

FIG. 2. Attenuation along [001] of 75-Mc/sec longitudinal wave vs the direction of H about the [001] axis, where $H=6500$ gauss. The direction (a) corresponds to [100] and (b) to [110]; these are the directions in which the curves shown in Fig. 1 were taken. The attenuation scale is relative to that at $H=0$.

to the magnet. The interpretation one should place on this polar pattern is not clear. Rodriguez's theory predicts in this situation that the high-field attenuation should become proportional to $\omega^2\tau$ (where ω is the angular frequency of the wave and τ is the electron relaxation time). Thus the pattern shown in Fig. 2 may reflect anisotropy of τ as well as of the Fermi surface.

Preliminary measurements also have been made of the attenuation of a plane polarized shear wave with H along the direction of propagation. As pointed out by Kjeldaas, this configuration is interesting because certain groups of electrons, selected by the value of the magnetic field, remain in resonance with the periodic fields.⁵ The results at the lower frequencies agree qualitatively with Kjeldaas' predictions except that the experimental attenuation initially increases with H . The attenuation at high frequencies does not diminish with increasing H as rapidly as the theory predicts. However, this may be due to a magnetically induced rotation of the plane of polarization, an

effect predicted by Kjeldaas. These results, as well as measurements in other crystallographic directions, will be discussed at more length in a subsequent paper.

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[†]Edgar Lewis Marston Fellow.

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SOME EFFECTS OF STRAIN IN THIN SPECIMENS ON ABSORPTION MEASUREMENTS AT LOW TEMPERATURE

G. G. Macfarlane, T. P. McLean,
J. E. Quarrington, and V. Roberts
Royal Radar Establishment,
Great Malvern, England
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Direct transition excitons^{1,2} and the magneto-optical effect^{2,3} have recently been investigated in Ge by making transmission measurements on polished plates 10 microns and less in thickness, over the range from room temperature to 1.5°K under high spectral resolving power. We have already drawn attention¹ to discrepancies between our measurements and those of the Lincoln group,³ which are much greater than the quoted limits of error. What we believe to be the explanation of these differences is now presented. It is emphasized that in order to get results which are accurately characteristic of the specimen, it must be mounted in a strain-free manner.

The discrepancies are twofold:

(a) At low temperatures the absorption line due to excitation of electrons into the ground state of the direct transition exciton is consistently observed by the Lincoln group at a higher energy than by us.

(b) The direct transition energy gaps E_0 deduced from the observations, which are in excellent agreement at room temperature,⁴ diverge

progressively on cooling, the Lincoln values being the higher.

Since (b) involves differences of interpretation, we focus attention on (a) which is entirely a matter of observation.

With the willing cooperation of the Lincoln group we have been able to make measurements on one of their specimens. For convenience this was done at 77°K, and confirmed the position of the exciton line in the Lincoln group's specimen to be in good agreement with their own measurements² (within ~0.001 ev). We therefore discount errors on either part in spectrometer calibration and difference in specimen temperature, and turn attention to the specimens themselves. The difference between them may be intrinsic or due to their experimental environment, but as we have noticed no significant variation between specimens taken from different crystals, the latter is the more likely.

A probable explanation was in terms of strains in the specimens, which would distort the band structure and show up as a shift or broadening of the absorption edge. Since the Lincoln specimens were glued to a glass backing they would certainly be under considerable strain on cooling, owing to differential contraction, although probably comparatively free from strain at room temperature, whereas ours being unbacked and freely suspended are strain-free at all temperatures. This would account for the progressive disparity between the observations on cooling. Furthermore our measurements and the Lincoln group's are in fairly good agreement in the indirect transition region.^{2,5} Here the absorption coefficient is about 100 cm⁻¹ or less and thick specimens are used, which would be much more difficult to strain, even if backed.

These ideas were tested as follows:

(i) The Lincoln technique was duplicated as far as possible, i.e., a specimen (RRE1) glued to glass with Araldite⁶ was prepared and measured at 77°K. In this, the exciton line appeared at a higher energy in rough agreement with the Lincoln value. Perfect agreement would not be expected as the strain taken up by the specimen depends on a number of details such as the expansion coefficient of the glass, the adhesive and its thickness, etc. It may be noted that using crystal quartz instead of glass produced a considerably larger shift to higher energy.

(ii) The position of the exciton line was observed in a freely mounted specimen (RRE2) which was then glued to a glass substrate and

remeasured. The line was shifted to higher energy as expected. These results are plotted in Fig. 1. In addition to the shift it is seen that backing the specimen also distorts the form of the transmission curve. In particular an extra band (marked *a* in Fig. 1) appears. This band was noted by the Lincoln group³ but its presence was unexplained. Our measurements indicate that it is produced by strain in the specimens and shifts along the energy scale with temperature in the same way as the absorption edge. It may well be linked with distortion of the band structure.

We have already shown¹ that the absorption coefficient of a freely mounted specimen follows Elliott's⁷ theoretical predictions at energies above E_0 . This is not so for the backed specimens.

(iii) Since the direction of shift was consistent with compressional strain,⁸ a system was sought which would impose a tension on the specimen when cooled, and should therefore produce a shift in the opposite direction. Assuming the backing to be the important factor, then this should be achieved by mounting a sample on fused silica.⁹ This was tried and a shift of about 0.005 ev occurred on cooling, in the direction of lower energy as expected. It is interesting that Rose-Innes⁹ used a very similar system deliberately to strain samples of Ge and Si. He estimated that the stresses involved correspond to about 10⁹ dyne cm⁻². Taking Paul and Warschauer's estimate⁸ of the pressure coefficient of E_0 for Ge to be 1.2×10^{-11} ev/dyne cm⁻² we might expect a shift of around 1.2×10^{-2} ev for this specimen configuration if all the strain is taken

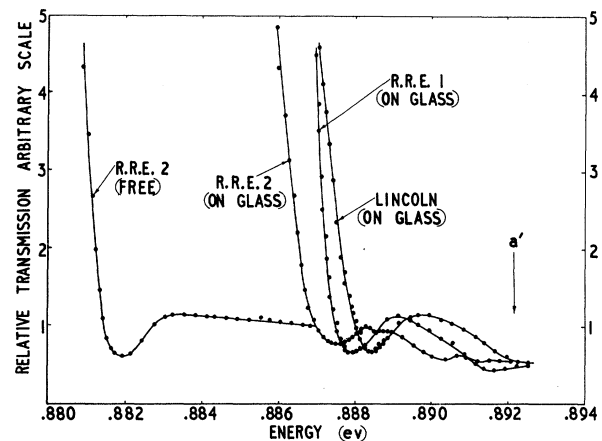


FIG. 1. Transmission ratio of various Ge specimen configurations at 77°K.

up by the specimen. This is about twice that actually observed.

The results clearly show that thin specimens must be mounted in a strain-free fashion for this type of measurement if data characteristic of the unstrained material are desired. It follows that cooling the specimen by conduction through a solid backing is unsatisfactory since it is practically impossible to arrange for the relative expansion to be zero. Recourse must be had to direct immersion in the cooling liquid, which brings its own difficulties,¹⁰ or immersion in thermal exchange gas.^{11,12} The latter method is used in this laboratory. These considerations will apply, of course, to other materials than Ge.

Strain in the specimens will also affect magneto-absorption measurements. Clearly, a uniform strain will shift the band edges and the adjacent Landau levels to roughly the same extent. The magneto-absorption bands will thus experience an appreciable shift (of the same order as that of the exciton absorption), but it is unlikely that changes in their relative positions will be detectable by the spectroscopic means currently in use. The practical situation with a backed specimen is almost certainly one of non-uniform strain and will be more complicated.

Finally it is emphasized that the condition of the specimens should be kept very much in mind when correlating data obtained from different experiments.

We are indebted to the Lincoln group for lending us two of their specimens and for communicating their results to us before publication. Our thin specimens were skillfully prepared by S. C. J. Brooke. This Letter is published by permission of H. B. M. Stationery Office.

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⁴In reference 1 we state that our value for E_0 at 291°K should be regarded as less reliable than those at the lower temperatures. This is so, but should not be taken to imply that it is unreliable in the present context. The discrepancies which we are now discussing (~ 0.006 eV) are more than ten times as great as the error in E_0 .

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MAGNETIC FORM FACTOR OF COBALT*

R. Nathans

The Pennsylvania State University,
University Park, Pennsylvania, and
Brookhaven National Laboratory,
Upton, New York
and

A. Paoletti

Comitato Nazionale Ricerche Nucleari,
Rome, Italy, and
Brookhaven National Laboratory,
Upton, New York

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We wish to report preliminary results on the magnetic form factor of the face-centered cubic phase of metallic cobalt, which indicate a deviation from spherical symmetry for its $3d$ electrons. These measurements represent a continuation of studies on the angular dependence of the magnetic scattering in the transition elements using a polarized neutron beam spectrometer¹; the results on iron and nickel have been already reported in reference 1. These studies were undertaken because of the current interest in the $3d$ electron configurations in the transition elements and the pertinence of magnetic form factor data to such discussions.

The sensitivity of the polarized beam technique in establishing the absolute magnitude of the magnetic scattering depends on the ratio of the nuclear scattering amplitude to the magnetic scattering amplitude at the different scattering angles. For cobalt, this ratio is very favorable and it is possible to obtain sizable differences in the reflectivities for beams of different polarization even for large scattering angles, where the magnetic scattering is greatly reduced. For this reason every effort was made to reduce the in-