excitons are in quasi-thermal equilibrium with the free carriers, i.e., if the most likely mode of breakup of the exciton is thermal dissociation. For a given n and p, $n_{X,\max} \simeq (N_X np/N_V N_C) \exp(E_X/kT) \simeq 4 \times 10^{-16} \{m \times (m_e + m_h)/m_e m_h\}^{3/2} T^{-3/2}\ np \exp(E_X/kT)$, where E_X is the binding energy of the exciton, N_X, N_V, N_C are the effective densities of states of the exciton, valence, and conduction bands, respectively, near their respective extrema. Taking $T=4°K$ and assuming that $\{\ \}^{3/2} \approx 1$ and that $E_X \approx 10kT \approx 4 \times 10^{-3}$ ev, we obtain $n_{X,\max} \approx 10^{-12} np$ under these conditions.

Li^7 AND F^{19} NUCLEAR MAGNETIC RESONANCES IN NEUTRON-IRRADIATED LiF†

P. J. Ring, J. G. O'Keefe, and P. J. Bray
Physics Department,
Brown University,
Providence, Rhode Island
(Received November 19, 1958)

Nuclear magnetic resonance examinations of LiF samples subjected to neutron dosages of the order of 10^{18} nvt have revealed the presence of constituent nuclei in environments other than those of the normal lattice sites. These nuclei produce narrow lines which are superimposed on the normal broad lines.

The fluorine line, Fig. 1, was observed in a single crystal[1] of LiF which had received a neutron dose of 1×10^{19} nvt. The resonance was observed at a frequency of 28.5 Mc/sec and the separation of the centers of the two derivative traces was 18.5 kc/sec. This is a shift of about 0.07% to a higher frequency for the more narrow

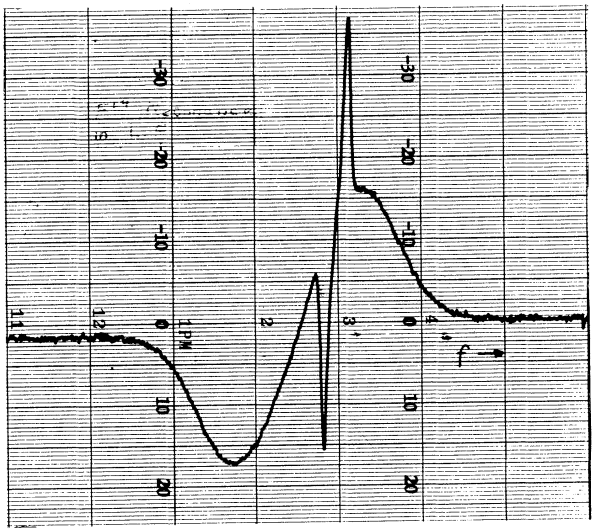

FIG. 1. F^{19} resonances in a neutron-irradiated single crystal of LiF.

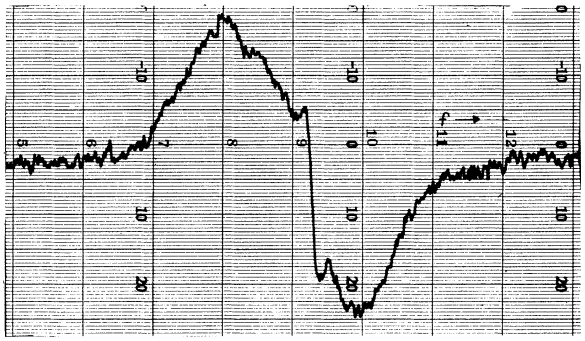

FIG. 2. Li^7 resonances in a polycrystalline sample of neutron-irradiated LiF.

line. This same combination of narrow and broad lines has been observed in another single-crystal sample of LiF that had received a dose of about 10^{18} nvt.

Comparison of the areas under the two F^{19} derivative curves, each of which was obtained with a modulation amplitude appropriate to the particular line, gives a value of 0.07 for the ratio of the area of the more narrow line to the total area. Thus about 7% of the fluorine nuclei are contributing to the narrow line. The frequency shift of the narrow line with respect to the wide line is comparable with the value 0.063% between HF and F_2 given by Gutowsky and Hoffman.[2] Thus the narrow line may be due to molecular fluorine. The frequency shift expected if the nuclei were ionic fluorine is much smaller than that measured.

The line width, that is the separation of maximum derivatives, of the broad line is approximately 47.4 kc/sec which is, within experimental error, in agreement with the value of 46.6 kc/sec calculated from the equation of Van Vleck.[3] The narrow line has a width of about 4 kc/sec.

The lithium line, Fig. 2, has been observed in a polycrystalline LiF sample which received a neutron dose of 1.6×10^{18} nvt. The sample was originally a single crystal[1] but after irradiation was found to be completely fractured.

The intensity of the narrow Li^7 line in the polycrystalline sample is not sufficient to allow a determination of the percentage of Li^7 nuclei contributing to it. Measurement of the frequency of this line and comparison of this value with that of Li^7 in a LiCl solution gives a value of $\Delta f/f = 0.028$ for the shift of the narrow line. This value compares favorably with the value[4] $\Delta H/H = 0.0249$ for the Knight shift in metallic lithium. The fluorine resonance in this polycrystalline sample exhibits a narrow line similar to that of

the single-crystal sample.

The broad lithium line in the single crystal has a separation of maximum slopes of 24 kc/sec for an orientation with the constant magnetic field along a [100] direction. This is larger than the value 20.6 kc/sec calculated from Van Vleck's equations.[3] Interactions of the Li^7 nuclear electrical quadrupole moments with field gradients arising from defects in the irradiated crystal may be responsible for this broadening.

These findings are in agreement with x-ray studies of neutron-irradiated LiF. Smallman and Willis[5] have concluded from their analysis that aggregates of fluorine atoms are trapped within the crystal. Lambert and Guinier[6] have concluded from small-angle scattering analysis that lithium atoms are present in the form of platelets parallel to the (100) planes. Thus the narrow Li^7 and F^{19} lines may be due to colloidal lithium metal and molecular fluorine gas.

Further studies of the lithium and halogen resonances, as functions of radiation dosage and post-irradiation annealing, are in progress on both single crystals and powders of LiF and other lithium halides. Quantitative determinations of the amount of damage and the behavior of the displaced metal and halide ions are now possible.

†Research supported by the U. S. Atomic Energy Commission.

[1]A cylindrical sample 1/2 in. long and 7/16 in. in diameter purchased from the Harshaw Chemical Company.

[2]H. S. Gutowsky and C. J. Hoffman, J. Chem. Phys. 19, 1259 (1951).

[3]J. H. Van Vleck, Phys. Rev. 74, 1168 (1948).

[4]W. D. Knight, Solid State Physics (Academic Press Inc., New York, 1956), Vol. 2, p. 93.

[5]R. E. Smallman and B. T. M. Willis, Phil. Mag. 2, 1018 (1957).

[6]M. Lambert and A. Guinier, Compt. rend. 245, 526 (1957).

OBSERVATION OF VERTICAL-INCIDENCE SCATTER FROM THE IONOSPHERE AT 41 Mc/sec

K. L. Bowles
Central Radio Propagation Laboratory,
National Bureau of Standards,
Boulder, Colorado
(Received November 12, 1958)

The possibility that incoherent scattering from free electrons in the ionosphere, vibrating independently, might be observed by radar techniques has apparently been considered by many workers although seldom seriously, because of the enormous sensitivity required. Recently Gordon recalled this possibility to the writer while remarking that he hoped soon to have a radar sensitive enough to observe incoherent electron scatter in addition to various astronomical objects.[1] Subsequent calculations indicated that a new 41-Mc/sec pulse transmitter, due to be received by the National Bureau of Standards, should permit observation of the incoherent electron scatter if a relatively simple antenna of large cross section were constructed.

The phenomenon of incoherent scattering of electromagnetic radiation by gas molecules has been recognized for many years at optical wavelengths.[2] The suggestion of observing electron scatter at radio wavelengths is a consequence of the relatively large radar cross section of electrons, compared with atoms or molecules. The optical observations have confirmed that the average distance between the scattering particles determines whether the particles may be considered to scatter independently. When they do scatter independently, the scattered power is proportional to the number of particles present. When observing a volume deep in wavelengths containing many particles having a mutual spacing shallow in wavelengths, the particles can no longer be considered to scatter independently. However, statistical fluctuations of the density of particles on a scale comparable to a wavelength gives rise to a different form of scattering, which turns out to be only slightly weaker than the completely independent scatter.[3] Optical experiments have apparently been somewhat inconclusive as to the exact criterion for close versus loose packing and the manner in which the scatter behaves in the transition region. One significant difference between the two kinds of scatter is apparent – that of frequency broadening of the scattering wave. The completely incoherent scatter should be heavily broadened due to Doppler shifting of the component scattered waves by thermal motions of the scatterers. The semi-incoherent scatter, mentioned above, will be broadened only slightly due to thermal fluctuations.[3] In both cases, radar observation of the scatter should provide a means of determining directly the electron density versus height profile of the ionosphere.

The brief observations reported herein were undertaken in an attempt to verify the existence