proximately 10^5 cm^{-2}. A crystal of germanium doped with 10^{18} indium atoms/cc was grown with a dislocation density less than 10^5 cm^{-2}. The measured $\langle \bar{R} \rangle$ varied with position along the face of the specimen, and those regions which gave high values were still present after 0.1 mm of germanium was removed by lapping and etching. Values of $\langle \bar{R} \rangle$ for such a region are given in Table I and are 2.5, 12, and 30% greater than the (111), (333), and (444) values, respectively, of a typical high-resistivity specimen. This shows that in a given region of the crystal, the effect on $\langle \bar{R} \rangle$ increases with order of reflection.

Table I. Integrated intensity for germanium crystals with chemical impurities.

	$\langle \bar{R} \rangle \times 10^4$		
Crystal	(111)	(333)	(444)
High resistivity	0.888	0.224	0.398
10^{18} indium	0.910	0.250	0.518
Lithium precipitate	1.00	0.279	0.555

Following the technique of Morin and Reiss,[3] lithium was diffused into a high resistivity, low dislocation content germanium crystal at 500°C and precipitated at room temperature. In this process, about 10^{18} lithium atoms/cc are dissolved and precipitated into about 10^{12} nuclei the order of 100 A in size. The measured $\langle \bar{R} \rangle$ given in the table for the (111), (333), and (444) reflections are 13, 25, and 40% greater, respectively, than the values before lithium precipitation. The reflection curves before lithium addition and after lithium precipitation for the (333) peak are shown in Fig. 1. Note that the half-width has increased and that the tails of the peak are higher and longer, indicating the presence of a diffuse scattering in the vicinity of the reflection. These results show that relatively low concentrations of chemical impurities can produce large increases in x-ray intensities for crystals in the nearly perfect state and suggest that point defects in general might affect this property in a similar manner.

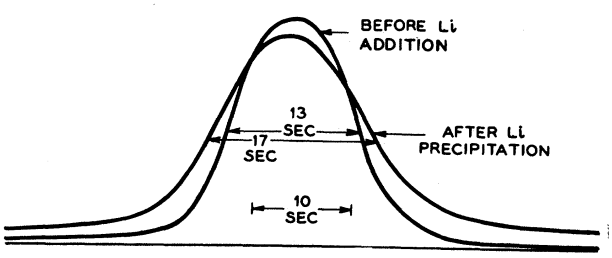

FIG. 1. Effect of lithium precipitation on (333) reflection from germanium.

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[2]B. W. Batterman, Bull. Am. Phys. Soc. Ser. II, 3, 106 (1958).
[3]F. J. Morin and H. Reiss, J. Phys. Chem. Solids 3, 196 (1957).

OPTICAL POLARIZATION OF ATOMIC HYDROGEN

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Several experiments have been performed recently in which it was demonstrated that the optical transmission of an optically oriented vapor could be used to detect the zero field hyperfine transitions of the alkali metals.[1,2] Successful experiments have also been reported in which other alkali metals have been oriented by spin-exchange collisions with sodium.[3,4] This paper reports an experiment in which the low-field Zeeman ($\Delta F = 0$) and the hyperfine ($\Delta F = 1$) transitions of the hydrogen atom were optically detected by a combination of these techniques. An experimental arrangement was used in which the hydrogen atoms can be produced in an atmosphere of optically oriented sodium atoms. Spin-exchange collisions between the hydrogen and sodium atoms then orient the hydrogen atoms. When a radio-frequency field is applied to disorient the hydrogen, there is a change in the sodium polarization and hence in the opacity of the sodium bulb.

The optical pumping apparatus is similar to that used by Dehmelt[5] in his studies on the electron. For this experiment a 300-cc Pyrex flask was filled with a small amount of vacuum-distilled sodium, 0.7 mm Hg of hydrogen, 1 cm Hg of helium, and 1 cm Hg of argon. All the gases

were from spectroscopically pure samples obtained from the Air Reduction Company. The bulb was provided with two 0.040-in. tungsten leads mounted at an angle of 90° and with the ends within the bulb separated by approximately 1 cm. The static magnetic field was 2.4 gauss, and was modulated 10% at 15 cycles/sec with a sine wave. At one point in each cycle a 30-Mc/sec oscillator was pulsed on for 3 milliseconds. This oscillator, which was coupled to the bulb through the tungsten leads, produced a discharge in the bulb, which dissociated the hydrogen molecules into atoms. The cell was operated at a temperature of 138°C. At this temperature the bulb transmitted approximately 40% of the incident sodium light and the radio-frequency sodium signal was a maximum. A war surplus *T*85/*APT*-5 grounded-grid, coaxial-line oscillator and a two-turn solenoid 4 in. in diameter and 4 in. long were used to produce the radio-frequency magnetic field at 1420 Mc/sec. The impedance matching was poor and there was insufficient radio-frequency power to maximize the hydrogen hyperfine transition signal.

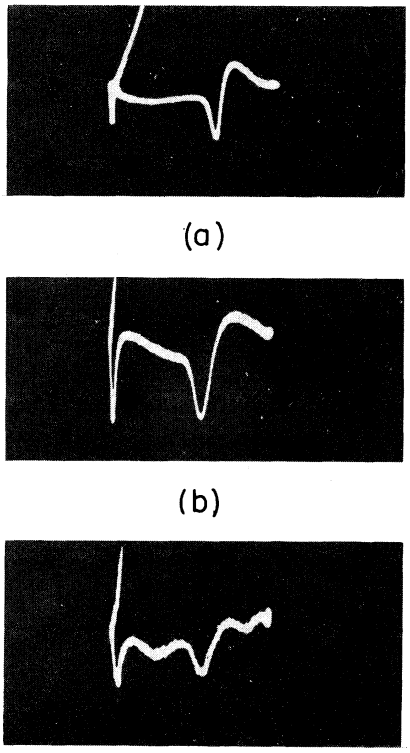

FIG. 1. For all of these traces the static magnetic field is 2.4 gauss. (a) The Zeeman transitions [$\Delta F = 0$, $\Delta M = \pm 1$] in sodium. The relative gain is one. Oscillator frequency is 1.5 Mc/sec. (b) The Zeeman transitions [$\Delta F = 0$, $\Delta M = \pm 1$] in the hydrogen atom. Oscillator frequency is 3 Mc/sec and the relative gain is 10. (c) The hyperfine transition [$F = 0$, $M = 0 \leftrightarrow F = 1$, $M = 1$] in the hydrogen atom. Oscillator frequency is at 1423 Mc/sec and the relative gain is 100. The large-amplitude noise in the trace is due to the sodium lamp.

Figure 1 shows three of the transitions observed. Figure 1(a) is the sodium signal at the frequency 1.5 Mc/sec. Figure 1(b) is the hydrogen atom low-field transition [$\Delta F = 0$, $\Delta M = \pm 1$] at 3 Mc/sec. Figure 1(c) shows the hyperfine transition [$F = 0$, $M = 0 \leftrightarrow F = 1$, $M = 1$] in the hydrogen atom at 1423 Mc/sec. The hyperfine transition [$F = 0$, $M = 0 \leftrightarrow F = 1$, $M = -1$] was also observed. The signal was still growing with increase of radio-frequency power when the maximum power available was applied.

The signal-to-noise ratio obtained with this simple apparatus suggests that with some improvements, this method could be used to remeasure the zero-field hyperfine splittings of hydrogen, deuterium, and tritium. This would be especially useful in the case of tritium as one need use only a very small sample.

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*Texas Company Fellow, 1957-58.

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OPTICAL PROPERTIES OF CRYSTALLINE BORON

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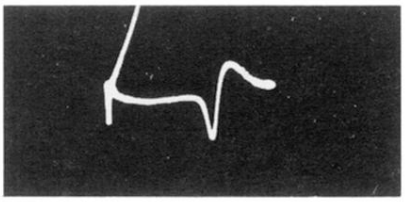
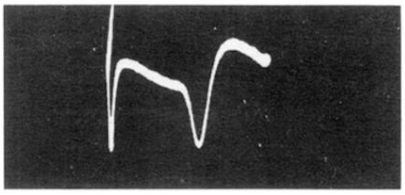
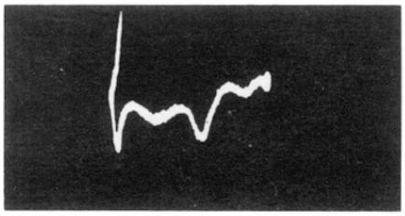
In recent years the crystallographic and electrical properties of boron have received increasing attention. Detailed studies on the crystal structure of boron have revealed three modifications, two rhombohedral types as well as one tetragonal.[1] Electrical measurements[2] of the resistivity as a function of temperature have established crystalline boron as a semiconductor with a thermal energy gap of about 1.4 ev at 0°K.



(a)



(b)



(c)

FIG. 1. For all of these traces the static magnetic field is 2.4 gauss. (a) The Zeeman transitions [$\Delta F = 0$, $\Delta M = \pm 1$] in sodium. The relative gain is one. Oscillator frequency is 1.5 Mc/sec. (b) The Zeeman transitions [$\Delta F = 0$, $\Delta M = \pm 1$] in the hydrogen atom. Oscillator frequency is 3 Mc/sec and the relative gain is 10. (c) The hyperfine transition [$F = 0$, $M = 0 \leftrightarrow F = 1$, $M = 1$] in the hydrogen atom. Oscillator frequency is at 1423 Mc/sec and the relative gain is 100. The large-amplitude noise in the trace is due to the sodium lamp.