purity. This effect has been observed and it has been possible to produce a cancellation between the Tb- and the Pr-induced shifts. This experiment further demonstrates the long range of the magnetic interaction involved.

Such an interaction should produce magnetic ordering even in the most dilute R.E.-Pd samples. Susceptibility measurements on 3% Gd in Pd indicate indeed $\theta = +12°K$ in $\chi = C/(T-\theta)$. For a given temperature (70°K), the susceptibility of $Pd_{98\%}Gd_{2\%}$ is increased by the admixture of 2% Tb and decreased by the admixture of 2% Nd; this is another consequence of the change of sign in $\vec{L}\cdot\vec{S}$ which results here in a change of sign of the indirect coupling between Gd and the different R.E. The long-range effects have so far only been observed in the host metal Pd and some of its alloys, where χ_p is about 100 times higher than in ordinary metals. The effect appears approximately in the range of alloys where the dilute transition elements produce anomalous magnetic moments, Curie temperatures, and θ values.[6] The fact that the R.E. show paramagnetic moments consistent with the ionic Landé g factors suggests, however, that the transition element-Pd interaction is considerably larger than the R.E.-Pd interaction reported here.

A simple extension of the RKY independent-particle calculation to include anomalous density-of-state functions does not appear capable of accounting for the range observed in Pd. It was, however, shown by Wolff[7] that these effects could considerably modify the range function if the electron-electron interaction is taken into account.

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ELECTRIC DIPOLE SPIN TRANSITIONS IN InSb

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The conduction band magnetic moment in InSb has been predicted to be very large, isotropic, and negative.[1] This has led to proposals[2] for its application to tunable infrared lasers. This material is one of a large class of (in general, anisotropic) solids with highly anomalous paramagnetic properties, which might be of interest in this area.

The theoretical predictions have received several indirect experimental confirmations[3-5]; however, the sign of the magnetic moment for the important intraband transitions has not received direct confirmation.

The writer attempted this measurement using circularly polarized radiation at 72 kMc/sec, the lowest frequency for which plasma effects[6] can be avoided in the purest materials available. These attempts were for some time unsuccessful, the spin resonance absorption being not significantly affected by a change from left to right circular polarization. The right-left symmetry, taken together with the fact that the strength of the spin transition unexpectedly increased on moving the sample away from the microwave magnetic field maximum (node of electric field) led to the conclusion that the transition being observed was of an electric dipole character. It now appears that these results can be explained on the basis of the band structure calculations for InSb of Kane.[7] Experimental confirmation of the negative magnetic moment was finally obtained by confining the sample to a cutoff region carrying only microwave magnetic field (Fig. 2).

Figure 1 shows the broad cyclotron resonance obtained at 1.3°K with a disk-shaped sample of

n-type InSb of nominal donor density 9×10^{13} cm^{-3}. Sample dimensions were 0.5 mm thick and 2.5 mm diameter. The sample was positioned near a node of electric field in a cylindrical TE_{311} cavity excited in circular polarization by a well-known technique.[8] Since the sample thickness corresponded to 1/20 wavelength and the positioning accuracy was of the same order, electric field effects could not be avoided with this arrangement.

Strong signals can be seen in Fig. 1 at magnetic field values corresponding to the spin resonance transition ($\pm$1000 gauss). Compared with the cyclotron line, these have been suppressed by a factor of approximately 4 by the electronic circuitry. One of the spin lines is shown in detail as an inset to Fig. 1. The linewidth is approximately 12 gauss (independent of temperature up to 4.2°K) and the g factor 51. The asymmetry of the line is reminiscent of distortion due to skin effect, as calculated by Dyson.[9] Careful comparison showed that (despite an apparent difference in Fig. 1) spin resonances for positive and negative fields were essentially identical. This behavior of the spin resonance was characteristic of many different samples, and all attempts to observe a distinction between positive and negative magnetic fields in this geometry, by eliminating linear polarization components, failed.

For the run of Fig. 1, the sample was cut as a disk lying in the (100) plane of the crystal. No significant anisotropy of the spin resonance in either polarization was found on varying the inclination of the magnetic field to the (100) axis of the disk. Whereas the existence of absorption for left- and right-hand polarization is a feature of the theory, the isotropic behavior does not agree with theoretical expectations. However, isotropic behavior with inclination of the magnetic field to the crystal axis is to be expected in the presence of very short scattering times, evinced by the cyclotron resonance. The same mechanism of scattering would also generate a longitudinal effect (absorption with the microwave H or E field parallel to the dc magnetic field) even if no such effect existed in its own right. The spin resonance saturates at microwave powers of the order of 10^{-9} watt at 1.3°K indicating a T_1 between 10^{-3} and 10^{-4} sec.

In order to avoid the electric field effect with a finite sample, a very small disk sample was placed in the mid-plane of the coupling hole which is used for magnetic excitation of the cavity. Such a coupling hole can be regarded as a cutoff waveguide of infinite phase velocity wherein the microwave energy is carried essentially as magnetic field. Absorption of the transmitted energy is observed (Fig. 2).

The difference in response to right and left circular polarization is seen to give an unam-

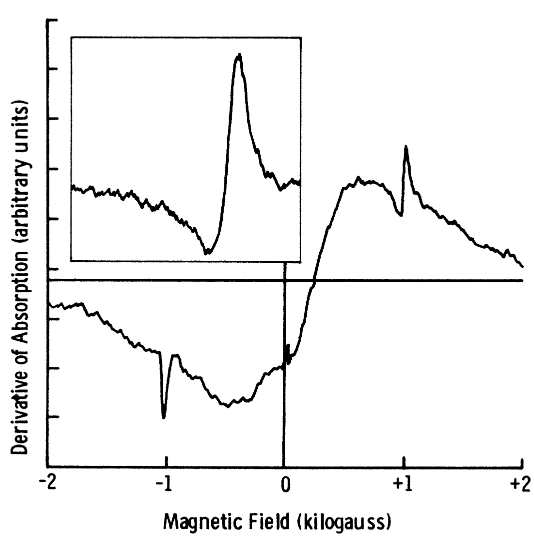

FIG. 1. Cyclotron resonance line with electric dipole spin lines superposed. Inset shows detail of one of the spin lines.

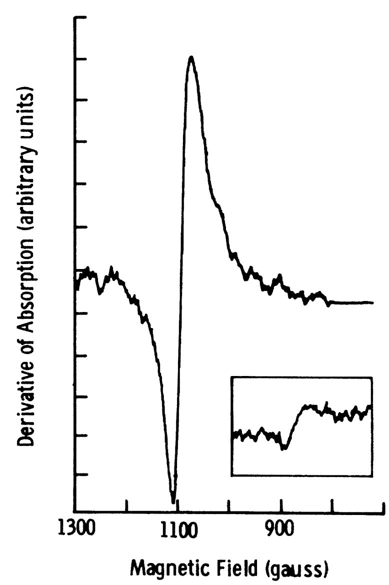

FIG. 2. Paramagnetic spin resonance absorption in negative circular polarization. Inset shows response to positive circular polarization on the same scale.

biguous result for the sign of the g factor, opposite to that generated by a sample of DPPH in the same apparatus, and therefore negative. The value recorded is -48. The breadth of the line is attributed partially to mounting strain, absent in the case of Fig. 1.

Anomalies of the carrier magnetic moment arise in the band theory of solids from antisymmetrical terms in the effective mass Hamiltonian, as first pointed out by Luttinger for Ge.[10] According to the band structure calculation of Kane[7] the spin-orbit effects, in the absence of inversion symmetry in the InSb crystal structure, remove the degeneracies of the valence bands near the center of the Brillouin zone, except for the special point k (000). A recent analysis by Rashba and Sheka[11] based on Kane's work shows that this crossing of the valence bands at k (000) leads to spin-dependent terms in the diagonalized velocity operator in the effective mass formalism. Electric dipole transitions between the different spin levels of adjacent Landau bands of the conduction band are shown to follow. Magnetic transitions of this type have been observed previously in Bi and Sb by Smith, Galt, and Merritt.[12] The electric dipole effect may also be made plausible[13] by considering a particle whose g factor varies with momentum being accelerated by the microwave electric field in the presence of a steady magnetic field. Off-diagonal components of the g factor tensor, arising from slight anisotropies of the band structure, will generate an equivalent microwave magnetic driving field which can flip the spin.

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SUGGESTED EXPERIMENT ON APPROXIMATE LOCALIZED MODES IN CRYSTALS*

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The secular equation which determines the lattice vibration frequencies of a lattice containing a single isotopic impurity is (for cubic Bravais lattices)

$$D(\omega)=1+\frac{\Delta m}{mN}\sum_q\frac{\omega^2}{\omega^2-\omega_q^{\,2}}=0, \qquad (1)$$

where $m+\Delta m$ is the impurity mass, and the sum is over the N phonons of the perfect lattice. If ω_D designates the largest ω_q, then it is well known[1] that if $\Delta m<0$, one of the solutions of Eq. (1) lies outside the continuum; $\omega>\omega_D$. It has been proposed that the Mössbauer effect be used to study this "localized mode,"[2] but because of the high driving velocities required, it would be difficult to observe the isolated peak directly.

In this Letter we point out that an approximate localized mode also can exist for $\Delta m>0$. Such a state decays into the continuum, but we shall show below that if $\Delta m/m \gg 1$ the decay rate is slow compared to the frequency. The situation here is closely analogous to the theory of the unstable V particle in the Lee model,[3] where it is shown that the V-particle energy is given by the solution of the analog of Eq. (1) in the limit $N\to\infty$ and the sum replaced by a principal value integral. The width of the state is then calculated by realizing that the complex response function of the system is $D^{-1}(Z)$, where Z is chosen slightly off the real axis for $\omega^2<\omega_D^{\,2}$ which is the locus of a cut for $N\to\infty$. Thus

$$D(\omega+i\epsilon)=(\omega-\omega_0)\,\mathrm{Re}D'(\omega_0)+\mathrm{Im}D(\omega+i\epsilon), \qquad (2)$$

where ω_0 satisfies $\mathrm{Re}D(\omega_0)=0$, and the width of