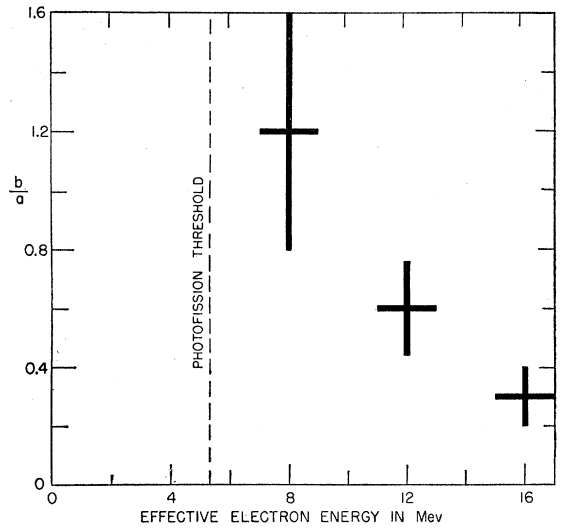

FIG. 3. The dependence of the asymmetry b/a as a function of effective electron energy for an angular distribution of the form $a+b\sin^2\theta$.

corresponds to a value for b/a of 0.30 ± 0.10, agreeing with the cylinder results within the errors of the two experiments.

A number of runs using the step-like geometry were made at energies from about 8 to 16 Mev. The asymmetry was found to increase rapidly as the accelerator energy was decreased (Fig. 3). Unfortunately the electron spectrum is about 3 Mev wide and it has not been possible to determine the "effective energy" of the electrons to better than about 1 Mev. This energy uncertainty and the use of a thick x-ray target prevent us at present from being able to give b/a as a function of photon energy.

No really convincing explanation of the observed angular distribution has so far been developed. The form of the distribution suggests an electric dipole transition, but the ratio of e/m values for the fission end products does not indicate a process involving a particularly large dipole moment. The energy dependence shows, moreover, that the effect is not largest at the dipole resonance peak in thorium ($\sim$15 Mev). This may, however, not be particularly significant because most fissions caused by 15-Mev photons may come from (γ,nf) reactions rather than (γ,f) reactions and the former would perhaps be expected to give a more isotropic fragment distribution. If very strong selection rules obtain for the allowed spins of the fragments at the moment of fission, the angular momentum brought in by the photon might on the average go mostly to the orbital momentum between the fragments. Although this would "explain" an angular distribution, it involves a rather arbitrary assumption. In order to investigate any dependence of the angular distribution on spins, we are preparing to repeat the experiment with a number of other fissionable materials having various ground-state spins.

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[1] In this geometrical correction, it is assumed that fragments emitted isotropically would emerge from a thick foil in a cosine distribution with respect to the foil normal. This has been checked experimentally to about 10 percent.

The Beta-Spectrum of He^6†

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THE beta-spectrum of He^6 is of great theoretical interest. Not only can its linear Kurie plot serve to exclude one of the Fierz interference terms (A, T), but its end point together with its half-life determines an ft value which helps to estimate the relative contributions of the Fermi (S or V) and Gamow-Teller (A or T) interactions in the process of beta-decay.

The only reported measurement of the He^6 beta-spectrum was made on a semicircular focusing magnetic spectrometer and gave an end point of 3.215 Mev.[1] This end point together with $t_{\frac{1}{2}}=0.823\pm0.013$ sec[2] yields an ft value of 584 sec.

Because of its theoretical interest we have recently remeasured the beta-spectrum of He^6 using the Columbia magnetic solenoidal spectrometer whose characteristics have been well investigated.

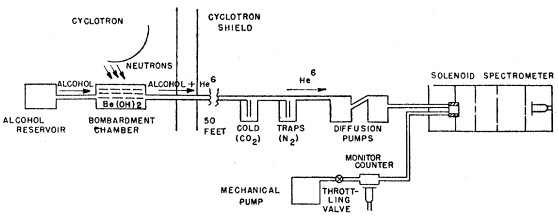

FIG. 1. Block diagram of apparatus.

The spectrometer was placed about 50 feet from the cyclotron to minimize the effects of stray fields from the cyclotron magnet. The spectrometer axis was oriented parallel to the small horizontal component of the nearly vertical stray field, while the vertical component was compensated by a pair of Thomson coils.

The He^6, produced by the reaction $Be^9(n,\alpha)He^6$, was swept from the target chamber with ethyl alcohol vapor. Before reaching the spectrometer source chamber, the alcohol vapor was frozen out in CO_2 and N_2 cold traps and the He^6 concentrated by two successive oil diffusion pumps as shown in Fig. 1.

The source chamber was an aluminum cylinder 1.5 cm diameter by 1 cm depth with a 2-mg/cm² mica front window and a 3-mg/cm² mica back window. After passing through the source chamber, the He^6 entered a monitor counter chamber and was finally evacuated by a mechanical pump.

Data were taken in the following manner to reduce background from the cyclotron. The cyclotron was turned on for 5 sec. A half-second later, the spectrometer and monitor GM counters were turned on for 5 sec. This cycle was controlled by a system of relays actuated by a cam shaft driven by a synchronous motor. Under these conditions the radioactive purity of the source was >98 percent.

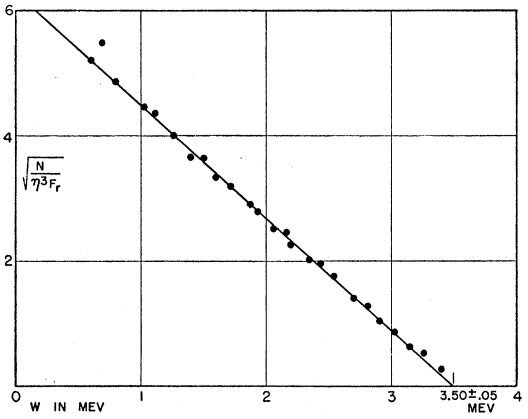

FIG. 2. Kurie plot of He^6 beta-spectrum.

The baffle slit in the spectrometer together with the source volume used gave 5–6 percent resolution. The Kurie plot shown in Fig. 2 is linear from its end point of 3.50 ± 0.05 Mev to about 0.6 Mev, below which counting statistics became very poor. The end point together with $t_{\frac{1}{2}}=0.823$ yields the ft value of He^6 of 815 ± 70 sec.[3] Moszkowski[4] estimated the relative contribution of

F and $G-T$ interactions by equating $ft|M|^2$ for the H^3-He^3 and He^6-Li^6 transitions. Using the old He^6 "ft" value he obtained $K=C_F^2/C_G^2=0.11\pm0.45$, which leads to the conclusion of the insignificant role of the F interaction in beta-decay. Similarly, Trigg[5] obtained a value of $K\approx0.5$ by considering all the mirror and the isobaric triad nuclei, but still relying primarily on the old He^6 "ft" value. If one repeats the calculation of Moszkowski using the new ft values for He^6 one obtains $K\leq1.4\pm0.7$ which completely alters the picture. The recent finding of the $C^{10}-B^{10*}$ and $O^{14}-N^{14*}$ transitions which should be allowed and favored $0-0$ transitions, demonstrates that the presence of the Fermi interaction in the β-process is definitely necessary.

A more general comparison of the He^6 ft value can be made with those of the odd A mirror nuclei in the manner of Kofoed-Hansen.[6] The linear plot $B=ft[(1-x)|\int 1|^2+x|\int\boldsymbol{\sigma}|^2]$ for the He^6-Li^6 transition passes through the region defined by the least squares fit for the odd A mirror nuclei ($B=2600\pm85$ and $x=0.50\pm0.05$).[6] Thus the ft value for He^6 is compatible with those of the mirror nuclei.[7,8]

Recently Dewan and his co-workers calculated the energy equivalent of the He^6-Li^6 mass difference by using Q-values of nuclear reactions. They gave a value 3.55 ± 0.03 Mev, which is in fair agreement with the direct spectroscopic determination.[9]

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[1] V. Perez-Mendez and H. Brown, Phys. Rev. **77**, 404 (1950).
[2] Holmes, Proc. Phys. Soc. (London) **62**, 293 (1949).
[3] The f value was calculated using a formula according to E. Feenberg and G. Trigg, Revs. Modern Phys. **22**, 399 (1950).
[4] S. Moszkowski, Phys. Rev. **82**, 118 (1951).
[5] G. L. Trigg, Phys. Rev. **86**, 506 (1952).
[6] O. Kofoed-Hansen, and A. Winther, Phys. Rev. **86**, 428 (1952).
[7] The latest value $ft=1019$ for H^3 [L. Langer (private communication)] seems low when compared with those of the mirror nuclei and so was not used in computing K.
[8] The value $|\int\boldsymbol{\sigma}|^2\leq5.4$ should be used for He^6-Li^6 to fit the observed magnetic and quadrupole moments of Li^6. This change does not alter the fit of He^6 with the mirror nuclei (D. C. Peaslee, private communication).
[9] J. T. Dewan *et al.*, Phys. Rev. **86**, 416 (1952).

Interpretation of the Low Temperature Hall Curve of a Degenerate Germanium Sample*

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GERMANIUM samples which have room temperature resistivities less than 0.01 ohm-cm show practically constant Hall coefficients from 300°K down to 1°K.[1] This implies a practically constant carrier density n of the order 10^{18} to 10^{19} per cm³. However, careful measurements made on an n-type antimony-doped sample, with $\rho(300°K)=0.0051$ ohm-cm show that the Hall coefficient R exhibits a maximum near 120°K (Fig. 1) and drops by 20 percent as the temperature decreases from 116°K to 1.3°K. Application of the common relation, $n=3\pi/(8Re)$, suggests that n *increases* by 20 percent as temperature drops, a behavior which would be opposite to that predicted by the concept that conduction electrons are due to thermal activation of donor impurity atoms.

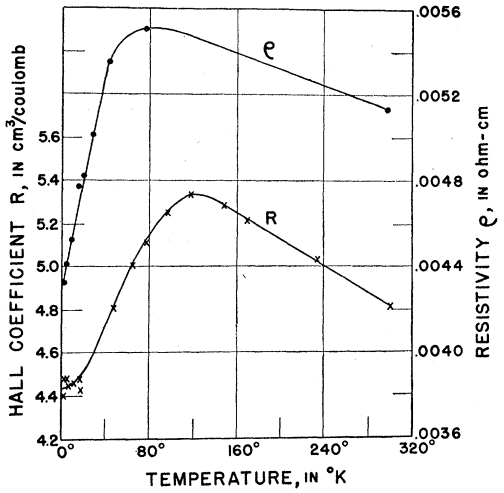

FIG. 1. Measured Hall and resistivity curves for n-type single crystal, antimony-doped germanium sample (Sb−6−6).

The Fermi level,[2] which is several kT below the bottom of the conduction band at 300°K, rises with decreasing temperature, crosses into the conduction band around 70°K and approaches a value of about 0.0048 ev above the bottom of the conduction band. Such a sample is termed degenerate, and Fermi-Dirac statistics are required in its analysis. With n as high as 10^{18} per cm³, scattering by impurity ions[3] is comparable with scattering by the lattice even at room temperature. At temperatures as low as 120°K, impurity scattering completely dominates, so that the use of a mean-free-path proportional to the square of the electron kinetic energy is justified. Consideration of these points shows that the low temperature drop in Hall coefficient is consistent with a *decrease* in carrier density.

Insertion of the Fermi-Dirac distribution function and a mean free path $l=Ke^2$ into the usual weak magnetic field expression for the Hall coefficient leads to the expression

$$|R|=\frac{3}{16\pi e}\left(\frac{h^2}{2mkT}\right)^{\frac{3}{2}}\frac{J_{7/2}(\zeta^*)}{\{J_2(\zeta^*)\}^2},\tag{1}$$

where ζ^* represents the ratio of the Fermi level ζ to kT, and $J_k(\zeta^*)$ represents the Fermi-Dirac integral[4]

$$J_k(\zeta^*)=\int^\infty x^k(1+e^{x-\zeta^*})^{-1}dx.\tag{2}$$

Apart from uncertainty in the effective mass m, the measurable quantity $|R|T^{\frac{3}{2}}$ uniquely determines ζ^* as a function of temperature. The carrier density is uniquely determined by ζ^* through the relation

$$n=4\pi h^{-3}(2mkT)^{\frac{3}{2}}J_{1/2}(\zeta^*).\tag{3}$$

One can find n directly from $|R|$ by numerically eliminating ζ^* between Eqs. (1) and (3) and making a plot of $|R|T^{\frac{3}{2}}$ *vs* $nT^{-\frac{3}{2}}$. Alternately, one may define a ratio

$$r=\frac{|R|}{(1/ne)}=\frac{3}{4}\frac{J_{7/2}(\zeta^*)J_{1/2}(\zeta^*)}{\{J_2(\zeta^*)\}^2};\tag{4}$$

then n may be found from $r/(e|R|)$. Table I gives the general relations among ζ^*, $|R|T^{\frac{3}{2}}$, and r applicable to any degenerate semiconductor.

TABLE I. Dependence of r, $|R|T^{3/2}$, and $nT^{-3/2}$ upon ζ^* for a degenerate semiconductor.

ζ^*[a]	r[b]	$\lvert R\rvert T^{3/2}$ °K$^{3/2}$ −cm³/coulomb	$nT^{-3/2}$ cm^{-3} °K$^{-3/2}$
−2.0	1.897	19.0×10^3	0.06245×10^{16}
−1.5	1.877	11.7	0.100
−1.0	1.846	7.28	0.158
−0.5	1.804	4.60	0.272
0.0	1.750	3.00	0.370
1.0	1.60	1.31	0.761
2.0	1.45	0.663	1.36
3.0	1.34	0.386	2.17
4.0	1.261	0.250	3.15
5.0	1.196	0.175	4.27
6.0	1.151	0.130	5.53
7.0	1.119	0.101	6.90
8.0	1.096	0.0816	8.38
9.0	1.079	0.0676	9.96
10.0	1.065	0.0572	11.6
11.0	1.055	0.0492	13.4
12.0	1.047	0.0429	15.2

[a] ζ^* is the ratio of the Fermi level to kT.
[b] r is defined as $|R|ne$, where R is the Hall coefficient and n the number of carriers per cm³.