Table. I. Estimates of critical field H_c and corresponding transition energy $E_T(H_c)$ of some allowed transitions (Ref. 6) for interband magnetoabsorption with $E \| H$. Energy levels are computed from Ref. 6 for H in the (100) direction. We assume that V_{OD} couples the extra electron in the state $a^c(N)$ to the electronic state $a^c(0)$ and the ehp state $a^-(2)a^c(0)$. Magnetic fields are in kG and energies in eV.

H_c	$E_T(H_c)$	Transition
164	0.547	$b^-(6)a^c(4)$
126	0.534	$b^-(7)a^c(5)$
103	0.527	$b^-(8)a^c(6)$
87	0.521	$b^-(9)a^c(7)$
75	0.517	$b^-(10)a^c(8)$

then (8) would not diverge as $D \to 0$ [although, of course, if η were sufficiently small, (8) could become very large]. The simplest band theories, such as the theory of Wallis and Bowlden,[7] are consistent with (10). The most complete theory available of the Landau-level spectrum of InSb near the Γ point of the valence and conduction bands has been given by Bell and Rogers.[8] These authors conclude that

$$[\partial \mathcal{E}_h(0, k_z)/\partial k_z]_{k_z=0} = 0$$

for the light holes, and their numerical computations for $H = 20$ kG indicate that if (11) is correct for heavy holes and/or conduction-band levels, η must be very small. Therefore, even if (11) should hold for some InSb Landau levels, we believe that strong mixing of electron and electron-ehp wave functions at critical magnetic field values would occur much as predicted here.

I am indebted to Dr. S. Groves for making available his program to compute energy levels by the theory of Pidgeon and Brown; I would also like to thank him for useful discussions.

*Operated with support from the U. S. Air Force.

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[5]Two necessary conditions for the nonvanishing of $M(k_{xe}, k_x, k_z)$ are that $k_{ze} + k_z - k_{zh} = 0$ and that $\varphi_{0,0,k_{xh}}$ and $\psi_{0,0,k_{xe}}$ both belong to the a set or both to the b set of Roth et al. [See L. M. Roth, B. Lax, and S. Zwerdling, Phys. Rev. 114, 90 (1959).]

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LORENZ NUMBER OF PURE PALLADIUM AT LOW TEMPERATURES

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(Received 2 October 1967)

The ideal electrical and thermal resistivities of pure Pd have been measured at temperatures from 2.5 to 19°K. The results yield an ideal Lorenz number (L_i) which has the value of 0.7×10^{-8} V^2/deg^2 and is independent of temperature below roughly 5°K. A comparison of these results with data on Re and Ni indicates that the low-temperature values of L_i are parameters which are characteristic of the individual metals.

The fact that the ideal electrical resistivity (ρ_i) of certain transition metals varies as T^2 at low temperatures has been attributed by many authors[1-5] to the dominance of electron-electron scattering at these temperatures. If electron-electron interactions are, indeed, dominant, the theoretical efforts[6] indicate that the ideal thermal resistivity (w_i) should then vary as T at those low temperatures where $\rho_i \propto T^2$. Prior to recent work in this laboratory[7] with Re and the very recent measurements of Ni by White and Tainsh,[8] there were no experimental determinations of the thermal resistivity at appropriately low temperatures which could

be used to deduce w_i with sufficient accuracy to check the electron-electron interaction theories. The recent theoretical work of Herring,[4] which suggests that the ideal Lorenz number $[L_i = \rho_i/(w_i T)]$ at low temperatures would be independent of temperature and have a universal value of 1.58×10^{-8} V²/deg² in metals with elaborate Fermi surfaces, lends particular interest to a low-temperature experimental investigation of both ρ_i and w_i in these metals. We report here the results of an experimental determination of L_i for a specimen of Pd at temperatures from 2.5 to 19°K.

The apparatus used for these measurements is described in detail elsewhere.[7] The specimen was a polycrystalline rod, about 2.4 mm in diameter, with a ratio of room-temperature to helium-temperature electrical resistivity of roughly 400. The same copper clamps served as contacts for measurements of both the electric potentials and the temperatures, so that one geometry determined both the net electrical, and the net thermal, resistance.

The results clearly show that not only does ρ_i vary as T^2 below about 5°K, but also that w_i varies as T below about 7°K. This can be seen in Fig. 1, where ρ (electrical) and w (thermal) are the total observed resistivities, and the straight lines drawn through the data at the lower temperatures yield

$$\rho = (2.68 + 0.0033T^2)\times10^{-8}\ \Omega\ \text{cm} \qquad (1)$$

and

$$wT = 1.08 + 0.0049T^2\ (°\text{K})^2\ \text{cm/W}. \qquad (2)$$

The total Lorenz numbers $(L = \rho/wt)$ as well as the ideal Lorenz numbers of Pd are shown in Fig. 2. At the lowest temperatures the data for L approach the Sommerfeld value, $L_S = 2.44\times10^{-8}$ V²/deg², which obtains when impurity scattering is dominant. The ideal Lorenz numbers, on the other hand, fall with decreasing temperature until they become temperature independent at about 5°K, with a residual value of L_i about 0.7×10^{-8} V²/deg². Represented in Fig. 2 as a dashed line are the ideal Lorenz numbers of rhenium (taken from our earlier work) which become constant at about 11°K with a value of about 0.5×10^{-8} V²/deg². It should be noted in Fig. 2 that measurements on a highly pure copper specimen in the same apparatus yield the well-known result; i.e., L_i falls rapidly to zero as the temperature approaches zero.

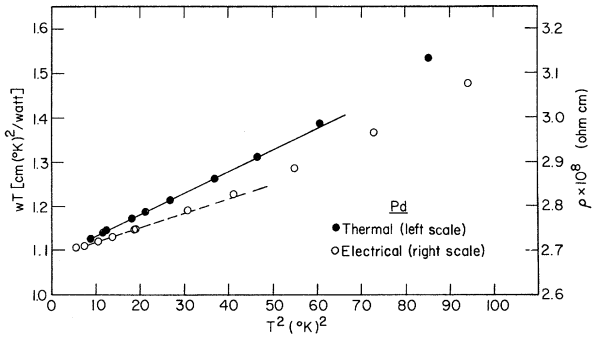

FIG. 1. Electrical resistivity, and product of thermal resistivity with temperature, as functions of the square of the absolute temperature.

Both the early treatments of electron-electron interactions for interband and intraband electron scattering, as well as the recent treatments[4,5] in terms of Fermi liquid theory, predict that L_i at low temperatures has some constant value. Thus the fact that L_i becomes temperature independent at low temperatures not only in the present Pd specimen but also in Re (and, in addition, in Ni[8]) seems to be strong evidence for the importance of electron-electron interactions in the transition metals at low temperatures. However, the fact that the residual values of L_i [i.e., (1.0, 0.7, and 0.5) $\times10^{-8}$ V²/deg² for Ni, Pd, and Re, respectively] are different in each of the three metals investigated so far indicates that these L_i values are parameters which are characteristic

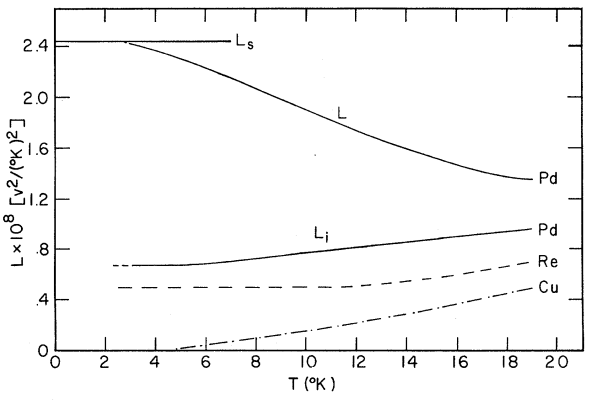

FIG. 2. Lorenz numbers of Pd as functions of temperature. L_S is the Sommerfeld value of 2.44×10^{-8} V²/deg², and L and L_i indicate, respectively, the total and ideal Lorenz numbers. Shown also are the ideal Lorenz numbers of Re (Ref. 7) and of Cu. All of the data were obtained with the same equipment, and under the same conditions.

of the individual metals. Thus any calculation of the residual values of L_i will probably require a consideration of features pertinent to the metal of interest. To the best of this author's knowledge, this has been carried out only in the case of Pd, where a recent refinement[9] of the s-electron–paramagnon scattering theory provides an estimate of the low-temperature value of L_i in terms of the Stoner enhancement factor $(1/K_0^2)$.[10] The experimental L_i of 0.7 then yields a $1/K_0^2$ of approximately 5. The value of $1/K_0^2$ for Pd is not known, but the above result is in fair agreement with a recent estimate of 8.[11]

The author is indebted to B. C. La Roy and R. Williams for the preparation of the Pd specimen and to A. C. Ehrlich for help in data acquisition. He is particularly grateful to A. I. Schindler and M. J. Rice for many stimulating discussions and for communication of the results of their work prior to publication.

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PARAMAGNETIC RESONANCE OF ERBIUM IN A SINGLE CRYSTAL OF MAGNESIUM*

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The anisotropic electron-paramagnetic-resonance spectrum of an erbium-doped single crystal of magnesium metal is characteristic of a uniaxially distorted Γ_7 doublet of the free-ion $^4I_{15/2}$ multiplet. The observed linewidth anisotropy is consistent with an isotropic conduction-electron–localized-electron exchange interaction.

We wish to report what we believe to be the first observation of an anisotropic electron-paramagnetic-resonance signal in a metal. We have observed the resonance spectrum of erbium-doped single-crystal magnesium metal in the liquid-helium range at both 9 and 35 Gc/sec. The g tensor is uniaxial, with $g_\parallel = 8.90 \pm 0.1$ and $g_\perp = 5.77 \pm 0.1$. If it is assumed that the uniaxial component of the crystalline field is small compared with the cubic field splitting, and the "parent" state is the Γ_7 level of the free-ion $^4I_{15/2}$ multiplet, these values obey the relation[1] $g_\parallel + 2g_\perp = 3g_c$, where $g_c = 6.8$. The line shape is found to be that predicted by Bloembergen[2] with a width which increases linearly with temperature. The broadening is anisotropic, the temperature-dependent part varying from 120 ± 20 G in the parallel direction to 140 ± 20 G in the perpendicular direction at 4.2°K. This anisotropy can be accounted for on the assumption that the conduction-electron–localized-electron exchange interaction is isotropic, and yields a value for the exchange integral of ± 0.13 eV. This value yields a calculated residual X-band ($T = 0$) linewidth[3] (cut-off Lorentzian) of 25 G for $h_{rf} \perp c$ axis, to be compared with an observed extrapolated $T = 0$ width of $\sim 110 \pm 30$ G. The residual linewidth was found to be $\sim 80 \pm 30$ G for $h_{rf} \parallel c$ axis.

Previous measurements[4] of the resonance properties of localized moments in metals were performed in cubic hosts. The first observation of the resonance of a non-S-state ion was reported recently by Griffiths and Coles.[5] They observed the resonance of Er dissolved in Ag in small-particle samples. Geschwind[6] observed the resonance of Mn in single crystals of Cu and found results similar to those reported earlier by Owen et al.[4] In order to examine the effects of a crystalline field on a moment dissolved in a metal, single crystals of magnesium doped with a variety of rare-earth metals were grown. The local symmetry of a rare-earth atom, assumed to substitute for a mag-