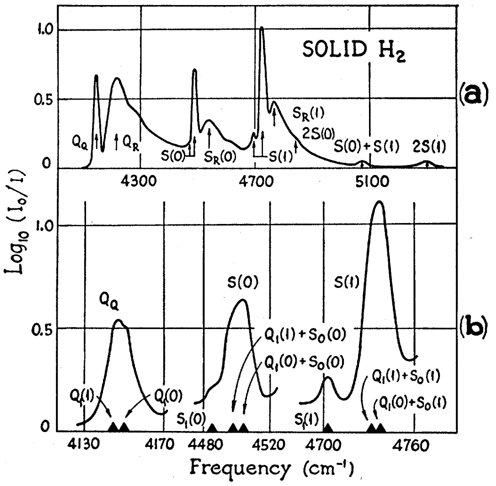

FIG. 1. (a) The fundamental infrared absorption of solid normal hydrogen observed by using a spectral slit width of 15 cm^{-1}. (b) The sharp components of the fundamental band observed with a spectral slit width of 2 cm^{-1}. The frequencies of the expected transitions are shown on the abscissa axis. Absorption at $Q_1(1)$, $Q_1(0)$, $S_1(0)$, and $S_1(1)$ results from a rotation-vibration transition in a single molecule, whereas absorption at $Q_1(1)+S_0(0)$, etc., results from simultaneous vibrational and rotational transitions in a pair of molecules.

single molecule. The strong S lines, however, have frequencies which correspond to a vibrational transition in one molecule accompanied by a rotational transition in the ground vibrational state of a second molecule. For each rotational transition there are two possibilities for the accompanying vibrational transition. For example, in the case of $J=0\rightarrow J=2$ these are $Q_1(0)+S_0(0)$ and $Q_1(1)+S_0(0)$, where the subscripts 0 and 1 indicate $\Delta v=0$ and $\Delta v=1$, respectively; these transitions are separated in frequency from one another and also from the single transition, $S_1(0)$, because of the vibration-rotation interaction. The frequencies of the expected transitions are indicated on the abscissa axis of Fig. 1(b). The agreement of the measured and calculated frequencies shown in Table I confirms the validity of the assignments.

At any given molecule in the solid the electric field due to the regularly spaced but presumably randomly oriented neighboring molecules is rapidly fluctuating about zero value. Also the dipoles induced in neighboring molecules by the quadrupole of the given molecule cancel one another on the average. The induced absorption for a single molecule should therefore be very weak. The situation is similar to a highly compressed gas where, in ternary and higher order collisions, the different induced moments tend to annul one another.[4] However, it has been pointed out by van Kranendonk[5] that for simultaneous transitions involving a pair of molecules the cancellation effect is not operative; in compressed gases, liquids, and solids, where a given molecule is in a more or less symmetrical environment, double transitions should be more probable than single transitions. The correctness of this view, which would be difficult to show in the gas at room temperature where the induced band is rather diffuse, is well confirmed by the above analysis of the spectrum of the solid.

TABLE I. Measured and calculated frequencies.

Frequency of maximum (cm^{-1})	Assignment	Calculated frequency[a] (cm^{-1})
4148	$Q_1(1)$	4144
4152	$Q_1(0)$	4150
4486	$S_1(0)$	4486
4503	$\{Q_1(1)+S_0(0)$ $\{Q_1(0)+S_0(0)$	4498 4504
4702	$S_1(1)$	4702
4736	$\{Q_1(1)+S_0(1)$ $\{Q_1(0)+S_0(1)$	4731 4736

[a] The frequencies of the $Q_1(1)$ and $Q_1(0)$ lines were observed in the Raman effect of the solid[3]; the other frequencies have been calculated by using the rotational constants for the gas [C. Cumming, Ph.D. thesis, University of Toronto (unpublished)].

In liquid hydrogen the lines due to quadrupole induction are somewhat more diffuse than in the solid; however, the greater intensity of the double transitions as compared with the single transitions is as marked as for the solid.

Preliminary experiments on the absorption of liquid and solid hydrogen in the overtone region have shown that the intensity of the double vibrational transition is much greater than that of the pure overtone; in the compressed gas at a density of 426 Amagat units[6] at 80°K, the difference between the two bands is much less marked.[7]

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[6] One Amagat unit of density is the density of the gas at a pressure of one international atmosphere and at 0°C.

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Measurement of the Spin and Gyromagnetic Ratio of As^{76}†

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THE spin and gyromagnetic ratio of 27-hour As^{76} have been measured by using the γ-ray anisotropy induced by several types of radio-frequency magnetic fields applied to a silicon crystal containing 5×10^{10} As^{76} atoms.

A silicon crystal doped with 3×10^{16} As^{75} atoms per cc was irradiated in the Brookhaven reactor and subsequently annealed in vacuum for 5 hours at 1100°C. The sample was placed in a rectangular TE_{10n} mode cavity resonant at 24 000 Mc/sec. The H-plane sides

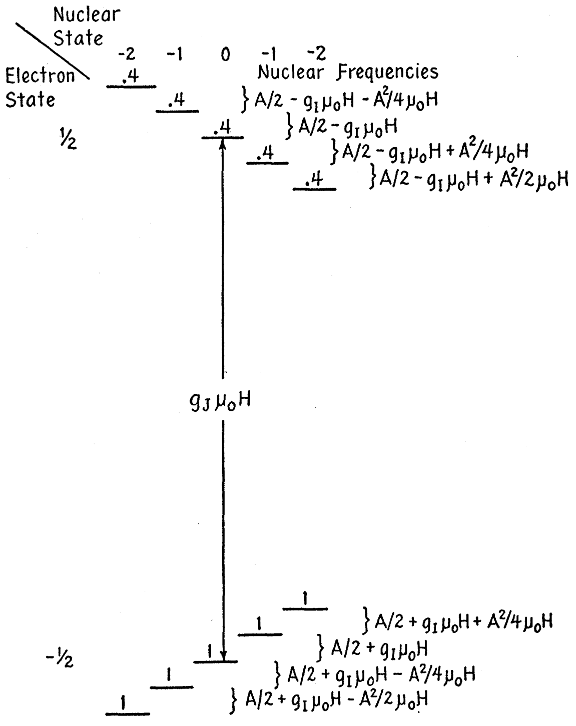

FIG. 1. Energy levels of an As^{76} donor electron in a high magnetic field.

were thinly silvered Lucite. A coil was wound on the cavity to permit application of a second rf magnetic field (10–200 Mc/sec). The cavity was immersed in helium at 1.25°K and the static magnetic field applied at an angle of 45° with the E field of the cavity. A NaI crystal and photomultiplier counted γ rays emitted perpendicularly to the static field.

The energy levels of the arsenic nucleus and its donor electron in a strong magnetic field to second order in the hyperfine interaction are

$$E_{m_J,m_I} = -(g_J\mu_0)Hm_J - (g_I\mu_n)Hm_I + Am_Im_J + \frac{A^2}{4\mu_0 H}m_J(I-2m_Jm_I)(I+2m_Jm_I+1),$$

where m_J and m_I are the strong-field quantum numbers for electron and nucleus.[1] The levels for nuclear spin two and negative moment are depicted in Fig. 1. Numbers beside each level are relative populations for 8500 gauss and 1.25°K.

Alignment of As^{76} was first produced by saturation of the forbidden transitions $(\frac{1}{2},m_I)\leftrightarrow(-\frac{1}{2},m_I+1)$ as proposed by Jeffries.[2] About 10 milliwatts of microwave power were applied to the cavity and the magnetic field was swept slowly over the region of the As^{75} resonances. Figure 2 shows the counting rate as a function of magnetic field, both for sweeping from high field (2a) and from low field (2b). Only two transitions were observed, and it can be seen that there was no relaxation of the alignment in the one hour required to sweep the field between the two transitions. This implies that the relaxation time for the forbidden transitions and the nuclear transitions is very long. The center of the two transitions is two gauss above the center of the As^{75} structure which is expected for the forbidden transitions if the moment of As^{76} is negative. The high-field transition always decreases the counting rate and the low-field one increases it. This shows unambiguously that As^{76} has a negative moment if it has a spin of two. The facts that only two transitions are observed and that the exact mixture of the β decay is unknown leave open the possibility that the observed transitions are either the pair $(-\frac{1}{2},2)\leftrightarrow(\frac{1}{2},1)$ and $(\frac{1}{2},-2)\leftrightarrow(-\frac{1}{2},-1)$ or the pair $(-\frac{1}{2},1)\leftrightarrow(\frac{1}{2},0)$ and $(\frac{1}{2},-1)\leftrightarrow(-\frac{1}{2},0)$. This was resolved in favor of the second alternative by a double-resonance experiment.[3] Alignment was produced by saturation of the high-field transition of Fig. 2(a). The second rf field was swept from 10 to 20 Mc/sec and from 40 to 55 Mc/sec. The alignment was partially destroyed at 43 and at 49 Mc/sec [Fig. 2(c)], in agreement with the 34-gauss splitting of Fig. 2(a).

A more precise determination of the hyperfine splitting was made by utilizing double adiabatic fast passage as proposed by Feher.[4] Figure 3(a) shows a typical series of such operations.

If As^{76} has spin two, the fact that only the two inside forbidden transitions are observed implies that the

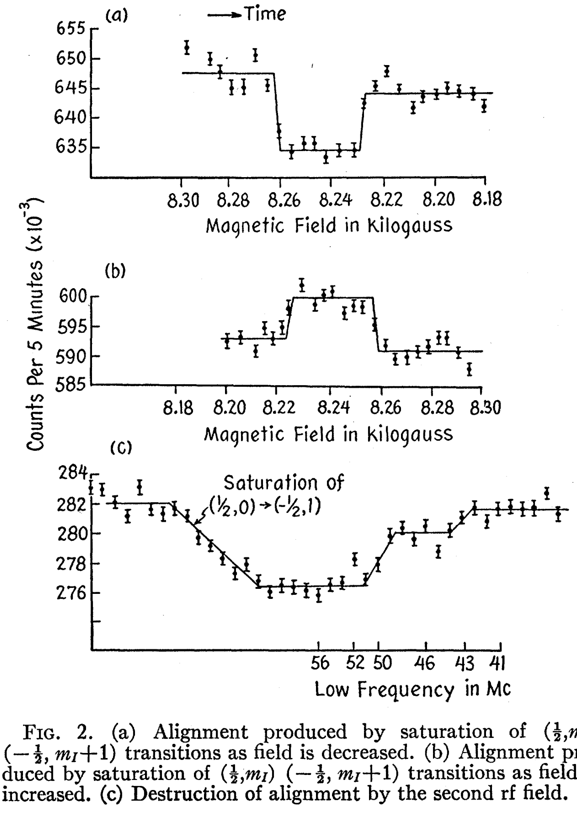

FIG. 2. (a) Alignment produced by saturation of $(\frac{1}{2},m_I)$ $(-\frac{1}{2},m_I+1)$ transitions as field is decreased. (b) Alignment produced by saturation of $(\frac{1}{2},m_I)$ $(-\frac{1}{2},m_I+1)$ transitions as field is increased. (c) Destruction of alignment by the second rf field.

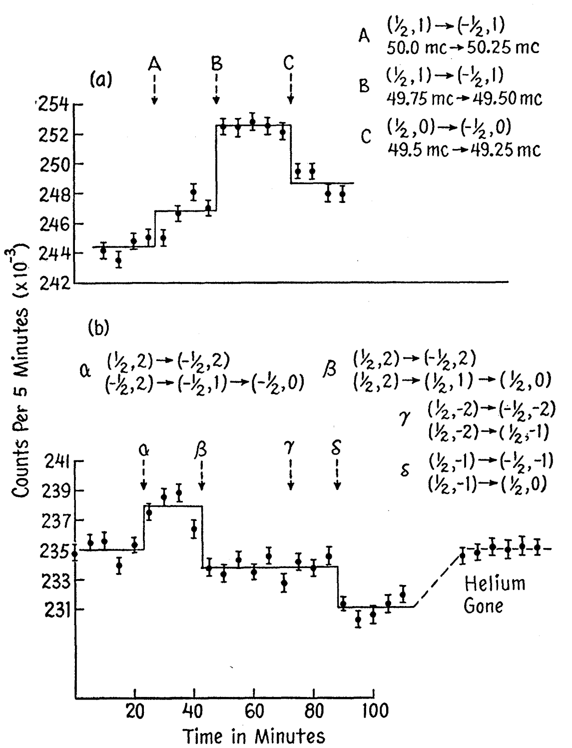

FIG. 3. (a) Double-fast-passage experiments used to find a precise value of hyperfine splitting. (b) Double-fast-passage experiments to show that spin is two.

β decay is such a mixture that γ-ray emission perpendicular to the steady field is affected only by the populations of the states with $m_I=0$. This hypothesis was verified in three ways. First the region where the $(-\frac{1}{2}, -1)\leftrightarrow(+\frac{1}{2}, -2)$ transition should be was swept over slowly with saturating microwave power. Then with microwave power off, the second rf field was swept over the proper range to invert the levels $(-\frac{1}{2}, -1)$, $(-\frac{1}{2}, 0)$. This decreased the counting rate. In a second experiment, the levels $(\frac{1}{2},2)$, $(-\frac{1}{2}, 2)$ were inverted, then the level pairs $(-\frac{1}{2}, 2)$, $(-\frac{1}{2}, 1)$ and $(-\frac{1}{2}, 1)$, $(-\frac{1}{2}, 0)$ were inverted successively. This increased the counting rate [Fig. 3(b)]. In the third experiment, the levels $(\frac{1}{2},2)$, $(-\frac{1}{2}, 2)$ were again inverted and the second rf swept so to invert $(\frac{1}{2},2)$, $(\frac{1}{2},1)$ and $(\frac{1}{2},1)$, $(\frac{1}{2},0)$ successively. As shown in Fig. 3(b), this decreased the counting rate.

From these data we obtain the hyperfine interaction as $A_{76}=-93.6\pm0.2$ Mc/sec. We have used the double-resonance technique to determine the hyperfine interaction of As^{75} to similar precision: $A_{75}=197.6\pm0.5$ Mc/sec. Thus from the Fermi-Segrè formula[1] and the signs of the anisotropies, $g_{76}=-0.453\pm0.002$. The long relaxation times noted above are at least 20 times longer than the corresponding ones in the stable isotope whereas the relaxation time for a $\Delta m_J=\pm1$, $\Delta m_I=0$ transition is about the same for the two isotopes. This accounts for previously reported failures to produce Overhauser effects in this sample.[5] The anisotropy observed here is too small to permit a pure $L=0$ β decay.[6] This is being analyzed more completely.

We are indebted to Professor R. V. Pound for expressing interest in this experiment and for many stimulating discussions during its execution. We wish to thank Dr. C. D. Jeffries for communication of his success with Co^{60} and Dr. G. Feher for pointing out the possibilities of the double-resonance experiments. We are also indebted to the Raytheon Manufacturing Company for supplying the doped silicon crystals, and the Office of Naval Research for the loan of high-power oscillators.

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Observation of the Acoustoelectric Effect

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IN a previous paper,[1] the theory of the acoustoelectric effect was given in terms of the simultaneous bunching of electrons and holes in a semiconductor under the action of the deformation potential of a traveling acoustic wave. It was there pointed out that if one were dealing with only one type of carrier, the electrostatic repulsion would prevent any appreciable bunching and the effect would therefore be extremely small.

Holstein[2] has pointed out that it should be possible to produce similar effects using only majority carriers, provided these carriers belong to something other than a "simple"[3] band. For example, in the case of n-type germanium one deals with a "multivalley" band having, most likely, minima at the four points where the $\langle 111\rangle$ axes cut the surface of the Brillouin zone. If one deforms the crystal, the effective deformation potentials seen by the electrons in the various valleys will not in general be the same. It then becomes possible for each class of electrons to bunch and still leave the condition of electrical neutrality undisturbed.

The equations governing this phenomenon are basically identical with those for the ambipolar case[1]; however, the underlying randomizing time is now the intervalley scattering time rather than the minority carrier lifetime. In order to observe the effect it is therefore necessary to work at relatively low temperatures so