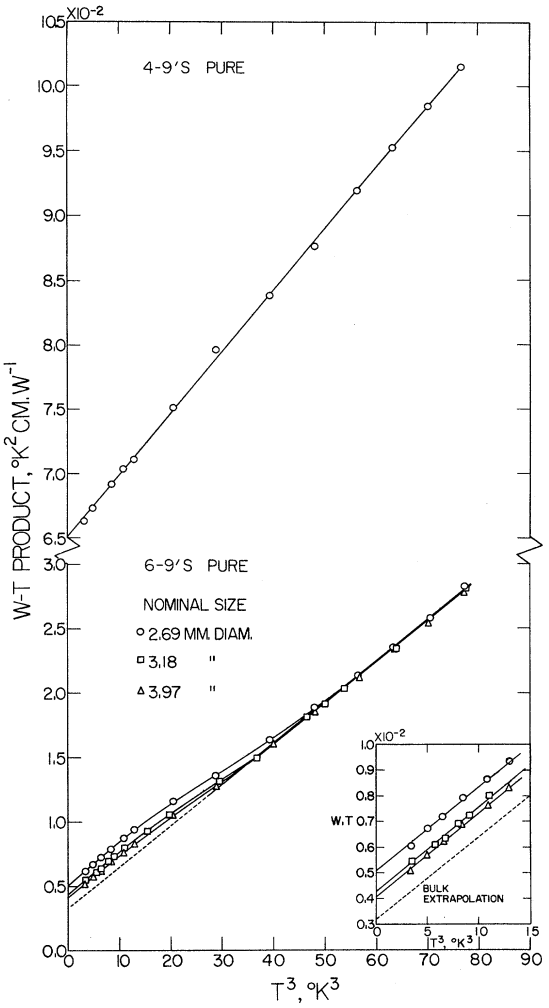

FIG. 1. Plot of WT against T^3 for A-axis crystals of different sizes. The top curve, which is for a less pure specimen, shows no boundary-scattering effects.

to a group of electrons from a limited portion of the Fermi surface, the range of temperatures for which l_{ep}/d varies from 1 to $\gg 1$ may be much smaller than that for the entire surface. The validity of Matthiessen's rule for these specimens provides another indication that the additional resistance due to boundary scattering is caused by a small fraction of the conduction electrons.

The assertion that the nonlinear part of the graph of WT versus T^3 is due to boundary scattering is further supported by the fact that an identical curve for an A-axis specimen of 99.99% gallium with $d = 3.175$ mm shows no deviation from a straight line (see top curve in Fig. 1). If we multiply the intercept obtained from the dotted line in Fig. 1 with the Lorentz number, we obtain a value of ρ which agrees reasonably well with the bulk residual resistivity value of Yaqub and Cochran.[5] This provides further evidence that the straight line for $T \geq T_1$ represents the bulk behavior.

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[1]R. S. Newbower and J. E. Neighbor, Phys. Rev. Letters 18, 538 (1967).

[2]M. Yaqub and J. F. Cochran, Phys. Rev. 137, A1182 (1965).

[3]J. E. Neighbor and C. A. Shiffman, Phys. Rev. Letters 19, 640 (1967).

[4]J. M. Ziman, Electrons and Phonons (Clarendon Press, Oxford, England, 1960).

[5]J. F. Cochran and M. Yaqub, Phys. Rev. 140, A2174 (1965).

SPECTROSCOPY OF ODD-ODD NUCLEI WITH DIRECT (d, α) REACTIONS*

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Until recently, two major obstacles impeded the successful investigation of heavier odd-odd nuclei by direct nuclear reactions: the need for very good experimental resolution, due to the high level densities of odd-odd nuclei, and the reduced usefulness of single-nucleon transfer reactions. The resolution necessary for medium-weight nuclei and the first 20 to 40 excited states is now easily obtained. The combination of tandem Van de Graaffs and modern magnetic spectrometers allows total resolving powers of 2000 and better[1,2] without the excessive loss in counting rate that used to restrict earlier high-resolution work. Generally, however, there remains a large ambiguity in the assignment of total angular momentum (J_f) for the final states if the target nucleus has nonzero J_i. Hence quantum numbers of odd-odd nuclei are most uniquely assigned in deuteron-transfer reactions on ev-