the angle between the [001] direction and the magnetic field in the ($\bar{1}10$) plane. These curves are shown in Fig. 2 in comparison with experimental points obtained with several samples.

The half-widths of the resonance lines were of the order of 1000 oersteds. From this fact it was estimated that the mean collision time was about 2×10^{-11} sec. This is approximately $\frac{1}{3}$ the collision time found for pure Ge at 4°K.

The authors would like to express their appreciation for the samples of silicon kindly provided by General Electric Research Laboratories and Bell Telephone Laboratories. We would also like to thank Professor C. Kittel and Dr. H. J. Zeiger for several helpful discussions.

[*] The M.I.T. research reported in this document was supported jointly by the Department of the Army, the Department of the Navy, and the Department of the Air Force. The University of California research has been supported in part by the U. S. Office of Naval Research and the U. S. Signal Corps.

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Effective Masses of Holes in Silicon*

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(Received August 9, 1954)

CYCLOTRON resonance experiments have been carried out on *p*-type silicon at 23 kMc/sec and 4°K. Carriers were excited by infrared light as described for germanium.[1] The beam from the light source was chopped at 900 cps, with a resulting amplitude modulation of the absorption signal. High sensitivity was achieved by a phase-sensitive detection method.[2] The reference signal for the detector was obtained from a phototube in the chopped beam.

Two resonance peaks were observed corresponding to effective masses m_1^* and m_2^*. The effective masses measured in the principal directions are summarized in Table I; m_0 is the free electron mass. From these data, by means of simple statistics, the approximate average effective mass of holes was calculated to be $0.39m_0$.

TABLE I.

Magnetic field parallel to:	[001]	[111]	[110]
m_1^*/m_0	0.171	0.160	0.163
m_2^*/m_0	0.46	0.56	0.53

The observations are consistent with the model used for germanium,[1,3] in which the top of the valence band occurs at $k=0$ and in which the constant energy surfaces in the Brillouin zone can be represented by two sets of warped surfaces centered about the origin. For these surfaces, the energy E is given as a function of the wave vector $\mathbf{k}$ by

$$E=(-\hbar^2/2m_0)\{ak^2\pm[b^2k^4-c(k_x{}^4+k_y{}^4+k_z{}^4)]^{\frac{1}{2}}\}, \quad (1)$$

where a, b, and c are constants. The approximate theoretical calculation of the resonance frequency and the effective mass at resonance was carried out as previously described[1,4] but a more exact expansion of the radical was used. The result is

$$1/m^*=(1/m_0)[A_\pm+B_\pm(1-3\cos^2\theta)^2], \quad (2)$$

where $A_\pm=a\pm b'\pm(c/12b')$, $B_\pm=\mp c/32b'$, $b'=(b^2-\frac{2}{3}c)^{\frac{1}{2}}$, and the plus and minus signs refer to the effective masses m_1^* and m_2^*, respectively. The constants can be determined from the values for m_1^* at $\theta=0$ and for m_2^* at $\theta=0°$ and 55°. The result for silicon is: $a=4.0$, $b^2=8.1$, and $c=6.5$. By using these values in Eq. (2), a theoretical curve was calculated for m_2^* and plotted in Fig. 1.

According to the perturbation theory[3] which describes the valence band structure of germanium around $\mathbf{k}=0$, three degenerate bands are split by spin-orbit interaction into the two bands described by Eq. (1) and a lower band for which the energy is

$$E_3=-E_0-(\hbar^2ak^2/2m_0)=-E_0-(\hbar^2k^2/2m_3^*), \quad (3)$$

where E_0 is the splitting at $\mathbf{k}=0$.[5,6] If this expression is correct for silicon, $m_3^*=0.25m_0$. We have not been able to detect holes in this normally filled band.

The authors would like to thank Mrs. Laura Roth and Dr. H. J. Zeiger for helpful suggestions and the

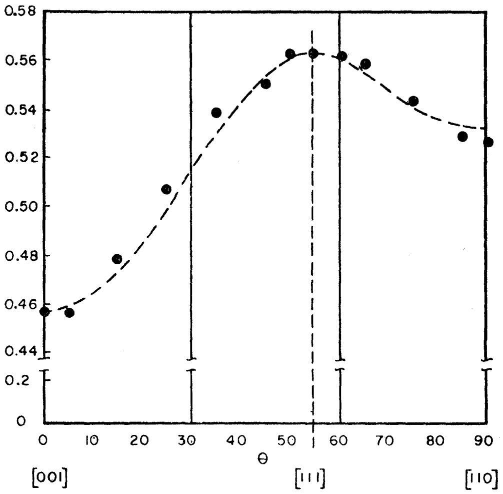

FIG. 1. The effective mass m_2^* of the heavy holes in silicon is plotted as a function of θ, the angle between the [001] direction and the magnetic field in the (110) plane. The points are experimental, and the curve is theoretical.

General Electric Research Laboratories and the Bell Telephone Laboratories for providing samples of silicon.

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* The research reported in this document was supported jointly by the Department of the Army, the Department of the Navy, and the Department of the Air Force.

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Finley-Freundlich Red-Shift Hypothesis

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(Received August 9, 1954)

In view of the possible serious physical implications[1,2] of the Finley-Freundlich hypothesis[3] that light, passing through an enclosure of energy density $u=bT^4$ and dimension h, suffers a red shift $\Delta\lambda/\lambda=AT^4h$ ($A=2\times10^{-29}$ cgs units), it appears desirable to state here two astronomical arguments preventing acceptance of this proposal unmodified.

Consider an eclipsing binary star system ($i=90^\circ$) in which the relative orbit is circular with radius a. Take $u_i=b_iT_i^4$ as the energy density at the surface of star i, the radius of which is R_i. The energy density in space at a point at distance h from star i is $u=u_iR_i^2/h^2$. If θ is the angle introduced in Fig. 1, the integrated energy density along the line of sight towards star 2, due to its companion's presence,[4] is $U_2=(u_1R_1^2/a)[(\pi-\theta)/\sin\theta]$, outside of eclipse. A change in the total energy density along the line of sight of many times $u_1R_1^2/a$, would occur in a single revolution. The quantity $u_1R_1^2/a$ corresponds to a predicted Freundlich shift of amount $\Delta V=cAT_1^4R_1^2/a$.

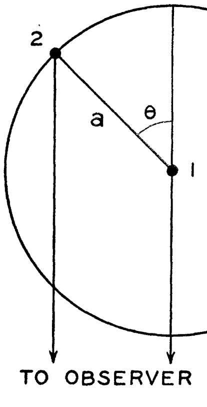

FIG. 1. A typical binary system.

Table I contains the predicted ΔV, together with other quantities of interest for five systems selected from the *Fourth Lick Catalog of Spectroscopic Binaries*,[5] Although there exists a slight uncertainty in spectral types and consequently in temperature, the predicted effect is certainly orders of magnitude too large and one can afford to be slightly uncritical of the observational data. Use of more recent spectral classifications[6] decreases ΔV by only 50 percent for the fainter star in *TX* Herculis, and not at all for the fainter star in *Z* Vulpeculae. The data for the system *Y* Cygni are particularly reliable.

It may be maintained that the hypothesis holds only in the presence of matter, the above argument then not being conclusive since the presence of matter in the orbital plane has not been demonstrated.

The unusual system of ϵ Aurigae[7] provides a natural test of this further possibility. While objections[8,9] have been raised to parts of the interpretation of this system, it still appears quite probable that during the eclipse, the light of the *cF* star passes *through* the outer part of its companion *I* star. During eclipse ionized lines arising from the outer parts of the *I* star indicate the presence of gaseous material. At eclipse, we therefore have the ideal situation of a long path length though matter in the presence of a radiation field.

TABLE I. Data for five systems. Column 1 gives the Fourth Lick Catalog number, Column 2 the star name, Column 3 the spectral type (*HD* Rev.) of each component (in all cases listed the spectral type being the same for both components), Column 4 the effective temperature corresponding to the spectral type, Column 5 the mean radius of the two components, the solar radius being taken as unity, Column 6 the semimajor axis of the relative orbit using the same unit of length, Column 7 the percentage contribution of each star to the total luminosity of the system, Column 8 the semiamplitudes of the two radial velocity curves, and Column 9 the predicted ΔV. In all cases the inclination of the orbital plane exceeds 86.5°.

1	2	3	4	5	6	7	8	9
No.	Star name	Type	Eff. temp. °K	Mean rad.	Semi-major axis	Lumin. contrib. percent	Semi-amplitudes km/sec	ΔV km/sec
78	*TT* Aur.	*B*3	18 000	4.3	11.7	68; 32	197: 246	70 000
115	*WW* Aur.	*A*7	8 000	2.1	12.5	55; 45	116; 135	610
251	*TX* Her.	*A*2	10 000	1.6	10.7	64; 36	121; 140	1 000
296	*Z* Vul.	*B*3	18 000	4.3	15.1	75; 25	96; 214	54 000
322	*Y* Cyg.	*O*9	25 000	5.9	28.4	50; 50	245; 241	200 000

If one uses the Yerkes model,[7] the maximum dip of the *cF* star below the *I* star's edge is 2.4×10^{13} cm and the radius of the *I* star is 2×10^{14} cm. If the *I* star was perfectly spherical, the *F* star's light would travel along a chord of the *I* star, 2×10^{14} cm long. If one uses $T_I=1200$°K, the predicted ΔV is 2400 km/sec. Judging from the observations, this is at least 200 times too large. If the path length is chosen so as to be equal to the effective length over which optical absorption occurs,[7] ΔV is decreased by a factor of ten. It is to be noted that the temperature used for this calculation is