

frequency equals ν_0 , that f is the oscillator strength, and that γ is the damping constant. Formula (1) may, with these assumptions, be reduced to

$$\frac{n_c^2 - 1}{n_c^2 + 2} = \frac{e^2}{3\pi m} \left(\frac{Nf}{(\nu_0^2 - \nu^2) + i\gamma\nu} \right). \quad (2)$$

Any change in the number of holes or electrons will correspond to an equivalent change in N . Thus n and k , and consequently R will be functions of N . Assuming small variations of N and restricting the calculation to the region of small absorption ($k \ll n$) one obtains for the change of the refractive index and reflection coefficient:

$$\Delta n = \frac{(n+2)^2}{18n} \left(\frac{fe^2}{3\pi m(\nu_0^2 - \nu^2)} \right) \Delta N; \quad \frac{\Delta R}{R} = \frac{4}{n^2 - 1} \Delta n.$$

With a reasonable estimate of the numerical values involved, $f \approx 1$, $\nu_0^2 - \nu^2 \approx 10^{28} \text{ sec}^{-2}$, $n_{\text{Ge}} = 4$, one obtains $\Delta n \approx 3 \times 10^{-20} \Delta N$; $\Delta R/R \approx 10^{-20} \Delta N$.

To explain the magnitude of the effect observed by Filiński ($\Delta R/R$ up to 1%), one has to permit ΔN to be as large as 10^{18} cm^{-3} . A change of volume concentration of this order of magnitude due to injection of minority carriers is out of the question. The presence of a surface layer, however, changes the situation. The difference in concentration of electrons (or holes) between a thin surface barrier region of p type, for instance, and the bulk of the Ge crystal of n type, might well be of this order of magnitude. Under the influence of a voltage applied to the diode, the barrier may be almost completely leveled. Thus the applied field might change the surface concentration by an amount sufficient to explain the Filiński effect.

The spectral distribution corresponding to the curve A of Filiński's paper is thus considered to be due to a primary effect. The occurrence of modulation of reflection in the region of strong absorption in germanium directly establishes the surface character of the effect.

It remains to explain the type B spectral distribution. The lack of modulation beyond the absorption edge of germanium suggests that in this case the reflected light has to pass through some layer of germanium. In fact one can obtain a curve of type B from A if a germanium filter is placed somewhere in the light path. One is thus led to the conclusion that in this case the modulated light is reflected by some surface lying deep within the germanium. Actually in some cases the overlapping of both types was observed.

The additional reflection due to a sharp jump Δn of the refractive index over some plane parallel to the crystal surface is given by $\Delta R/R = 4(\Delta n)^2 / (n^2 - 1)^2$ in the case of negligible absorption. To obtain a value for $\Delta R/R$ of one percent, one has to assume a corresponding ΔN of the order of 10^{19} cm^{-3} . Such a value

seems to be permissible for the p - n junctions formed in indium-doped germanium crystals for which the type B effect was observed.

Thus the hypothesis that the Filiński effect is due to the influence of the current carriers on the refractive index and that the modulation takes place in the region of either surface or internal p - n junctions seems to explain its main features. The quantitative theory and an explanation of the spectral distribution require knowledge of the oscillator strength and damping constants over the entire range of the absorption spectrum. The effect should not be restricted, of course, to germanium, and the investigation of other substances is under way.

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Detection of Submillimeter Solar Radiation*

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PRELIMINARY results are given here of experiments aimed at finding regions in the submillimeter wavelength range at which solar radiation is appreciably transmitted by the earth's atmosphere.

Figure 1 shows a spectrum of the sun observed at the Jungfrauoch, Switzerland (altitude 3450 meters). In the wavelength range shown (1 mm to 300μ) there are several maxima which indicate regions of transmission and which extend the observed wavelength range of

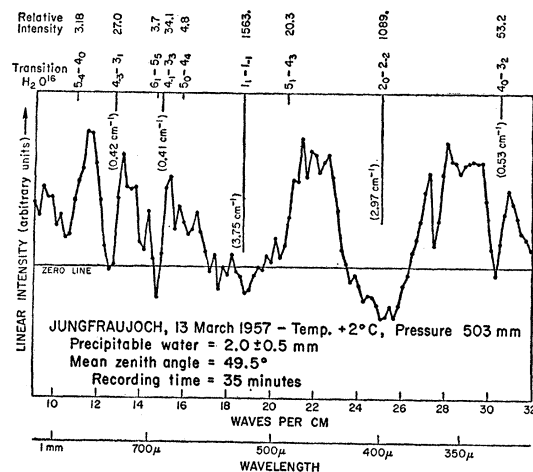


FIG. 1. Submillimeter spectrum of solar radiation showing regions of atmospheric transmission and absorption. The calculated positions and intensities of pure rotation lines of H_2O are given. The numbers in parentheses are calculated half-widths for selected lines.

solar radiation beyond the limit of about 1 mm previously reported.^{1,2}

The principal regions of high absorption correspond to the calculated positions³ of pure rotation lines of H₂O¹⁶ as indicated on the spectrum. There is also correlation with the calculated intensities and half-widths³ of these lines. The negative intensities in these regions of high absorption are attributed to emission from water vapor which is at a lower effective temperature than the receiver. There are also other reproducible absorption features which remain to be positively identified, but of these, some are tentatively ascribed to ozone.

The observations were made with a two-beam interferometer⁴ of 30-cm aperture and a Golay-type thermal detector. Spectra were obtained from the interferograms by digital computation.⁵ For the present purpose, the spectral intensity has been calculated only at equally spaced points 0.2 cm⁻¹ apart, this interval being chosen to equal the spectral resolution of the system.

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Proposal for a Nuclear Quadrupole Maser

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THE amplification of microwave power by means of stimulated emission by the power saturation of one transition in a multiple energy level system has been discussed by Basov and Prokhorov.¹ The application of this technique to paramagnetic solids has been considered by Bloembergen² and such a system is reported to have been successfully operated by Scovil, Feher, and Seidel.³ In this note, attention is called to another broad class of substances, namely, those exhibiting pure quadrupole transitions, that have the requisite properties for the production of stimulated emission and hence possible amplification.

The feasibility of these schemes depends upon the existence of suitable energy levels and matrix elements

of the magnetic moment operator between the various levels. If in a system of at least three energy levels, transitions are allowed between the lowest and the highest level, the power saturation of this transition can result in a net emission of radiation between the intermediate level and either of the two saturated levels. The theory of a three-level "maser" has been given by Bloembergen² and applied to a nuclear quadrupole system. A nucleus of spin $I \geq \frac{5}{2}$ or $I \geq 2$ possessing an electric quadrupole moment, when present in a crystalline electric field of lower than cubic symmetry, yields at least three unequally spaced energy levels. In general, transitions between adjacent levels with selection rule $\Delta|M|=1$ obtain in purely axially symmetric fields. However, if the crystalline field has large deviations from axial symmetry, the "forbidden" transitions $\Delta|M|=2$ acquire observable intensities.⁴ The power saturation of a $\Delta|M|=2$ transition will allow the observation of stimulated emission of a $\Delta|M|=1$ transition and if such emission is great enough to overcome all losses of radiation, the system can be used as an amplifier, or oscillator.

The basic difference between the use of a paramagnetic substance and one exhibiting pure quadrupole resonance is that in the former the energy level separations are determined to first order by the strength of an applied magnetic field, while in the latter the level separations are fixed by the crystalline electric field gradient. Another important difference is that in the quadrupole case the transition probabilities are $\sim 10^{-5}$ as great as in the paramagnetic case since the coupling to the radiation field is through the magnetic dipole moment of the nucleus rather than the magnetic moment of the electron. However, crystalline substances such as I₂ and its compounds are not lossy and by the use of a large filling factor, it may be possible to provide the conditions for amplification at low temperatures.

The successful operation of a three-level "maser" depends upon crystals with favorable relaxation times, and consequently the consideration of substances that exhibit pure quadrupole spectra is of interest. An attribute of a pure quadrupole system is that the built-in crystalline field determines the frequency and no external magnetic field is necessary. This feature, to first order, obviates tunability; however, in the case of single crystals, the Zeeman splitting of the levels can provide some tunability.

Although most pure quadrupole spectra have been observed at submicrowave frequencies, nuclei with atomic numbers above 50, especially the rare earths, may have solid-state quadrupole interactions sufficiently large to be observed in the microwave region. With nuclei of spin $I \geq \frac{7}{2}$ or $I \geq 3$ one can have four-level systems with obvious extensions of the "maser" principle. In systems where sufficient intensity cannot be obtained to yield amplification, the observation of the induced emission of the allowed $\Delta|M|=1$ transi-