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

Table I. Parameters of radar equipment used.

Operating frequency	40.92 Mc/sec
Peak pulse power	(4 to 6) × 10^6 watts
Pulse duration	(50 to 150) × 10^{-6} sec
Average power	4 × 10^4 watts maximum
Receiver bandwidth	10, 15, or 30 kc/sec
Antenna cross section	116 × 140 meters (1024 half-wave elements in phase above ground)
Antenna polarization	north-south
Calculated antenna gain	~35 decibels/isotropic

of the incoherent or semi-incoherent scatter by the free electrons of the ionosphere. The parameters of the equipment used are given in Table I. Operation of the antenna has been checked by total power recordings of the emissions from the radio point source in Cygnus (Cygnus A) which happens to pass through the center of the beam. The beam width is within one-half degree of the calculated 3.75° and the intensity of the Cygnus signal is approximately 10 times that of the average galactic background in the same regio of the sky.

Examples of "A 'scope" photographs taken on October 21 and 22, 1958, during daylight hours are presented in Fig. 1. The rise in noise level peaking broadly at about 350 km range is interpreted by the writer as the scatter type of echo mentioned above. Inverse distance variation makes the echo intensity below this height nearly constant down to E-region heights, although the ionization density may be expected to decrease by about a factor of 10. Reception at frequencies slightly separated from the transmitted frequency indicated little thermal broadening (F-region line broadening of the order of 100 kc/sec is expected for incoherent electron scatter). Conditions of the experiment did not permit observation of polarization effects.

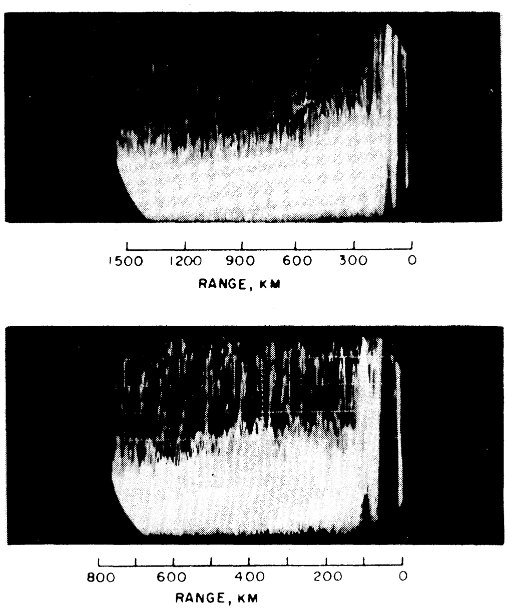

FIG. 1. (a) Pulse width 140 μsec (21 km); bandwidth 10 kc. (b) Pulse width 120 μsec (18 km); bandwidth 15 kc

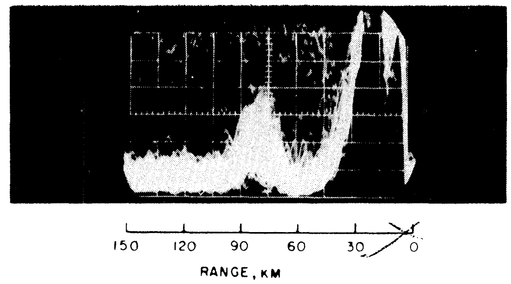

FIG. 2. Pulse width 50 μsec (~8 km); bandwidth 30 kc.

The strong echo at about 85 km range is illustrated in Fig. 2 on an expanded range scale. This echo, observed continuously at 75 to 90 km height, is interpreted as due to ionospheric scattering of the turbulent variety as discussed in many recent papers.[4]

Care was taken in the observation to eliminate the possibility that other known types of reflections might in fact account for the echoes shown. Owing to shortage of time and difficulties with frequent malfunctions of equipment, the present records are contaminated with impulse noise and were taken only during daylight hours. Efforts are under way to make more extensive higher quality observations.

---

[1] W. E. Gordon, Union Radio-Scientifique Internationale-Institute of Radio Engineers Fall Meeting, Pennsylvania State University, October 22, 1958 (unpublished).

[2] See, for example, discussion and references given by S. Bhagavantam, in Scattering of Light and the Raman Effect (Chemical Publishing Company, Brooklyn, 1942), Chap. 3.

[3] F. Wolfers, J. phys. radium 9, 1-5 (1948).

[4] See, for example, K. L. Bowles, in Annals of the International Geophysical Year (Pergamon Press, London, 1957), Vol. 3, Part 4, pp. 346-360.

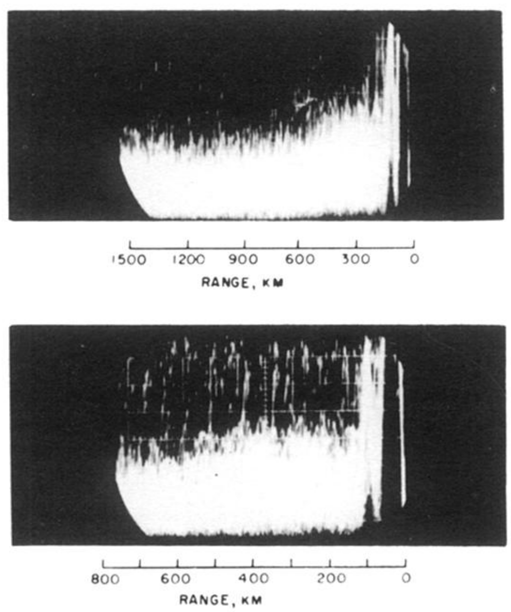

FIG. 1. (a) Pulse width 140 μsec (21 km); bandwidth 10 kc. (b) Pulse width 120 μsec (18 km); bandwidth 15 kc

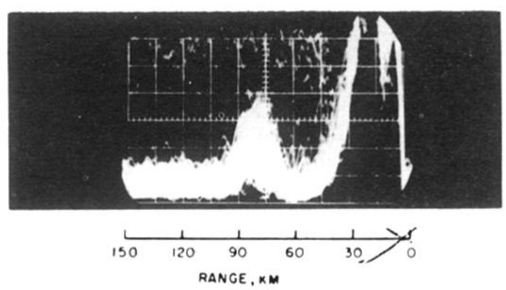

FIG. 2. Pulse width 50 μsec (~8 km); bandwidth 30 kc.