Table I. Summary of results.

Sample	Temperature of exposure °C	Initial number of carriers cm^{-3}	Initial mobility cm^2/volt sec.	Mobility at minimum cm^2/volt sec.	Number of acceptors per incident neutron cm^{-3}
1	~32	2.0×10^{15}	2920	2200	1.7
2	30	4.3×10^{14}	2010	2020	1.5
3	20	8.9×10^{14}	2600	2190	3.5
4	~32	2.8×10^{16}	2180	1440	2.6
5	~32	5.5×10^{16}	800	13,700	5.2
6	−79	——	10,000	——	4.3
7	−79	——	6070	——	3.1
8	−79	——	4530	——	3.2

is smaller than the mean value of K given above by a factor of 4. Consequently, since recombination of defects should be negligible initially, one might suspect both of these factors to be important in the general case.

The assumed thermal equilibrium between electrons and holes seems to hold reasonably well in every case but one, sample 5, which has an abnormally low initial mobility indicating an inhomogeneous distribution of impurity centers. An impurity gradient perpendicular to the direction of current would obscure the correct minimum conductivity. Also the presence of a $P-N$ barrier (the gradient parallel to current) would cause a conductivity minimum much higher than the expected value since Lark-Horovitz and co-workers[5] have shown that such a boundary is photo-sensitive to high energy radiations. In either case the calculated value of the mobility at the minimum conductivity would be spurious and high. Thus one is led to the conclusion that photoelectric effects caused by β- and γ-radiation are in general negligible in uniform samples.

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[1] Davis, Johnson, Lark-Horovitz, and Siegel, Phys. Rev. **74**, 1255 (1948); W. E. Johnson and K. Lark-Horovitz, Phys. Rev. **76**, 422 (1944). K. Lark-Horovitz and J. C. Pigg (private communication).

[2] Cleland, Lark-Horovitz, and Pigg, Phys. Rev. **78**, 814 (1950).

[3] V. A. Johnson (private communication).

[4] G. E. Evans (unpublished results).

[5] Orman, Fan, Goldsmith, and Lark-Horovitz, Phys. Rev. **78**, 646(A) (1950).

The Photon Yield of Electron-Hole Pairs in Germanium

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It is the purpose of this letter to report that photo-conductivity measurements, made on a single crystal of n-type germanium, indicate a yield of one electron-hole pair per photon absorbed, for wave-lengths less than the long wave limit.

A uniform electric field E is established in a long rectangular specimen of uniform cross section and conductivity, and a portion of one surface is irradiated with I photons per second of monochromatic light of known wave-length, the number being determined by a calibrated thermocouple. The number of photons I_A absorbed in the sample is calculated from the optical constants[1] by subtracting the reflection and transmission losses. Regions at the ends which are long in comparison with the respective mean ranges of positive holes are left unilluminated so that a negligible fraction of these reach the specimen terminals.

The specimen was cut from a single crystal[2] of n-type germanium having a uniform resistivity of about 5 ohm cm. Its approximate dimensions were 0.05 cm×0.05 cm×2.0 cm. When placed in the plane of the image of the exit slit of a monochromator all of the light could be made to fall on one face of the specimen over a length $l=1.5$ cm. The lifetime of holes, τ_p was 67×10^{-6} sec.[3] The field E with one volt across the terminals was such that the mean range of holes was approximately 0.5 mm. The light intensity was such that the field in the illuminated region was not reduced by more than one percent from the dark-current value for the largest photo-currents. Photo-currents were measured by a.c. techniques using pulsed light. The light pulser was synchronized with an auxiliary circuit such that the voltage across the terminals was maintained constant.

If the total number of electron-hole pairs produced per second is Y then the number of holes in the steady state is $Y\tau_p$. Thus the holes increase the conductance of the illuminated region of length l by an amount,[4]

$$\Delta G = Y\tau_p e(\mu_p+\mu_n)/l^2.$$

This segment is in series with the two ends of the filament and the contact resistances of the terminals, the total resistance being R_T. With the voltage V across the terminals, and if the resistance of the segment is R_l, then the change in current is $\Delta i = V\Delta G(R_l/R_T)^2 = V\Delta G(El/V)^2$ which leads to

$$Y = \Delta i V/e\tau_p E^2(\mu_p+\mu_n).$$

Values of Y were calculated using $\mu_p=1700$ and $\mu_n=3600$ cm^2/volt-sec.[5]

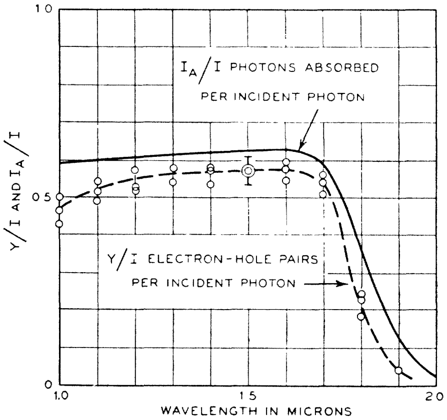

Fig. 1. The ratios I_A/I and Y/I *vs.* wave-length.

The experimental results are summarized in Fig. 1 in which we have plotted I_A/I and Y/I as functions of wave-length from 1.0μ to 2.0μ, the latter being just below the long wave limit of photosensitivity. Within the limits of experimental error, which we cannot claim to be better than 10 percent, and over the major portion of this range of wave-lengths, the two characteristics may be considered coincident.

Thus it appears that each photon absorbed produces one hole-electron pair. The apparent divergence near the long wave limit may reasonably be ascribed to the increase in experimental error with a photo-current which becomes vanishingly small in this region. On the other hand, the divergence for wave-lengths less than 1.2μ may be accounted for by recombination through the concentration of carriers generated in a region which is less than 10^{-4} cm in thickness.

In addition to those already mentioned thanks are due to W. Shockley for suggesting this experiment, to J. Bardeen and W. van Roosbroeck for valuable help in its theoretical aspects, and to H. R. Moore for furnishing the electronic measuring equipment.

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[1] Refractive indices and absorption coefficients of Ge by H. B. Briggs, unpublished.

[2] Furnished by G. K. Teal and J. B. Little described in Bull. Am. Phys. Soc. **25**, No. 2, 16 (1950).

[3] Measured by J. R. Haynes.

[4] See Shockley, Pearson and Haynes, Bell Sys. Tech. J. **28**, 344 (1949) for similar calculations.

[5] These are drift mobilities measured by J. R. Haynes.