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Letters to the Editor

The Polarization of Sodium Atoms*

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A SUBSTANTIAL quantity of strongly polarized atoms could serve as a source of oriented nuclei for nuclear physics experiments, as a source of polarized electrons, or, because of the enormously enhanced signal, as an interesting material for microwave spectroscopy and nuclear magnetic resonance experiments. Kastler[1] has suggested that circularly-polarized resonance radiation will polarize atoms. This polarization effect results from the fact that there is a fairly large probability that the angular momentum carried by the absorbed photon is retained by the atom in the emission process. Bitter and Brossel[2] have looked for this polarization with negative results, and more recently Brossel, Kastler, and Winter[3] have obtained a positive result. On the other hand, Bitter, Lacey, and Richter[4] have reported a negative result. We have obtained a polarization of sodium vapor which is in agreement with the expected value. The energy level diagram including the hyperfine structure and a typical set of transitions produced by the scattering of resonance radiation is shown in Fig. 1. Note that on the average m_F is greater after the scattering.

A schematic view of the apparatus is shown in Fig. 2. A sodium beam was used only because this is a convenient way of guaranteeing that the contamination by foreign gas is insignificant. The transverse components of the earth's magnetic field are roughly balanced out by a set of coils. An additional magnetic field H along the axis of the system (direction of incident light) could be varied as a parameter. As a means of detecting whether the sodium beam has been polarized, the plane-polarization ratio of the scattered light is measured.

Figure 3 shows a plot of the polarization ratio of the scattered light *vs* the magnetic field applied along the axis defined by the incident beam. The dip at 0.12 gauss is explained by the fact that this is the field necessary to balance this component of the earth's field. With zero magnetic field along the axis, a small residual transverse component of the magnetic field serves to mix the m_F states destroying the polarization. The asymmetry about 0.12 gauss is probably caused by the rather large inhomogeneities in the axial magnetic field. The polarization effect is intensity-dependent indicating a multiple-photon effect. The form of the dependence indicates an essentially 2-photon effect.

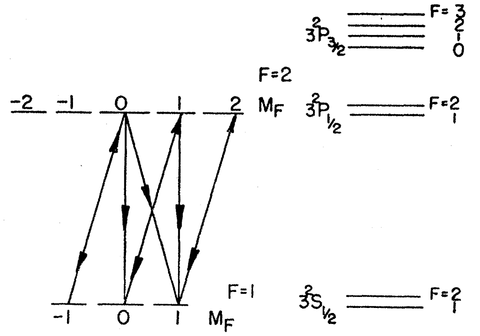

FIG. 1. Energy level diagram of sodium with a sample of the transitions involved, in this case transitions via the $3^2P_{\frac{1}{2}}F=2$ states.

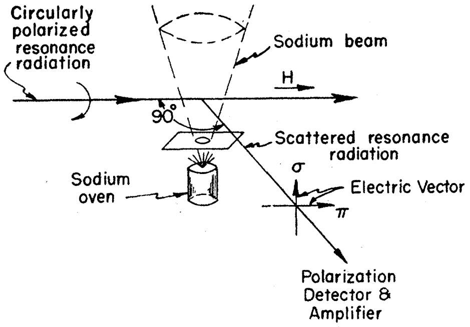

FIG. 2. Schematic view of apparatus.

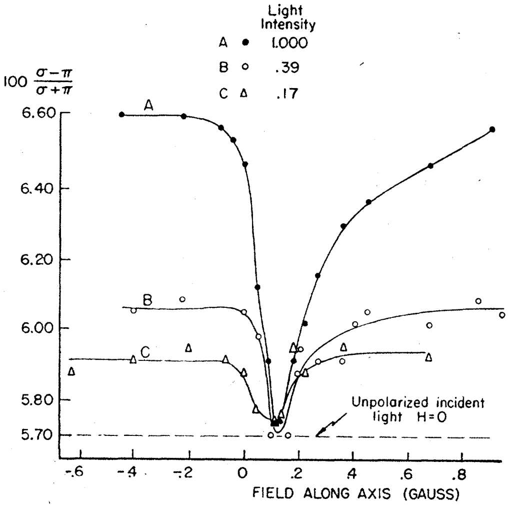

FIG. 3. Polarization ratio of the scattered resonance radiation.

Observations on the light source showed that for curve A, Fig. 3, the two lines of the doublet had about the same peak intensity of 8×10^4 photons/cm² at the position of the beam, this being computed from photometric measurements and the ob-

TABLE I. Polarization effects of one-, two-, and three-photon scattering.

No. of scattered photons	Occupation numbers after photon scattering								Average values		Polarization ratio
		$F=1$				$F=2$					
	$m_F=1$	0	-1	2	1	0	-1	-2	m_F	m_I	
1	0.182	0.119	0.075	0.247	0.168	0.106	0.063	0.040	0.626	0.523	0.070
2	0.194	0.082	0.038	0.399	0.174	0.071	0.029	0.012	1.075	0.884	0.173
3	0.173	0.049	0.018	0.546	0.156	0.042	0.012	0.004	1.384	1.116	0.313

served widths of 10^{10} and 1.4×10^{10} sec^{-1} for the $P_{\frac{1}{2}}$ and $P_{\frac{3}{2}}$ components. This intensity ratio indicates some self-reversal. However, the line contours showed no real dip in the peak but a peak somewhat flattened by self-reversal. These peak intensities predict a total absorption of 0.16 photon per atom in the illuminated part of the beam.

With zero magnetic field along the axis (applied $H=0.12$ gauss), the measured polarization ratio agrees with that calculated, assuming no atomic polarization. Also, this is in agreement with the results of Ellett and Heydenburg[5] and with our measurements on unpolarized incident light.

The polarization ratio intensity dependence (Fig. 3) is in good agreement with that computed from the known light intensity. The measured shift in polarization ratio for curve A ($R=0.9$ percent) agrees with the computed value of 0.8 percent. The polarization ratio is found to be independent of sodium beam intensity indicating negligible light trapping.

The computed effect of one-, two- and three-photon scattering on the occupation numbers of the states and the mean values of m_F and m_I are given in Table I. The polarization ratio of the salt scattered photon is also given. Equal peak intensities of the sodium D lines were assumed in the computation.

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Hall Effect and Conductivity of InSb Single Crystals

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WELKER[1] has described the conductivity and room temperature Hall effect of polycrystalline samples of the semiconducting compound indium antimonide, InSb. More recently Breckenridge, Hosler, and Oshinsky[2] have reported similar measurements as a function of temperature on polycrystalline samples.

We have recently grown large single crystals of InSb. The preparation of the compound has been described earlier,[3] and the material used in these measurements was extensively purified by zone refining.[4] The single crystals were grown from this material by the pulling technique developed by Teal and Little for germanium.[5] The resulting crystals were quite similar in appearance to single crystals of germanium.

The Hall effect and conductivity of these single crystals have been measured and the results are shown in Figs. 1 and 2. In these figures, the points are experimental values and the solid lines are calculated as described below.

Samples A and B show a reversal in the sign of the Hall coefficient R at 155°K and 182°K, respectively. These samples are p type below these temperatures and n type above. Sample C is n type down to the lowest temperature attained. The densities of extrinsic carriers in A, B, and C obtained from the expression

$$R=7.4\times10^{18}/n, \tag{1}$$

are 2.1×10^{15}, 1.2×10^{16}, and 1.7×10^{16} per cubic centimeter, respectively.

In a nondegenerate semiconductor, the Hall coefficient R and conductivity σ are given by the expressions,[6]

$$\sigma=e(n\mu_n+p\mu_p), \tag{2}$$

$$R=\frac{3\pi}{8e}\frac{nb^2+p}{(nb+p)^2}, \tag{3}$$

where n and p are the densities of electrons and holes, respectively, μ_n and μ_p the respective carrier mobilities, e the electronic charge, and $b=\mu_n/\mu_p$. In the temperature range where only one type of

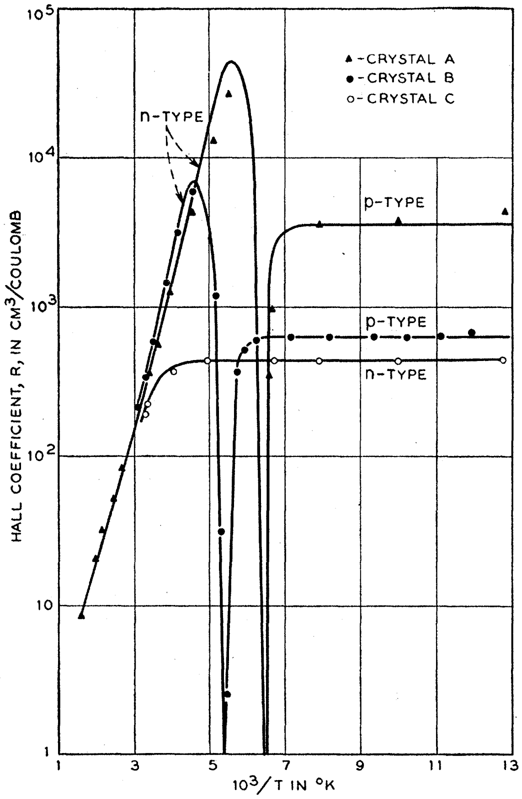

FIG. 1. Hall coefficient of indium antimonide as a function of temperature.

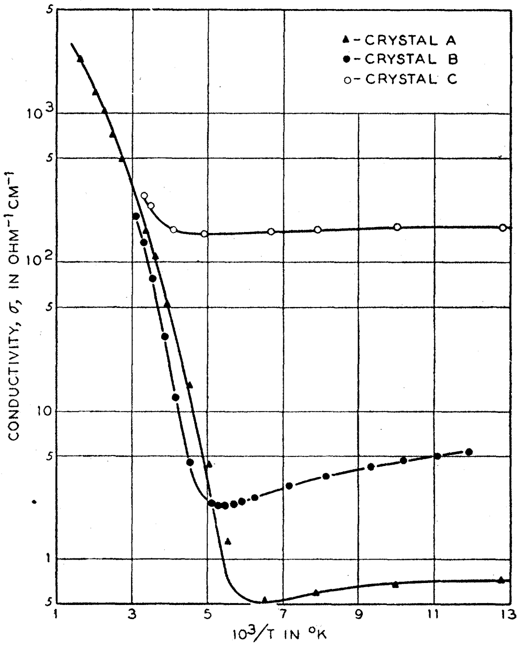

FIG. 2. Conductivity of indium antimonide as a function of temperature.