

undisturbed during a trial. The post had been previously drilled out from the rear to within 0.040 in. of the radiator, and the sources were placed in position, alternately, from outside the vacuum chamber. Source strengths used were 3 mc RdTh, 7 mc Co⁶⁰, 5 to 10 mc Na²⁴, and 5 mc Ra. Peak determinations again were employed in taking the momentum ratios.

The secondary electron spectrum of RaC from 2.1 to 2.7 Mev is shown in Fig. 3. The second gamma-ray has an energy of 2.452 ± 0.012 Mev, and an intensity 35 to 40 percent of that of the 2.208-Mev gamma-ray. There is also some slight but inconclusive evidence of a weak gamma-ray of energy about 2.6 Mev.

Errors assigned include estimates of uncertainty in current measurement, relative peak shift, stray field correction, and location of the line peaks. The statistical accuracy and number of the experimental points form the basis for the weights assigned in column 4 of the Tables I and II.

It is a pleasure to acknowledge the aid and advice of Dr. L. G. Elliott, and the assistance rendered by Mr. D. W. Smellie.

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Infra-Red Absorption of Silicon*

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IN a previous communication¹ the measurements on infra-red transmission through bulk silicon were reported. It was pointed out that for frequencies lower than that required for excitations across the forbidden energy gap the magnitude of absorption does not agree with the classical Drude theory for free charge carriers.

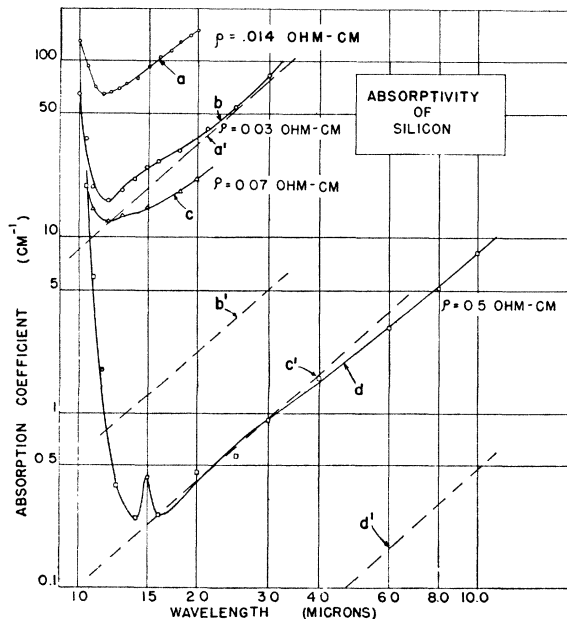


FIG. 1. Absorption coefficient as function of wave-length. The solid curves a, b, c, and d are determined experimentally. The corresponding dashed curves a', b', c', and d', are calculated from Eq. (2).

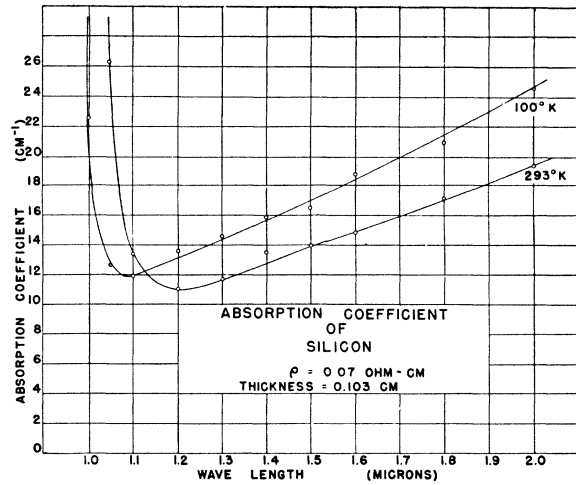


FIG. 2. Typical temperature dependence of absorption coefficient for samples with sloping Hall curves in the impurity range.

Results of further measurements on bulk samples of different resistivities are shown in Fig. 1. The dotted lines are calculated according to the Drude theory

$$\sigma = nk\nu = \frac{e^2}{2\pi m} [n_c \gamma / (\nu^2 + \gamma^2)]. \quad (1)$$

In our measurements $\nu \gg \gamma$. In terms of the d.c. conductivity σ_0 and Hall constant R we have

$$\sigma = \frac{e^2}{4\pi^2 m^2} (3\pi/8R^2 \sigma_0 \nu^2). \quad (2)$$

The absorption coefficient is

$$\mu = 4\pi k / \lambda = 4\pi \sigma / nc. \quad (3)$$

The calculated values are seen to be too low in all cases. As pointed out previously, the discrepancy is even larger for germanium. Quantum mechanically the absorption due to free carriers can be regarded as a broadening of the zero-frequency absorption line due to the scattering of electrons by the lattice. Such treatment gives an expression² identical to (1). However, for $\nu \gg \gamma$ the absorption should be regarded more appropriately as a two-stage process, the absorption of a photon leading to an intermediate state which goes over to a final state by interaction with the lattice.³ In this case γ' determining the absorption will not be the same γ for d.c. conduction. This could be the reason for the discrepancy.

For a given frequency, μ of the different samples plotted against $n_c \gamma$ cannot be fitted well by a straight line. The plot of μ versus n_c seems to give a better fit to a straight line. Measurements on more samples of different varieties are being made to obtain a more reliable conclusion. If μ is really proportional to n_c , a possible explanation is an overlapping of energy bands. Mullaney⁴ has shown that silicon has two bands of zero width at the top of the group of filled bands below the conduction band. Absorptions producing transitions of holes at the top to the interior of the filled bands should therefore extend to very low frequencies. Such absorption without the aid of lattice interaction will be just proportional to the number of holes. Measurements on an *N*-type sample showed that the absorption is comparable with that expected of *P*-type samples of the same n_c . Although Mullaney's treatment does not give narrow bands at the bottom of the conduction bands the treatment is admittedly unsatisfactory for those bands.

Measurements at low temperatures revealed absorptions due to the ionization of the impurity centers. Figure 2 shows a typical case where the absorption at 100°K is higher than at room temperature. The impurity activation energy is 0.058 eV and the impurity concentration N is 1.1×10^{18} as calculated from the Hall

curve. At 100°K the hole concentration n_c is only one-tenth of the room temperature value; however, the absorption is increased. The absorption at the lower temperature must be, therefore, predominantly due to the ionization of the impurities, most of which are normally un-ionized at this temperature. On the other hand, the concentration of un-ionized impurities ($N-n_c$) available for absorption at room temperature is one-fourth of that at 100°K but the absorption is reduced only by about 20 percent. Evidently the absorption at room temperature is largely due to the free holes. Samples with flat Hall curves, indicating no change in n_c and ($N-n_c$), show a steady decrease in absorption with decreasing temperature,¹ which confirms the above explanation. Absorptions due to impurity centers introduced by nucleon bombardment have been reported⁵ earlier and will be discussed in a future communication.

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³ We are indebted to Professor H. Fröhlich for discussions on this point.

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Masses of Cr⁵⁰, Cr⁵², and Fe⁵⁴ *

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A DOUBLE-FOCUSING mass spectrograph¹ has been used to photograph the doublets at mass number 25, 26, and 27 formed by doubly charged Cr⁵⁰, Cr⁵², Fe⁵⁴ and singly charged C₂H, C₂H₂, and C₂H₃. Typical C₂H₂-Cr⁵² and C₂H₃-Fe⁵⁴ doublets are shown in Fig. 1. The metallic ions were obtained from a high frequency spark between stainless steel electrodes. The method by which the hydrocarbon ions were obtained is described below.

Source of hydrocarbon lines.—The hydrocarbon ions used in the present work were secured in a most fortuitous manner. Faint lines at mass numbers 24, 25, 26, 27, 28, and 29 were observed in the course of other work, and were attributed to C₂, C₂H, C₂H₂, C₂H₃ coming from the silicone in the diffusion pumps. These lines were intensified by removing the liquid air trap from the source vacuum system, and thereafter provided accurate and easily obtained standard masses. In addition to the group mentioned, two other series of suitable intensity have been observed, namely C, CH, CH₂, and C₃, C₃H, C₃H₂. These hydrocarbon molecules are ionized in the same high frequency spark which creates the metallic ions.

Mass of Cr⁵⁰.—The C₂H-Cr⁵⁰ doublet at mass number 25 was photographed with an exposure time of ten minutes. From nine photographs of this doublet, the difference in packing fraction² between C₂H and Cr⁵⁰ was found to be $\Delta f = 14.26 \pm 0.03$, with extreme values of 14.09 and 14.43. The Cr⁵⁰-Cr⁵² separation, assumed to be integral, served as the mass scale. Using Bainbridge's³ recommended values of $H^1 = 1.0081283 \pm 0.0000028$ and $C^{12} = 12.003856 \pm 0.000019$, the packing fraction of C₂H is $f = 6.336 \pm 0.016$. This value, when combined with the above packing fraction difference, gives for Cr⁵⁰ $f = -7.92 \pm 0.04$. The only other measurement of the mass of Cr⁵⁰ has been made by Ogata,⁴ using six photographs of the C₂H₂-Cr⁵⁰ doublet, who found the packing fraction of Cr⁵⁰ to be $f = -7.11 \pm 0.08$. The present value of -7.92 ± 0.04 corresponds to a mass of Cr⁵⁰ = 49.96040 ± 0.00020.

Mass of Cr⁵².—The C₂H₂-Cr⁵² doublet at mass number 26 was photographed with an exposure time of five minutes. From 14 photographs of this doublet, the packing fraction difference was found to be $\Delta f = 17.41 \pm 0.025$ with extreme values of 17.22 and 17.62. The Cr⁵²-Cr⁵³ separation provided a suitable mass scale.

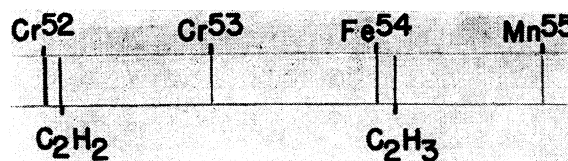


FIG. 1. Mass spectrum showing the doublets at mass numbers 26 and 27 formed by doubly charged Cr⁵², Fe⁵⁴ and singly charged C₂H₂, C₂H₃. Magnification 4 ×.

If the packing fraction of C₂H₂ is assumed to be $f = 9.218 \pm 0.017$,³ that of Cr⁵² is calculated to be $f = -8.19 \pm 0.04$. This is to be compared to Aston's value⁵ of -8.18 ± 0.15 and Ogata's⁴ value of -8.47 ± 0.08 . The mass of Cr⁵² is calculated from the present packing fraction value of -8.19 ± 0.04 to be 51.95741 ± 0.00021 .

Mass of Fe⁵⁴.—The exposure time for photographing the C₂H₃-Fe⁵⁴ doublet was also five minutes. Seventeen photographs of this doublet yielded a packing fraction difference $\Delta f = 19.91 \pm 0.04$, with extreme values of 19.52 and 20.17. The separation between Fe⁵⁴ and the overexposed Fe⁵⁶, assumed to be integral, served as the mass scale. With a packing fraction of C₂H₃ of 11.887 ± 0.018 ,³ that of Fe⁵⁴ is found to be -8.03 ± 0.05 . Dempster⁶ has measured this packing fraction to be -7.5 ± 0.8 while Ogata⁴ has obtained -7.83 ± 0.09 . The present value gives the mass of Fe⁵⁴ = 53.95664 ± 0.00027.

In these experiments care has been taken to minimize the effect on the doublet spacing (a) of retardation of the ions by residual gas in the mass spectrograph, as observed by Dempster and Shaw,⁷ and (b) of local inhomogeneities in the magnetic field. The first effect has been studied in this laboratory⁸ in connection with the Cu⁶⁵-Pt¹⁹⁵ doublet, and has been found in that case to be negligible at pressures less than 9×10^{-6} mm Hg. In the present experiments the pressure was kept less than 5×10^{-6} mm Hg. The second effect, due to local inhomogeneities in the magnetic field, or to local electric fields in the magnetic analyzer arising from charged dust particles on the magnet pole faces, was minimized by photographing the doublets in several different positions on the photographic plate. The errors given in this Letter are probable errors based on the internal consistency of the data.

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¹ H. E. Duckworth, *Rev. Sci. Instr.* **21**, 54 (1950).

² The term "packing fraction" is defined as $f = (A - I)/I$, where A is the mass of the atom in question, and I is the nearest integer. In this letter the factor $\times 10^{-4}$ is to be understood and is not written in expressing the numerical value of the packing fraction.

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On the Disintegration Scheme of I¹³¹

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SEVERAL different decay schemes have been proposed¹⁻³ for the important radioisotope I¹³¹. In particular, Metzger and Deutsch¹ and Kern *et al.*² have published substantially different experimental results for the energy of the soft beta-component. In view of the importance of this component in determining the decay scheme, it seems worth while to report our measurement of the I¹³¹ beta-spectrum.⁴