metry; therefore the lattice band usually observed must correspond to combination modes, and the observed temperature dependence indicates that acoustical modes are also involved. The introduction of lattice defects affects the crystal symmetry, consequently the normal optical modes may become slightly active. This seems to be a likely explanation of the 20.5-micron band and its insensitiveness to the temperature variation.

The 3.9-micron band is a direct indication that a new type of absorption center is formed as a result of the heat treatment. The curves of Fig. 1 show that, while the irradiation-produced long-wavelength bands were not affected appreciably by the heat treatment, the strong 1.8-micron band was considerably reduced. Thus it appears that the centers responsible for the 3.9-micron band evolved from the defects giving the 1.8-micron band. It is also possible that the centers are formed as a result of a change in the ionization of the defects, since the annealing lowered the resistivity and the Fermi level.

Figure 1 shows that the heat treatment produced a general decrease of the transmission measured at room temperature. Longo observed that the reduction in transmission persists to very long wavelengths, beyond 100 microns. This effect has been found to be much smaller in the transmission measured at liquid nitrogen temperature. Measurements made on various samples indicate that this effect is connected in some way with the presence of impurities. The effect was pronounced in samples which were initially p type with high acceptor (boron) concentrations, whereas in samples of initial high resistivities no appreciable effect was observed after the same amount of irradiation and similar heat treatment.

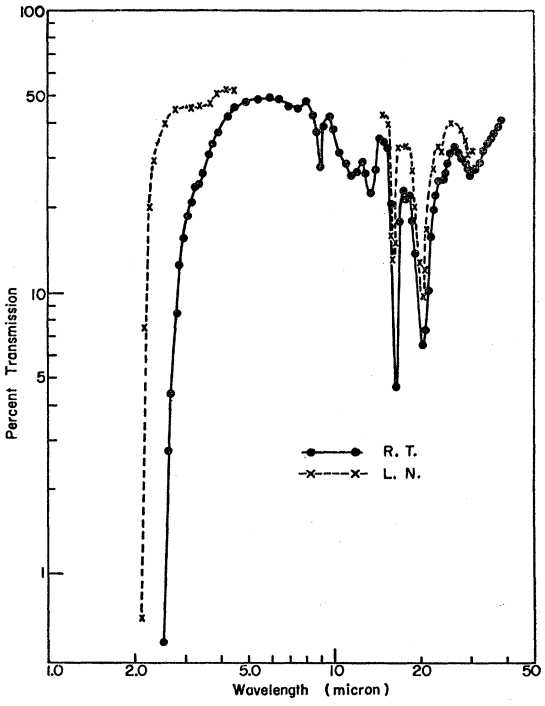

FIG. 2. Percent transmission as a function of wavelength for a p-type silicon sample irradiated with 10^{19} cm^{-2} fast neutrons. The original resistivity of the sample was 30 ohm cm.

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Optical Detection of Zero-Field Hyperfine Splitting of Na^{23}

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FOLLOWING a suggestion by Dicke[1] for an atomic sodium clock employing buffer gas reduction of the Doppler width and following recent approaches[2,3] to increasing useful population differences and detection sensitivity by employing optical orientation methods,[4] we have investigated the $\Delta F=1$ hyperfine microwave transitions in a buffer gas cell of Na^{23}, and especially the $\Delta F=1$, $m_F=0\rightarrow m_F=0$ transition, with a view to making a redetermination of the hyperfine splitting in the ground state, and investigating the system as a possible clock. It is possible with good signal-to-noise to observe the depolarization of a beam of circularly polarized light when $\Delta m_F=+1$ transitions in the ground state hyperfine structure are saturated by either rf[3,4] or microwaves, because the angular momentum of the system is directly disturbed. We have found that an observable and useful depolarization is also present when $\Delta m_F=0$ transitions are saturated. For the $\Delta m_F=0$, $m_F=0$ transition the effect is "second order" in comparison to $\Delta m_F=1$ transitions.

The experimental apparatus is essentially similar to that of other workers.[3] Sodium in a gas cell of about 1-liter volume was maintained at a temperature of 120 to 130°C. Buffer gases of spectroscopically pure argon and neon ranging in pressure from 1 to 50 mm Hg were used to reduce the Doppler width. A beam of circularly polarized resonance radiation from standard sodium lamps running on dc was passed through the sodium cell and focused on a type 927 photocell. An homogenous magnetic field of a few gauss was produced in the region of the cell with a set of Helmholtz pairs.

The sodium cell was irradiated with microwave power by a wave guide horn with suitable polarization for either σ or π excitation. The microwave oscillator was frequency-modulated at 30 cycles per second and the output of the photocell amplifier was fed into a phase-sensitive detector, thus obtaining the derivative of the resonance line. The microwave frequency was obtained by multiplication from a crystal oscillator at 24.6 Mc/sec. The frequency of the crystal oscillator was measured with a Berkeley counter monitored with station *WWV* with a short-term accuracy of 1 part in 10^8 to 1 part in 10^7. It was found that the $\Delta m_F=0$, $m_F=0$ transition would be observed with a signal-to-noise ratio barely sufficient for direct display on a scope and with a signal-to-noise ratio of 20:1 when a bandwidth reduction to 0.05 cps was made with a lock-in amplifier.

The value of the hyperfine splitting of Na^{23} in the ground state was found to be

$$(1771.6262+0.0022H^2)\times10^6\pm100 \text{ cycles/sec.}$$

This frequency was obtained by direct measurements on a line whose width was 400 cps. The line width in this case is determined mostly by microwave saturation effects and partly by noise and instability in the oscillator. The value obtained by this method is slightly lower than the value given by atomic beam measurements.[5]

The effect of buffer gas pressure in shifting the hyperfine frequency was studied. Argon pressures of 1 mm, 5 mm, 10 mm, and 50 mm were used. No observable pressure shifts were measured with argon although the accuracy of the measurements leave the possibility that a pressure shift of several cps/mm might be present. Such a magnitude would be in agreement with measurements on Rb^{87}.[2] Neon shifts for pressures of 1 mm, 5 mm, 10 mm, and 50 mm were measured. A pressure shift to higher frequencies of 80 cps/mm was found. This surprising result we believe to be caused by exchange of the valence electron to the similar neon core with an accompanying spin-orbit interaction. We have also measured by microwave methods an effective cross section of 5×10^{-14} cm^2 for exchange collisions between sodium atoms which determine the line width at higher pressures of sodium.

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Ground-State Energy of Two-Electron Atoms. Corrective Results

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IN a Letter[1] last year we gave a preliminary report dealing with the ground-state energies of the He atom and homologous two-electron ions calculated by means of a 24-term function containing a nonconventional logarithmic term together with 3 terms of the type introduced by Kinoshita[2] in his formal solution of the Schrödinger equation for He. The contribution from this logarithmic term to the ground state energy in the limiting case of nuclear charge $Z\rightarrow\infty$ was of the order of magnitude 5–6 in the fifth decimal place as measured in Rydberg units, i.e., about 5 cm^{-1} in wave number units. For finite Z the contribution was smaller, but it did not surprise us that a contribution of about 2 cm^{-1} remained in the case of He. Soon afterwards we had a report of results obtained by Kinoshita for the ground-state energy of He, using a 39-term function. His energy value was about one cm^{-1} behind ours, in spite of his numerous terms. Because of the obviously well-adapted form of our logarithmic term, however, we did not for this reason mistrust our calculations. Then we had a report of the Hart and Herzberg[3] calculations based on a 20-parameter conventional wave function. The energy value obtained by these authors was only about one cm^{-1} behind that of Kinoshita. Next, from preliminary calculations they had found only a negligible contribution from our logarithmic term. On account of this discrepancy we decided to recalculate our matrix elements and as a matter of fact no mistake could be found in our basic calculations using the matrix $M-L+2N$ in place of the kinetic integral M (L and N being Coulomb and normalization integrals, respectively). Hence the important $Z\rightarrow\infty$ results were correct. However, for finite Z we had at a later stage to introduce also the M matrix and it was finally found that in the transition from $M-L+2N$ to M two figures containing the sequences $\cdots6480\cdots$ and $\cdots6048\cdots$ had in some way been confused. The mistake was, however, outside the row and column of the logarithmic term.

The correction of this mistake at first displaced the energy of He 2–3 cm^{-1} backwards, i.e., behind both the Kinoshita and the Hart-Herzberg values. It therefore

TABLE I. Corrected values of $E_2(Z)$.

Z	A	$-E_2(Z)$ Incorrect	$-E_2(Z)$ Corrected	Z	A	$-E_2(Z)$ Incorrect	$-E_2(Z)$ Corrected
1	H^-	0.305451	0.305434	7	N^{5+}	0.312893	0.312883
2	He	0.307457	0.307443	8	O^{6+}	0.313192	0.313182
3	Li^+	0.309818	0.309821	9	F^{7+}	0.313426	0.313417
4	Be^{++}	0.311131	0.311126	10	Ne^{8+}	0.313613	0.313604
5	B^{3+}	0.311945	0.311936	16	Ca^{18+}	0.314459	0.314457
6	C^{4+}	0.312496	0.312486	∞		0.315311	0.315315