quite differently. As examples of this complexity, the increases in energy content of diamond and silicon carbide were found to begin to anneal at 150°C and were progressive (though not uniform) over some hundreds of degrees while the changes in lattice constant (and density) seemed to anneal less readily, requiring somewhat higher temperatures. On annealing irradiated quartz, two of the properties, the density and refractive index, were found to exhibit further decreases below temperatures of about 600°C, and it was not until higher temperatures were reached that a change in the direction of the properties of unirradiated quartz began to take place. Annealing of the major properties in quartz was sluggish below the quartz-Tridymite transition, and it is therefore presumed that restoration of the original state of the substance by annealing may not be possible after extensive irradiation. All of the observed effects are similar to those described for the metamict minerals.[4] Magnesium oxide, spinel, and sapphire have been irradiated and show effects which are an order of magnitude smaller than for the above substances, as might be expected from conclusions reached in studies of metamict minerals.[5] The damaging which is here described may therefore be termed, in the older nomenclature, an artificial metamictization.

Radiation damage in quartz has been reported by Berman[6] who measured its thermal conductivity. Wittels' recent announcement of the marked alteration in its x-ray diffraction pattern[7] has made it desirable to make our results on this subject more widely known even though the work is still in progress. Wittels' work and ours seem to be in substantial agreement although we have found that small changes in the x-ray diffraction patterns are easily observed between 500 and 600°C, somewhat lower than reported by him, and small changes in the density occur by 450°C, the region in which Berman observed substantial annealing of the thermal conductivity changes.

The results announced here were obtained by a number of people. The irradiations were prepared by L. H. Fuchs and W. Primak, who with P. Day measured some of the properties. W. H. Zachariasen and later S. Siegel and J. Taylor made the x-ray diffraction studies. The energy contents were determined by E. J. Prosen, W. H. Johnson, W. A. Fraser, and L. B. Eddy at the National Bureau of Standards. The results will be reported in detail in several papers.

[1] An oral paper on this subject was delivered by W. Primak at a Ceramic Conference, Battelle Memorial Institute, October 28, 1952 (unpublished).
[2] F. Seitz, Discussions Faraday Soc. 5, 280 (1949).
[3] It has been brought to our attention that M. H. Wittels has recently also observed such a change in heat capacity.
[4] A. Pabst, Am. Mineralogist 37, 137 (1952).
[5] P. Pellas, Compt. rend. 233, 369 (1951).
[6] R. Berman, Proc. Roy. Soc. (London) A208, 90 (1951).
[7] M. H. Wittels, Phys. Rev. 89, 656 (1953).

The Magnetic Susceptibility of Germanium*

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IN preparation for a study of the effect of fast neutron bombardment on the magnetic properties of Ge, the specific magnetic susceptibility χ of both p- and n-type Ge with various impurity concentrations has been measured as a function of temperature in the range from 65°K to 300°K. The Faraday method was used throughout and the specimens were single crystals cut in the form of cubes 0.5 cm on edge.[1] The susceptibility balance was a refinement of the type used by Hutchison and Reekie[2] as modified by McGuire and Lane,[3] special features of which will be described elsewhere. The balance is sufficiently sensitive to detect differential weight changes of 0.2 μg. An Arthur D. Little Bitter-type electromagnet furnished the inhomogeneous magnetic field, (HdH/dz $\sim 10^8$ gauss^2 cm^{-1}). The field was controlled to better than 0.05 percent by means of the Hall voltage developed across a germanium crystal.[4] The value of HdH/dz was determined for each specimen by the magnetic buoyancy effect of oxygen, whose volume susceptibility κ at 760 mm Hg and 20°C is $1.434 \pm 0.004 \times 10^{-7}$ cgs unit.[5] The absolute precision of the calibration is ± 0.6 percent. The relative precision of χ *vs* T data on any one sample, however is better than ± 0.1 percent. Measurements of χ as a function of field strength indicated the absence of ferromagnetic impurity.

Curves of the diamagnetic susceptibility *vs* temperature for representative specimens are shown in Fig. 1. Curves 1, 2, and 5

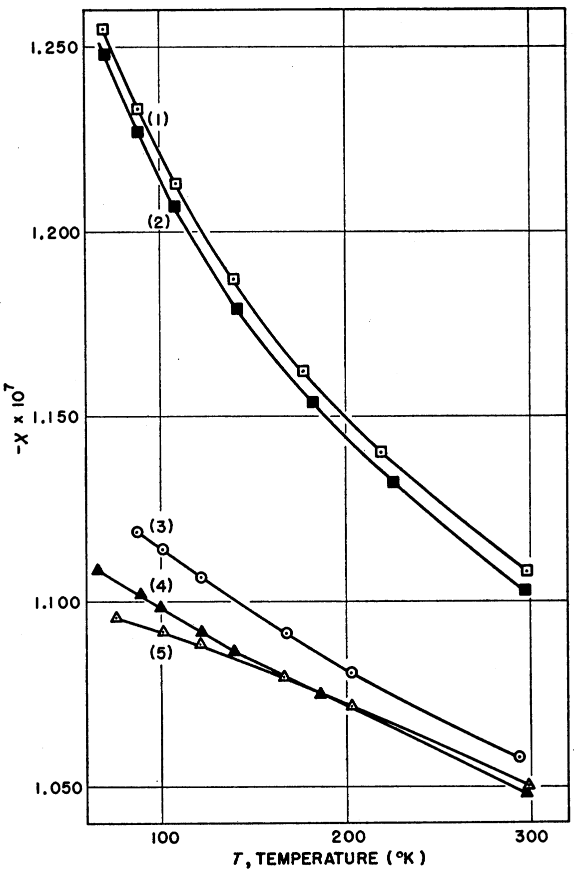

FIG. 1. Diamagnetic susceptibility *vs* temperature curves for single crystal cubes of germanium. Curves 1 and 2 are for low-resistivity n-type material, while 3 and 4 are for low-resistivity p-type material. Curve 5 is for high-resistivity n-type germanium.

are those of n-type samples whose room temperature electron concentrations were 7×10^{17}, 1×10^{18} and 1.3×10^{14} cm^{-3}-respectively, while curves 3 and 4 were obtained for p-type Ge in which the hole concentrations were 5.4×10^{17} and 2.1×10^{17} cm^{-3}-respectively. The carrier concentrations were inferred from Hall coefficient measurements made on plates cut adjacent to one of the cube faces.[6]

In their treatment of the magnetic behavior of gray tin, Busch and Mooser[7] divide the magnetic susceptibility into three parts: (1) the diamagnetic contribution χ_a due to the tin atoms alone which they assume to be temperature-independent, (2) the paramagnetic contribution χ_I due to those impurity atoms or ions which possess an unpaired electron, and (3) the free carrier contribution χ_c which has both a paramagnetic spin component and a diamagnetic Landau orbital component, the latter being greater the smaller the effective mass of the carrier. In the case of Ge it appears from Fig. 1 that in contrast to the assumptions concerning α−Sn the term χ_a is temperature-dependent, the slope of all of the χ *vs* T curves being $\sim 2.5\times 10^{-11}$ cgs units/deg in the high-temperature range. The curve of the high-resistivity material (curve 5) shows concave downward curvature which is characteristic of both *n*- and *p*-type high-resistivity germanium. The curves for low-resistivity material are markedly concave upward, this being more pronounced for the *n*-type specimens. This difference in curvature is presumably due to the sum of the impurity and carrier contributions (χ_I and χ_c) which would be negligible in the case of curve 5. Thus, it appears that the Landau orbital dimagnetism of the free carriers exceeds the paramagnetism of the free carriers and impurities with unpaired electrons in both electron and hold conductors. From considerations similar to those of Busch and Mooser for the case of $\alpha-$Sn it can be shown that for germanium the ratio of the free electronic mass to the carrier effective mass is ~ 4 for holes and ~ 6 for electrons.

A more detailed report of this work based on more extensive data will be submitted for publication in the near future.

One of the authors (D. K. Stevens) is indebted to Professor H. D. Crockford for his aid in the capacity as advisor from the University of North Carolina.

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[1] The authors are indebted to Miss Louise Roth of Purdue University for preparing samples.

[2] T. S. Hutchison and J. Reekie, J. Sci. Instr. **23**, 209 (1946).

[3] T. R. McGuire and C. T. Lane, Rev. Sci. Instr. **20**, 489 (1949).

[4] Thanks are due to J. C. Pigg of this laboratory for the design of the field control equipment, details of which are being submitted for publication.

[5] P. W. Selwood, *Magnetochemistry* (Interscience Publishers, Inc., New York, 1943), p. 29.

[6] We are indebted to J. W. Cleland of this laboratory for the Hall coefficient measurements.

[7] G. Busch and E. Mooser, Z. Physik. Chem. **198**, 23 (1951).

The Contribution of Solar x-Rays to *E*-Layer Ionization

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Attempts to attribute *E*-layer ionization to absorption of solar ultraviolet radiation lead to serious difficulties. The most recent rocket measurements[1] of the intensity of the solar continuum in the neighborhood of 1200A indicated an upper limit of about 0.01 ergs cm^{-2} sec^{-1} per 100A corresponding to a black body temperature of 4500°K. The extrapolated intensity at 1000A would be less than 0.0004 ergs cm^{-2} sec^{-1} per 100A, and the intensity of radiation capable of ionizing the atmospheric constituents ($800<\lambda<1000$A) would be entirely inadequate to account for *E*-layer ionization. On the other hand, it has been known for some time that the soft x-ray spectrum between 10A and 100A furnishes a source of ionizing radiation with absorption coefficients appropriate for layer formation between 100 km and 120 km. The x-ray possibility was first indicated by Hulburt[2] and by Vegard[3] in 1938. Since Edlén,[4] in 1940, identified the lines of the visible coronal spectrum with highly ionized atoms such as Fe xv and Ca xiii, it has been recognized that the solar corona may be a source of x-rays of sufficient intensity to make an important contribution to *E*-layer ionization. More recently, Hoyle and Bates[5] treated the x-ray absorption process in detail and concluded that conditions for *E*-layer formation were satisfied by an x-ray spectrum with a maximum either near 38A or near 9.5A.

Rocket experiments performed since 1948 have provided positive evidence for soft x-rays in the ionosphere. Detection was accomplished with photographic films,[6] thermoluminescent materials,[7] and photon counters.[8] In the latter type of experiment, intensity data were telemetered to a ground station continuously throughout the flight. The first photon-counter experiment[8] was performed in V-2 No. 49, September 1949, using counters with beryllium windows capable of transmitting an appreciable percentage of the x-ray flux up to a wavelength of about 10A. X-rays were detected only above 87 kilometers, from which it was concluded that the spectrum had a short-wavelength limit at about 7A. Between this limit and the spectral cutoff of the photon counters at 10A, the x-ray flux incident on the earth's atmosphere amounted to between 10^{-4} and 10^{-3} ergs cm^{-2} sec^{-1}.

In May 1952, counters flown in two Aerobee rockets again gave indication of x-rays above 90 km. These tubes also used beryllium windows, but the apertures were larger than those of V-2 No. 49 and the sensitivity at 7A was about ten times greater. The results emphasized again the fact that the x-ray spectrum of a quiet sun had a well defined short-wavelength limit at about 7A. No information however was obtained regarding the x-ray flux beyond 10A.

An experiment to determine the x-ray intensity out to 100A was attempted in a Viking rocket (No. IX) in December, 1952. A number of tubes were prepared with windows of graded x-ray spectral transmission characteristics, utilizing thin films of beryllium, aluminum, soft glass, and nitrocellulose. Tube dimensions and gas fillings were selected in combination with the above window materials to produce bands of spectral response peaking in different parts of the spectrum. Although the rocket attained an altitude of 218 km, it developed an excessively high roll rate and faulty telemetering, which left only a small portion of the experimental data suitable for interpretation. Sufficient information was obtained from three tubes, however, to indicate a large flux of x-rays above 10A within the *E*-region. A photon counter with an aluminum window, 0.00025 inch thick, sensitive to radiation between 8 and 20A, measured a flux of about 0.6 erg cm^{-2} sec^{-1}. The variation with altitude is shown in Fig. 1. Two tubes with nitrocellulose windows, sensitive to wavelengths as long as 60A, detected about 1.0 erg cm^{-2} sec^{-1} at the top of the atmosphere.

Although none of the attempts to measure the full x-ray spec-

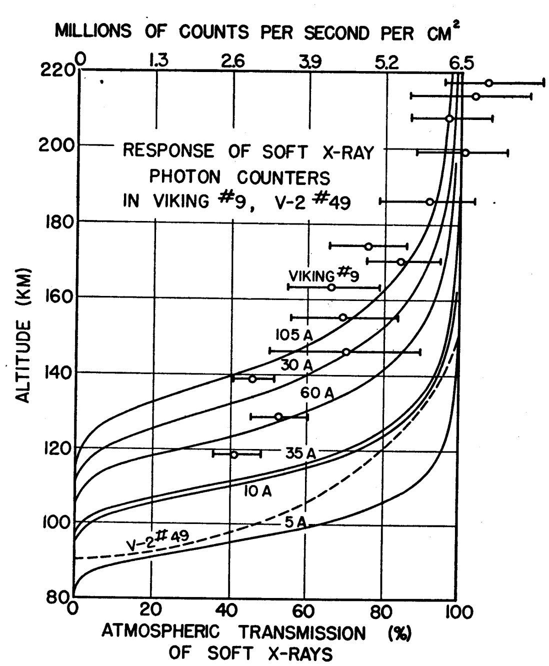

Fig. 1. Variation with altitude of the atmospheric transmission of soft x-rays. The solid lines are computed from absorption coefficients published by A. H. Compton and S. K. Allison [*X-Rays in Theory and Experiment* (MacMillan and Company, New York, 1935)]. The dashed curve is the averaged experimental data of two beryllium window photon counters in V-2, 49. Each open circle is the average of approximately 15 exposures of an aluminum window photon counter flown i Viking IX. The length of the bar through the circle represents the rms deviation of the data. The rocket was stable to 118 km with the photon counter looking away from the sun. Above 118 km the rocket rolled very rapidly and the tube received about 200 exposures to the sun.