Letters to the Editor

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Overhauser Effect in a Free Radical

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ON theoretical grounds Overhauser[1] has predicted an interaction between paramagnetic and nuclear resonance. If the former is saturated, one of the processes trying to restore thermodynamic equilibrium is such that the change of angular momentum in an electron spin flip is compensated by a change in direction of a nuclear spin. Thus the ground state population of the nuclear spin system is increased. This increase can be detected by an enhanced nuclear resonance. According to Overhauser's first paper this effect would be confined to metals. It has been found in Li by Carver and Slichter.[2] Bloch[3] has pointed out that the effect might expected in nonmetals too. In this letter we give a brief description of a preliminary experiment in which the Overhauser effect was found in the free radical diphenylpicrylhydrazyl (DPPH).

The sample was placed in a glass tube inside a coil, that was inserted in a 3-cm resonant cavity, with the axis perpendicular to the magnetostatic field. The coil consisted of two groups of 20 windings each, separated by a gap of 2 mm in order to increase the penetration of the microwave field into the coil. The cavity, made of rectangular wave guide, was fed by a 70-watt klystron. The incident power could be measured by means of a calibrated attenuator in front of a monitor. Nuclear resonance in the coil was observed by a Thomas oscillator.[4] In DPPH a weak proton resonance was found, the peak height in 10 mm^3 being of the same order as that in 1 mm^3 H_2O with 2.5×10^{17} Fe^{3+} ions mm^{-3} added. In the field where paramagnetic resonance occurred (3300 oersted), the proton resonance was at about 14 Mc/sec.

At high microwave power levels the electron spin resonance showed saturation. At the same time the proton spin resonance increased by Overhauser effect (Fig. 1). During the experiment the sample was kept at room temperature by cooling with a jet of cold air, as it was found that towards higher temperatures the proton peak height increased as a result of decreasing line width. When the peak height was increased by Overhauser effect, no change in line width was observed. The temperature of the sample was checked by a thermocouple. The incident power was limited to 8 w by the cooling capacity of the air jet.

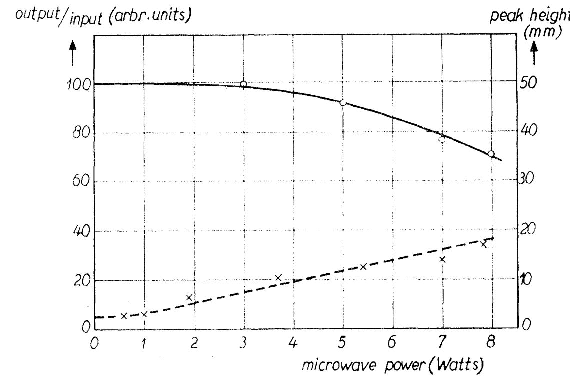

FIG. 1. Solid curve: output/input for electron spin resonance. Dotted curve: peak height of proton resonance on oscilloscope screen. Both are plotted against incident microwave power.

From paramagnetic resonance experiments it is well known that in DPPH there is an appreciable interaction between the electron hole and the nitrogen nuclear spin.[5] Therefore it would be interesting to see if the nitrogen nuclear resonance shows Overhauser effect. Unfortunately the nitrogen resonance will be extremely weak and cannot be detected by a simple oscillator.

We are indebted to Professor Casimir for suggesting the experiment, to Mr. van Iperen for providing the klystron, and to Dr. Klaassens for preparing the free radical sample.

[1] A. W. Overhauser, Phys. Rev. **92**, 411 (1953).
[2] T. R. Carver and C. P. Slichter, Phys. Rev. **92**, 212 (1953).
[3] F. Bloch, Phys. Rev. **93**, 944 (1954). See also J. Korringa, Phys. Rev. **94**, 1388 (1954).
[4] H. A. Thomas, Electronics **25**, 114 (1952).
[5] Hutchison, Pastor, and Kowalsky, J. Chem. Phys. **20**, 534 (1952).

Anomalous Optical Behavior of InSb and InAs

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BURSTEIN[1] has recently proposed an explanation of the anomalous optical behavior of InSb observed by Tanenbaum and Briggs.[2] This explanation is based on the small effective electron mass m_n and the resultant low density of states in the conduction band. In degenerate n-type InSb, the lowest unfilled level in the conduction band rises above the bottom of the band as the electron concentration, n, increases. E_0, the optical energy gap, is determined by the energy separation between the lowest unoccupied level in the conduction band and the corresponding level in the valence band.

Thus E_0 is a function of n in degenerate n-type samples. A similar argument holds for degenerate p-type InSb in which E_0 should depend on p, the hole density.

We have observed room temperature transmission spectra of a number of degenerate n-type InSb samples. Figure 1 shows the effect of increasing n by doping

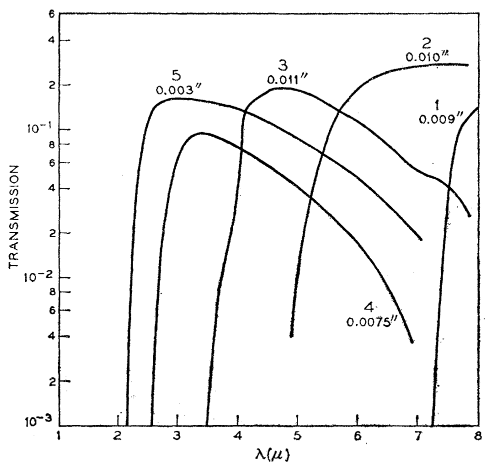

FIG. 1. Transmission spectra of n-type InSb samples; n ranges from 5×10^{15} cm^{-3} for curve 1 to about 10^{19} cm^{-3} for curves 4 and 5. Sample thicknesses are as shown.

with Te. Curve 1 is for "pure" InSb with an extrinsic electron density of 5×10^{15} cm^{-3}. All doped specimens were prepared from this material. Curves 2 through 5 demonstrate the increased displacement of the absorption edge to shorter wavelength as n is increased.

The observed dependence of E_0 on n at room temperature is shown by the solid curve in Fig. 2 which gives most weight to the single-crystal samples. The points at 1 and 2×10^{17} cm^{-3} were obtained from Ni- and Fe-doped samples, respectively. All others were determined from InSb doped with Te. To minimize errors arising from concentration gradients, optical measurements were taken on the same samples used for measurement of electron density after these had been ground thin enough to give reasonable transmission. E_0 was calculated from the wavelength at 0.1 percent transmission. The dashed line in Fig. 2 is the theoretical curve calculated from the data of Tanenbaum and Maita[3] with the assumption of spherical energy surfaces. The experimental results agree with theory in the respect that E_0 seems to depend only on n. The consistency of results obtained from samples containing widely different impurities makes it appear very unlikely that the anomalous behavior of E_0 is caused by a specific impurity. An increase of 0.5 ev in E_0 was also obtained for a highly degenerate p-type sample. This ΔE_0 is in reasonable agreement with that predicted by Burstein.[1]

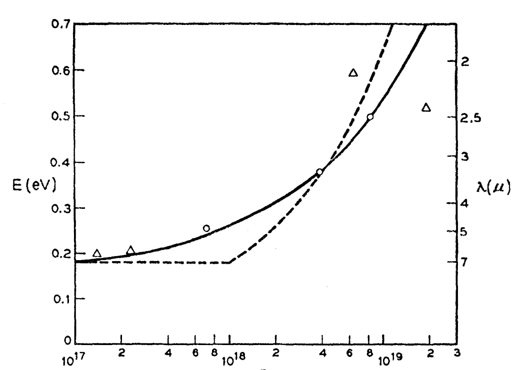

FIG. 2. Dependence of E_0 and λ on n(cm^{-3}) in InSb. ----- calculated, ——— experimental, ○ single crystal samples, △ polycrystalline samples.

The discrepancies between theory and experiment are the observed ΔE_0 below $n=10^{18}$ cm^{-3} and the form of the dependence of E_0 on n. Explanation of the shift of the absorption edge below $n=10^{18}$ cm^{-3} requires the assumption that m_n is even smaller than the calculated value.[1] This implies that the effective hole mass and the thermal energy gap are also somewhat lower than previously reported.[1,3] Agreement between the slopes of the theoretical and experimental curves can be obtained by assuming that the effective electron mass increases linearly with the height of the Fermi level above the bottom of the conduction band. Exact calculations are unwarranted until more complete data are available and the theoretical uncertainties are resolved.

Since high electron mobilities have also been observed for InAs in this laboratory and by Folberth, Grimm, and Weiss,[4] a similar anomalous optical behavior might be expected for this compound. We have observed shifts of the absorption limit toward shorter wavelength with increasing electron density in InAs. However, the effect is not large and the maximum observed shift amounts to only 0.7 μ.

[1] E. Burstein, Phys. Rev. **93**, 632 (1954).
[2] M. Tanenbaum and H. B. Briggs, Phys. Rev. **91**, 1561 (1953).
[3] M. Tanenbaum and J. P. Maita, Phys. Rev. **91**, 1009 (1953).
[4] Folberth, Grimm, and Weiss, Z. Naturforsch. **8a**, 826 (1953).

Energy Losses of Electrons Passing through an MgO Foil

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IT is well known that in the case of an insulator or a semiconductor there is a forbidden band above the valence band, and the width of this forbidden band is not known very accurately. Its measurement is regarded as an important problem for various reasons.

In the case of MgO, the width of the first forbidden band is believed to be certainly greater than 7.3 ev and,