Letters to the Editor

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The Band Width of the *F* Band in KBr at 78°K†

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(Received July 6, 1953)

THE *F* band in alkali halide crystals is known to have a frequency and half-width depending on the material and temperature of measurement. The half-width *W* also may be affected by the interaction of the *F* centers with other imperfections or dislocations in the lattice. An understanding of this effect would be of particular interest in view of certain bleaching experiments on *F* bands in KBr at low temperatures where the optical instability was determined to be a function of the mode and temperature of formation of the *F* centers.[1] The effect was interpreted as a result of the recombination of electron surplus and hole centers existing in high concentrations in the vicinity of lattice imperfections.

There is a rather large spread in the values for *W* reported in the literature. For example, for KBr at approximately 78°K, *W* has been reported as 0.20[2] and 0.23 ev.[3] Since such differences are greater than can be accounted for considering variations in temperature and resolving power, a study has been made to determine the reproducibility of *W* in a given sample.

The experimental techniques have been described before.[2] The measurements were made with a Beckman Model DU Spectrophotometer at a slit width of 0.06 mm corresponding to a band pass of 27A at 600 mμ. Under these conditions of measurement the apparent broadening of the band contour due to slit width can be neglected.

The contribution of the broad *F'* band to the intensity of the *F* band was eliminated by optically bleaching the *F'* band. A small optically stable *K* band (also called V_0) at 530 mμ also overlaps the *F* band. The *K* band contribution was estimated by evaluating the dissymmetry introduced into the *F* band envelope. This approximation showed that in ignoring the contribution of the *K* band, the error in the value of *W* was less than ¼ mμ or 0.001 ev.

Table I gives measurements of *W* in five specimens cleaved from a single additively colored Harshaw crystal.[4]

In Table II are summarized the results on several samples: samples 2 and 4 were cleaved from the same Harshaw crystal, sample 3 was from a different Harshaw crystal, and sample 5 was from a crystal[5] shown to be particularly pure.[1] Each measurement was made on an individual specimen. The values of $\log_{10}(I_0/I)$ for the x-rayed samples varied in the range 0.400 to 0.850.

TABLE I. Half-width in additively colored KBr at 78°K.

Specimen No.	$\log_{10}(I_0/I)$	Half-width in ev
1	1.516	0.208_8
2	0.670	0.209_4
3	0.737	0.208_7
4	1.172	0.208_2
5	1.550	0.208_2
	Mean	0.208_6
	Probable error	0.000_3

TABLE II. Summary of half-widths at 78°K.

Sample No.	Half-width in ev	Probable error	Number of measurements
1. KBr additively colored	0.208_6	0.000_3	5
2. KBr (Harshaw) x-rayed at 300°K	0.201_8	0.000_4	6
3. KBr (Harshaw) x-rayed at 300°K	0.196_7	0.000_9	3
4. KBr (Harshaw) x-rayed at 78°K	0.200_0	0.000_5	4
5. KBr (Schulman) x-rayed at 300°K	0.201_1	0.000_7	3

Table II indicates that *W* can be measured to 0.001 ev. The dependence of *W* on the mode of formation of the *F* centers is not certain. Although the values of *W* for the x-ray colored crystals are appreciably lower than for the additively colored, only a single sample of the latter was available for measurement. The variation in *W* for crystals colored by x-radiation is greater than the probable error of the measurement. No correlation is observed between *W* and concentration of *F* centers, or between *W* and susceptibility to optical bleaching.

† This research was supported by the Bureau of Ordnance, U. S. Navy.
* Now at Zenith Radio Corporation, Research Division, 6001 W. Dickens Avenue, Chicago, Illinois.
[1] Markham, Platt, and Mador (to be published).
[2] W. H. Duerig and J. J. Markham, Phys. Rev. **88**, 1043 (1953).
[3] E. Mollwo, Z. Physik **85**, 56 (1933).
[4] This crystal was additively colored by A. B. Scott of Oregon State College.
[5] This crystal was prepared by J. H. Schulman of the Naval Research Laboratory.

Relation between the de Haas-van Alphen Effect and the Magnetoresistance in Bismuth

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(Received June 12, 1953)

FROM magnetoresistance and magnetic susceptibility data on bismuth monocrystals at low temperatures de Haas and van Alphen[1] concluded that "a connection exists between this resistance and magnetization perpendicular to it," but the nature of this "connection" was not ascertained. Recently, Alers and Webber[2] compared their new low-temperature magnetoresistance data on bismuth with Shoenberg's[3] magnetic susceptibility data and noted certain correlating features. In order to clarify and extend this correlation, low-temperature magnetic susceptibility measurements were undertaken in fields up to 25 kilogauss using the same bismuth single crystal (*7b*) used by Alers and Webber in their magnetoresistance measurements. Only the section between the potential leads (obtained by cleaving in liquid nitrogen) was used, however.

Inasmuch as this investigation utilized the torision balance method,[3] the exact geometry employed in the magnetoresistance measurements (*viz.*, *H* perpendicular to the trigonal or 3-axis and one binary or 1-axis) could only be approximated.[4] However, in the case of bismuth, with small angles ϕ between the bisectrix or 2-axis and *H* and for the 1-axis perpendicular to *H*, the susceptibility difference $\chi_3-\chi_2$ yielded by the torsion balance method may be treated in the same manner as $-\chi_2$ in comparing susceptibility and magnetoresistance data. For example, if $\phi=\pm5°$ the oscillation periods (or positions of maxima and minima) in $\chi_3-\chi_2$ differ by less than 3 percent from those in $-\chi_2$ for $\phi=0$.

According to the electronic scheme proposed by Shoenberg[3] for bismuth the pertinent constant energy surfaces in momentum space consist of three long thin ellipsoids (two of which are obtainable from the other by rotations about the 3-axis of 120° and 240°) such that the susceptibility will in general contain three oscillating terms whose amplitudes and periods depend upon the orientation of the crystal with respect to the field. For small ϕ and for *H* perpendicular to the 1-axis, two of these terms are

approximately equivalent such that a term having a period P and two terms having a period $\approx P\cos 60°$ in H^{-1} exist in the susceptibility. However, if, as was actually the case in this study, H differs from perpendicularity to the 1-axis by a small angle δ as a result of inexact orienting techniques, then the observed periods will be given approximately by $P\cos\delta$ and $P\cos(60°\pm\delta)$.

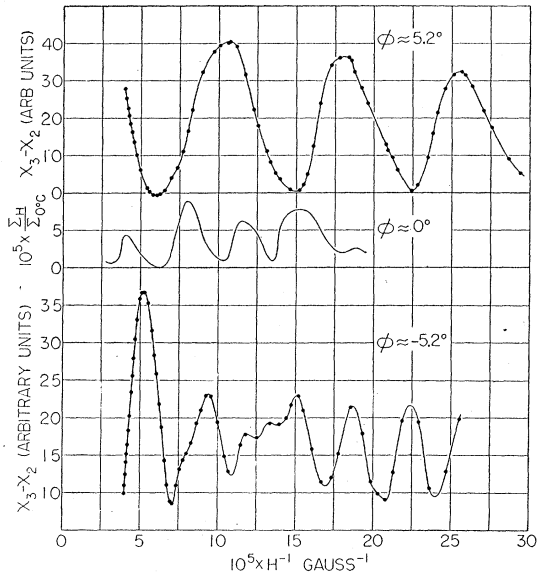

FIG. 1. The oscillating portion of the conductivity (as observed by Alers and Webber for $\phi=0$) and $\chi_3-\chi_2$ plotted as functions of H^{-1} for $T=4.2°$K.

In Fig. 1 the susceptibility data (which show essential agreement with Shoenberg's[3] lower field measurements) obtained at 4.2°K are plotted along with the data for the oscillating portion of the conductivity as observed by Alers and Webber also at 4.2°K. In the susceptibility curves the long period term ($P\cos\delta$)

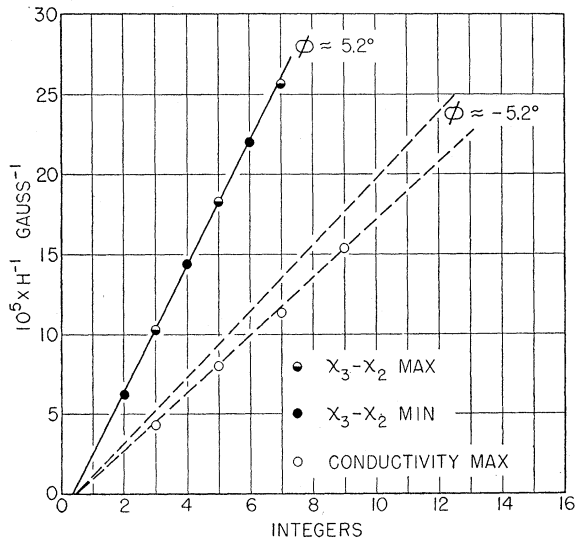

FIG. 2. Values of H^{-1} for which susceptibility and conductivity maxima and minima occur plotted against odd and even integers, respectively. The dashed lines represent the short period susceptibility oscillations.

is most important for $\phi\approx 5.2°$, while two shorter period terms ($P\cos[60°\pm\delta]$) predominate for $\phi\approx -5.2°$. A more illuminating means of comparison is provided in Fig. 2. The solid line is obtained by plotting values of H^{-1} for which maxima and minima in $\chi_3-\chi_2$ occur in the long period term for $\phi\approx 5.2°$ against odd and even integers, respectively, and the dashed lines are obtained for the two short period terms derived from an analysis of the susceptibility curve for $\phi\approx -5.2°$. (This analysis also yielded a value of $\delta\approx 2.5°$ illustrating the sensitivity of the short period oscillations to slight errors in orientation.) The open circles represent values of H^{-1} for which Alers and Webber (see Table II of reference 2) observed maxima in the oscillating portion of the conductivity. The proximity of these points to the dashed lines despite slightly different geometries supports the belief that the magnetoresistance oscillations have the same period as the short period susceptibility oscillations, and that both phenomena arise from a common electronic structure. Exact correlation would require that the open circles fall midway between the dashed lines. Then for H along the 2-axis a maximum in diamagnetism would correspond to a maximum in conductivity in the 3-direction. In the case of the long period term the conductivity data do not justify critical comparison, and it appears that effort toward a more rigorous correlation might profitably be devoted to an investigation of graphite in which the relevant de Haas-van Alphen electronic structure is less complicated.

I wish to express my thanks to Mr. P. B. Alers and Dr. R. T. Webber for the bismuth crystal and much helpful discussion.

[1] W. H. de Haas and P. M. van Alphen, Proc. Acad. Sci. Amsterdam **33**, 1106 (1930); Commens. Kamerlingh Onnes Lab. Univ. Leiden **212a** (1930).
[2] P. B. Alers and R. T. Webber, Phys. Rev. **91**, 1060 (1953).
[3] D. Shoenberg, Proc. Roy. Soc. (London) **A170**, 341 (1939).
[4] The notation is that of Shoenberg in reference 3. The 1, 2, and 3 axes are orthogonal.

Lyman-Alpha Radiation in the Solar Spectrum

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(Received June 29, 1953)

THE intensity of the Lyman-alpha line of hydrogen (λ1216A) in the solar spectrum was measured by means of photon counters flown in three Aerobee rockets at the White Sands Proving Grounds, New Mexico, during May 1952. Each flight provided a continuous telemetered record of the intensity *versus* altitude up to about 128 kilometers. A preliminary study[1] of the data showed that HL_α was first detected[2] at approximately the same altitude in each flight, 74±2 km (18°–20° sun elevation). From the variation of intensity with residual air path, an absorption coefficient was computed, 0.046 cm^{-1} (base e, NTP) which compares well with 0.063 cm^{-1} obtained in laboratory measurements of the attentuation of HL_α in dry air at low pressures.[3,4] The discrepancy between these two absorption coefficients is equivalent to an altitude error of 2.2 kilometers or a 27 percent difference in pressure. Pressure data were taken from the Rocket Panel report[5] and are estimated to have a probable error of ±15 percent in the neighborhood of 80 kilometers.

The photon counters used in these flights were sensitive to a narrow band of wavelengths from 1180A to 1300A. Although the spectral sensitivity curve between these limits had a jagged appearance due to the absorption lines of chlorine gas, which was one of the gas components in the photon counter, the sensitivity over a range of several angstroms in the immediate neighborhood of HL_α was fairly constant. The conversion from counting rate to flux of incident energy was obtained by comparison with the response of photomultiplier tubes coated with sodium salycilate or vacuum pump oil,[6,7] which were in turn compared with a calibrated mercury lamp at λ2536A. By a stroke of good fortune, the photon counter tube used in the most satisfactory flight was recovered undamaged. It was subjected to careful recalibration during the past year and no significant drift in characteristics from its preflight calibration was detected. The measured solar intensity based on this tube was 0.10±0.02 erg cm^{-2} sec^{-1} at the top of the atmosphere. No unusual solar activity was observed