$\cdot(1-x)K_2O\cdot 2SiO_2$ ($x=0-1$). The induced absorption bands are given in Fig. 2.

Figure 2 shows clearly that the relative intensity of the two visible bands is nearly proportional to the molecular ratio of Na_2O to K_2O.

Moreover the induced absorption bands of Na_2O-SiO_2 series glasses are given in Fig. 3. Therefore it is concluded that the visible bands in alkali silicate glasses are due to electrons trapped by oxygen vacancies which neighbor alkali ions.

The ultraviolet band is bleached with the visible bands by irradiation with visible light and the visible bands are bleached with the uv band by irradiation with 313 mμ light.

Further, in $K_2O\cdot 2SiO_2$ glass which was prepared in the reducing condition, the uv band decreases and the visible bands increase in intensity compared with the intensities observed in the specimens prepared in the neutral condition.

On the other hand, the uv band in all glasses studied has its peak at about 3.98 ev. Moreover, this peak position does not change in the mixed alkali silicate glasses.

Therefore it is concluded that the uv band is the one characteristic of "oxygen," that is, it arises from positive holes trapped by alkali vacancies neighboring oxygen.

In the alkali silicate glasses studied, the three absorption bands are always observed, although in some cases they are difficult to resolve. A remarkable regularity in the peak position and the relative intensity of the two visible bands was found, as shown in Figs. 1 and 3.

A full account will appear in the *Journal of the Physical Society of Japan.*

[1] Ryosuke Yokota, J. Phys. Soc. Japan **7**, 316 (1952); **7**, 222 (1952); Phys. Rev. **91**, 1013 (1953).

Submillimeter Wave Spectroscopy*

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An extension of microwave spectroscopy into the submillimeter wave region has been achieved. A spectrum line at 0.77-mm wavelength (389 kMc/sec) has been precisely measured with harmonics from a 5-Mc/sec marker monitored by the standard 5-Mc/sec signal broadcast by the National Bureau of Standards. This and other submillimeter wave lines of OCS which have been measured are listed in Table I.

Figure 1 shows a recording of several rotational lines in the sub-millimeter range obtained with different harmonics of a *K*-band klystron (Raytheon 2K33). Because of centrifugal stretching the rotational lines are not exactly integral multiples as are the harmonics from the oscillator. For this reason, the different rotational lines are separated on the tracing. The tuning was such as to optimize the lines of highest frequency. Therefore, this recording does not indicate the optimum performance which was obtained on the lower-frequency lines. With tuning to maximize it, the line at 0.88 mm could be recorded with a signal-to-noise ratio of 30 to 1; that at 0.95 mm, with 60 to 1; that at 1.03 mm, with 100 to 1.

The highest frequency previously recorded by electronic methods is the 1.03-mm line of OCS for which a signal-to-noise ratio of 7 to 1 was obtained.[1] The signal-to-noise ratio obtainable at one millimeter has now been increased by a factor of at least 10. Figure 2 shows a scope tracing of the 1.03-mm line obtained with a 60-cps video sweep spectrometer. A recording of it is included in Fig. 1.

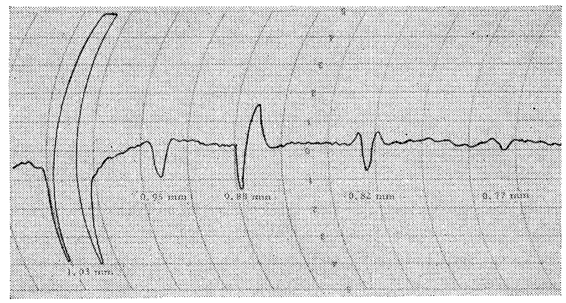

Fig. 1. Recording of the 24th, 26th, 28th, 30th, and 32nd rotational lines of OCS with the 12–16th harmonics of a *K*-band klystron. A phase sensitive lock-in amplifier tuned to 4000 cps was used with 2000-cps repeller modulation of the klystron. Cell length 15 cm, cell volume 0.2 cc. Wavelength of lines are indicated on the chart; frequencies range from 291 to 389 kMc/sec.

The present results have been made possible by a further reduction in size and by refinements of the crystal multiplier and detector units already described by King and Gordy.[1,2] More experimental details will be given in a full length report to be written later. It is evident that the coherent electronic methods of the radio region now overlap effectively the noncoherent optical or heat methods customarily employed in the far infrared region. Rotational lines of such light diatomic hydrides as DCl and HI now fall within the microwave region. Already lines of DBr have been measured in the one-millimeter region.[3]

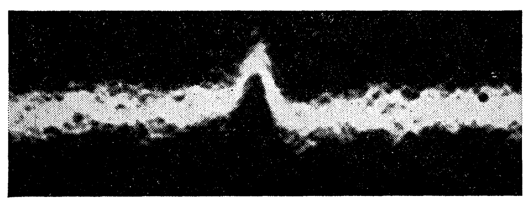

Fig. 2. Cathode-ray oscilloscope trace of the 24th rotational line of OCS at 1.03-mm wavelength (291 kMc/sec). An ordinary crystal video receiver was employed with a 60-cps sweep and an amplifier band width of 6 kc/sec.

Although there are many obvious uses of high-resolution spectroscopy in the 1-mm region, one advantage which probably is not generally realized is the small quantity of material required for spectral examination in this region. The total volume of the wave-guide cell used in the present work is 0.2 cc. In this cell with a pressure of only 5×10^{-3} mm of Hg, the signal-to-noise ratio of 100 to 1 could be obtained at 1-mm wavelength. This represents a total of 5×10^{13} molecules, or one hundredth of a microgram of OCS, neglecting that adsorbed on the cell walls. Actually the lines could easily be detected with only 5×10^{12} molecules or one-thousandth microgram of OCS in the absorbing path. We have in progress a cooperative program with Dr. Ralph Livingston's group at the Oak Ridge National Laboratory for utilizing

Table I. Observed lines of $O^{16}C^{12}S^{32}$.

Oscillator harmonic	Transition	Frequency in Mc/sec Calculated[a]	Observed[b]	Wavelength in mm
12	23–24	291 839.27	291 839.23 ±0.60	1.03
13	25–26	316 145.59	316 144.7 ±1.0	0.949
14	27–28	340 448.64	340 449.2 ±1.0	0.881
15	29–30	364 748.16	364 747.5 ±1.5	0.823
16	31–32	389 043.12	389 041 ±2.0	0.771

[a] Calculated with $B_0=6081.494$ Mc/sec and $D_J=1.310$ kc/sec.
[b] The two lower-frequency lines were measured on the scope, and the others on the recorder.

this advantage of the shorter millimeter wave region for measurement of the moments of radioactive nuclei.

We wish to thank Mr. M. Whitfield, shop supervisor, for his cooperation and advice, and Mr. W. B. Francis, instrument maker, for his excellent work on the microwave components.

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† Shell Oil Company Fellow.

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[2] W. C. King and W. Gordy, Phys. Rev. **90**, 319 (1953).
[3] W. Gordy and C. A. Burrus, Phys. Rev. **93**, 419 (1954).

Angle of Divergence of Pairs Produced by Photons

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ILFORD nuclear emulsions ($G\,5$, 600μ) were scanned systematically for high-energy electron pairs produced by γ rays from cosmic radiation. The plates were exposed for three weeks on the Monte Rosa (Capanna Margherita 4550 m) and processed at our laboratory in Berne according to the Brussels method.[1] The plateau blob density obtained was 30.6 blobs per 100μ.

The angle of divergence and the photon energy of 126 pairs have been measured for 212 pairs found in a certain area. The photon energy $k=E_{+}+E_{\mathrm{l}}$ was determined by multiple scattering measurements on both tracks of the pairs. E_{+} and E_{-} are the total energies, the pairs being supposed to be electron-positron pairs. The measured values of the angle ω were reduced to values

$$\omega_{\mathrm{red}}=\omega[\phi(a=0.5)/\phi(a)],\quad a=E_{\mathrm{l}}/k,$$

corrected for symmetrical energy partition, E_{l} being the lower one of the particle energies. $\phi(a)$ is a function given by Borsellino,[2] which represents the influence of the energy partition according to his Eq. (15) for the most probable values of the angle:

$$\omega_p=(4mc^2/k)\phi(a).$$

Figure 1 shows the values of k *vs* ω_{red}. Curve 1 is Borsellino's theoretical most probable value ω_p for $a=0.5$. Curve 2 is the root-mean-square value $\langle\omega^2\rangle$ of Stearns.[3] Both curves represent the values for symmetrical energy partition. The limits of error of the experimental values were calculated with the relative mean deviation $0.75/\sqrt{N}$ of the second differences (sagitta method of multiple scattering measurement), N being the number of the independent second differences on the track. The points indicated by triangles are measurements given by Occhialini.[4]

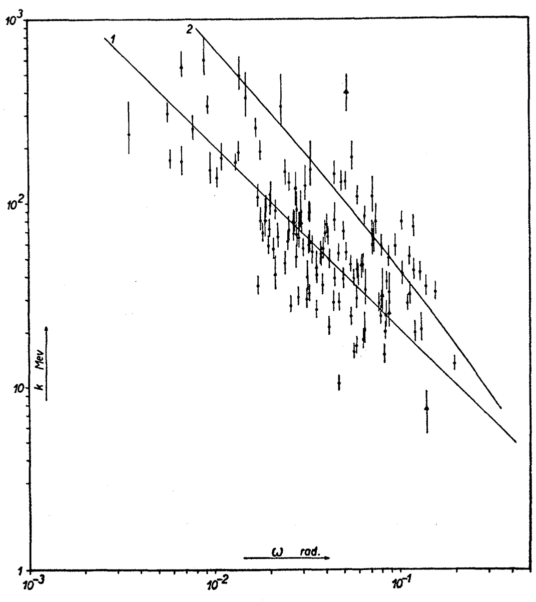

FIG. 1. The correlation between angle of divergence and photon energy k. The experimental points represent the reduced values ω_{red} belonging to the symmetrical energy distribution. Curve 1 is Borsellino's most probable value ω_p and curve 2 the root-mean-square value $\langle\omega^2\rangle$ of Stearns.

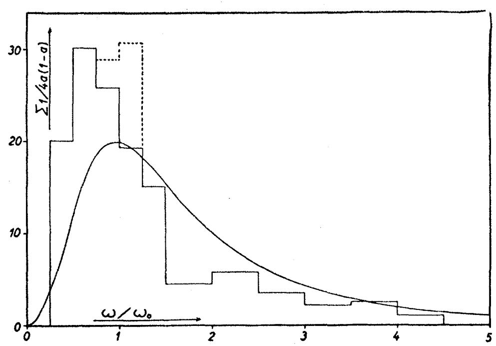

FIG. 2. The distribution of pairs in ω/ω_0. The full-line histogram includes the pairs with $a>0.1$; the dotted line shows the histogram including all pairs where both ω and k have been measured. Theoretical curve: Borsellino's probability.

Figure 2 represents the frequency distribution of the pairs in ω/ω_0, with

$$\omega_0=(mc^2k)/(E_{+}E_{-}).$$

The histogram represents the correct number of pairs in a interval 0.25 of ω/ω_0. Each pair has been multiplied by a weight factor

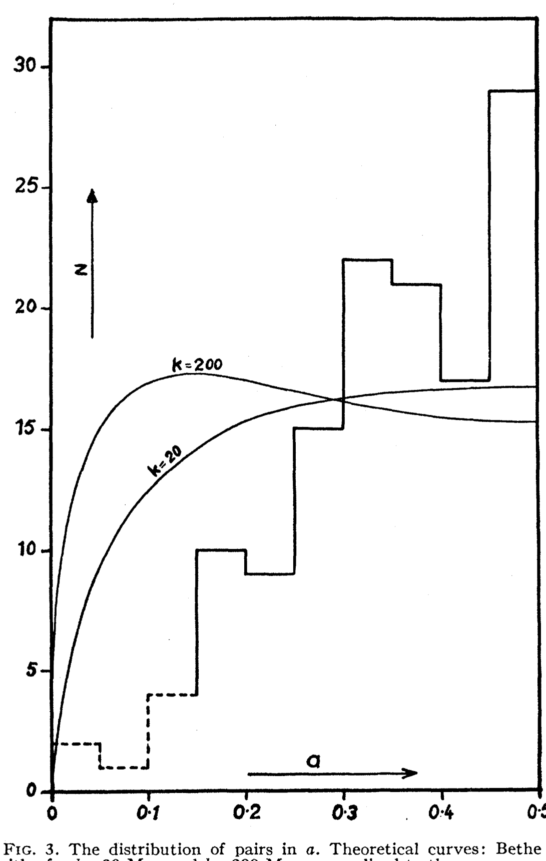

FIG. 3. The distribution of pairs in a. Theoretical curves: Bethe and Heitler for $k=20$ Mev and $k=200$ Mev, normalized to the same area with the histogram in the interval $0.15<a<0.5$.

FIG. 1. Recording of the 24th, 26th, 28th, 30th, and 32nd rotational lines of OCS with the 12–16th harmonics of a *K*-band klystron. A phase sensitive lock-in amplifier tuned to 4000 cps was used with 2000-cps repeller modulation of the klystron. Cell length 15 cm, cell volume 0.2 cc. Wavelength of lines are indicated on the chart; frequencies range from 291 to 389 kMc/sec.

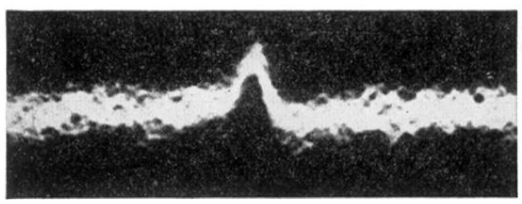

FIG. 2. Cathode-ray oscilloscope trace of the 24th rotational line of OCS at 1.03-mm wavelength (291 kMc/sec). An ordinary crystal video receiver was employed with a 60-cps sweep and an amplifier band width of 6 kc/sec.