nuclear resonance acoustic absorption eliminates the limitation due to skin effect of conventional nuclear magnetic resonance in conducting materials. It should be possible to extend acoustic absorption techniques to the study of electron spin resonance.

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Optically Detected Field-Independent Transition In Sodium Vapor

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THE hyperfine transition $m_F=0 \rightarrow m_F=0$ ($\Delta F=1$) in the ground state of alkali atoms is of interest because it is virtually independent of magnetic field in weak fields, which suggests its use in atomic frequency standards.[1] Previously these transitions have been observed in atomic beam experiments,[1,2] and Carver and Dicke[3] have observed the transition in Rb^{87} vapor by using optical methods to obtain polarization together with microwave detection. In this note we report observation of the resonance in sodium vapor by optical detection, using the techniques developed earlier by Dehmelt[4,5] and by us.[6]

The experimental arrangement is shown in Fig. 1. Unfiltered, unpolarized light from a sodium lamp is transmitted in the direction of the earth's magnetic field through a quartz absorption cell placed in a resonant cavity. The absorption cell contains sodium metal and vapor at about 125°C in argon buffer at

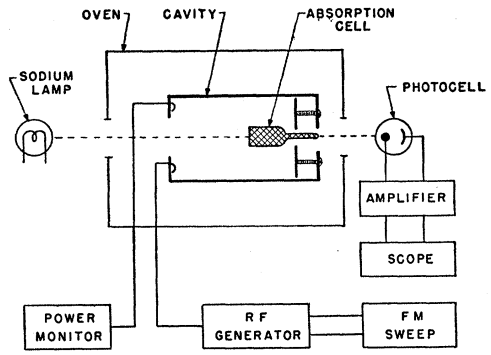

FIG. 1. Diagram of apparatus (lenses in optical system are not shown). Cavity and absorption cell are drawn approximately to scale.

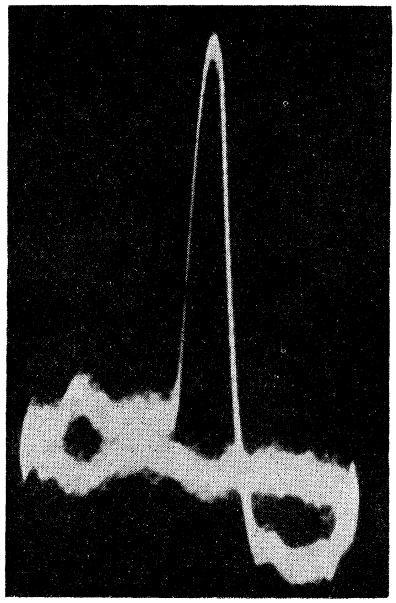

FIG. 2. Oscilloscope signal of field-independent resonance.

10-cm Hg pressure[7] and the cavity, operating in the TE_{010} mode, is tunable around 1772 Mc/sec. The transmitted light is observed by photocell. Passage through the hyperfine resonances by the frequency-modulated rf generator causes a decrease in intensity of the transmitted light which is indicated on an oscilloscope.

According to the earlier analyses,[5,6] optical pumping and detection by transmitted light is feasible only if there are differences in the rates, P_i, at which atoms in the different ground state sublevels absorb light. In the earlier work on sodium, employing circularly polarized light and a D_1-D_2 intensity difference, it was assumed that the P_i's depended only on the optical matrix elements. In this situation, however, the two $m_F=0$ levels always have the same value of P_i and no signal can be observed. What is required, instead, is a difference in light *intensity* exciting atoms out of these two levels. It is assumed that in the present experiment an intensity difference is achieved in the following way. Light incident at the front part of the absorption cell is absorbed and scattered separately by sodium atoms in the two F levels, since the hyperfine splitting is greater than the Doppler- and pressure-broadened optical absorption line width. The rate of attenuation is proportional to the number of magnetic sublevels in each F level—3 and 5 for the lower and upper F levels respectively. This provides the necessary intensity difference at the rear of the absorption cell and produces there a greater population in the upper states.

Figure 2 shows the oscilloscope signal when the noise bandwidth is about 10^3 cps. Most of the observed noise is traceable to fluctuations in lamp brightness. The $0 \rightarrow 0$ line can be readily told apart from the other

hyperfine lines by its field independence and by its behavior when a circular polarizer is placed in the light beam in front of the cavity. A line characterized only by the quantum number $m=0$ should behave the same when either left-handed or right-handed polarized light is used. This is not true of the other transitions.

The experiment has also been attempted in potassium, with negative results. The reason for failure may be the fact that the relatively low hyperfine frequency—462 Mc/sec in K^{39}—is about equal to the optical absorption line width. In the stable rubidium and cesium isotopes, however, the splitting is greater than in sodium, so the success of the experiment in these materials seems assured.

[1] Such an instrument employing a cesium beam is manufactured by the National Company, Malden, Massachusetts.
[2] N. Ramsey, *Molecular Beams* (Oxford University Press, New York, 1956).
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[4] H. G. Dehmelt, Phys. Rev. **103**, 1125 (1956).
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[7] This pressure was chosen for reasons other than the present experiment and is probably not optimal.

Electron Spin Resonance of H Centers

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WE have x-rayed KCl crystals at 20°K and investigated their paramagnetic resonance spectra at this temperature, first without warming up, and then after pulse annealing at various temperatures. Before warming up, the spectra of two types of trapped-hole centers are predominant. The first type is an electron deficiency equally shared by two equivalent halide ions. Its basic hyperfine spectrum, which was extensively discussed in previous work,[1] is represented schematically in Fig. 1. The hyperfine splitting of the second-type center, which is the subject of this Letter, can be derived qualitatively from the hyperfine splitting of the first center by splitting every single line into a miniature pattern of the same kind. This is illustrated in Fig. 2, which shows a recording of that part of the "primary" spectrum which is encircled in Fig. 1. It can be concluded that the electron deficiency in the second center interacts strongly with two equivalent halogen nuclei, $\alpha=1$ and 2, but in addition interacts weakly with two more halogen nuclei, $\alpha=3$ and 4, which are again equivalent to each other. To a good approximation the hyperfine interaction with halogen nuclei 1 and 2 is axially symmetric, the axis being exactly a [110] axis of the crystal. The hyperfine interaction with halogen nuclei 3 and 4 is also roughly axially symmetric, and the axis seems to coincide with the axis of the hyperfine interaction between the hole and nuclei 1 and 2. Thus it is most likely that the four nuclei lie in a straight row (with nuclei 3 and 4 at the ends) along a [110] axis. All six [110] axes are equally populated with these centers.

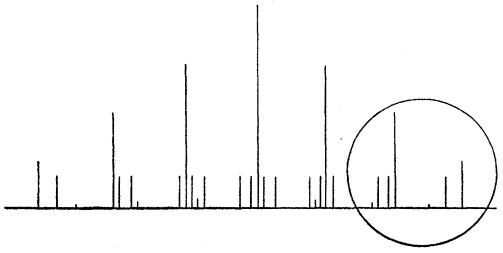

FIG. 1. Basic hyperfine splitting of Cl_2^- molecule ion.

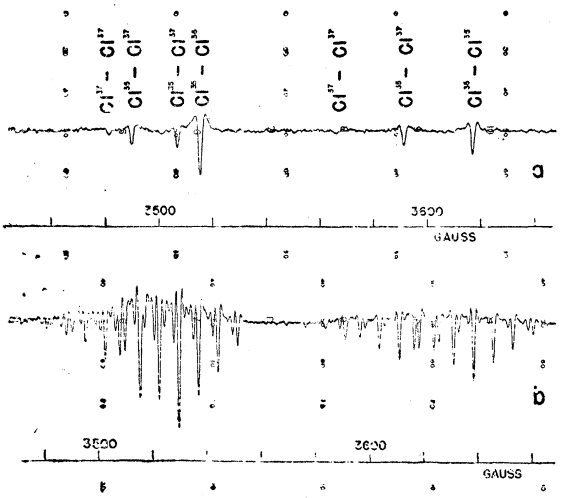

FIG. 2. Hyperfine splitting in the part of the basic spectrum encircled in Fig. 1. Derivative of dispersion measured at 20°K and 9.28 kMc/sec. (a) First-type center (V center of reference 1); (b) second-type center (H center).

The hyperfine interaction with the four nuclei can be written in the form

$$g_0\beta_0\mathbf{S}\cdot\sum_{\alpha=1}^{4}\mathbf{T}^{(\alpha)}\cdot\mathbf{I}^{(\alpha)},$$

where $\mathbf{T}^{(1)}=\mathbf{T}^{(2)}$ and $\mathbf{T}^{(3)}=\mathbf{T}^{(4)}$. The experimentally determined magnitudes of the tensor components are given in Table I. The principal axes $x'y'z'$ are the same for all tensors, and they are oriented with respect to the crystal axes as in our previous work[1] on the first

TABLE I. Absolute values (in gauss) of the principal components of the hyperfine-interaction tensors for the two types of centers. Data for the first-type center are taken from reference 1: $\mathbf{T}^{(1)}=\mathbf{T}^{(2)}$ from Table V, and the upper limits for the principal components of $\mathbf{T}^{(3)}=\mathbf{T}^{(4)}$ from the line width.

	$\mathbf{T}^{(1)}=\mathbf{T}^{(2)}$			$\mathbf{T}^{(3)}=\mathbf{T}^{(4)}$		
	$\lvert T_{x'}\rvert$	$\lvert T_{y'}\rvert$	$\lvert T_{z'}\rvert$	$\lvert T_{x'}\rvert$	$\lvert T_{y'}\rvert$	$\lvert T_{z'}\rvert$
1st-type center	~9	~9	101	<0.4	<0.4	<0.4
2nd-type center	~0	~0	109	2.7	3.1	7.3

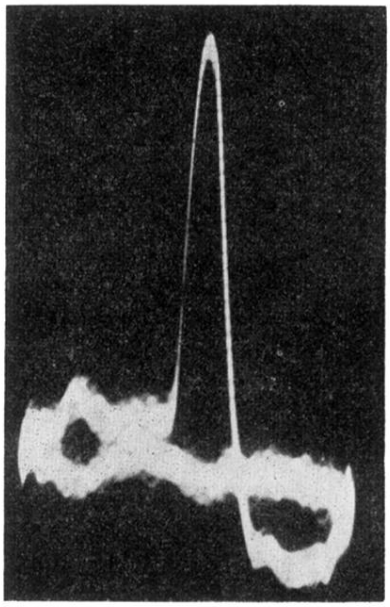

FIG. 2. Oscilloscope signal of field-independent resonance.