has to be modified is

$$\Theta=\frac{1}{4}\csc^2(\tfrac{1}{2}\theta)\{(\boldsymbol{\mu}\cdot\mathbf{p}_i\times\mathbf{p}_f)^2+\tfrac{1}{4}\mu^2(\mathbf{p}_i-\mathbf{p}_f)^4 -\tfrac{1}{4}(\mathbf{p}_i-\mathbf{p}_f)^2[\boldsymbol{\mu}\cdot(\mathbf{p}_i-\mathbf{p}_f)]^2\}. \quad (4)$$

With the replacements (2), it becomes

$$\Theta=(1-\tfrac{1}{2}s^{-1})\Theta_c+\tfrac{1}{2}s^{-1}[1+\sin^2(\tfrac{1}{2}\theta)], \quad (5)$$

where Θ_c is the function called Θ in reference 1:

$$\Theta_c=\cos^2(\tfrac{1}{2}\theta)\cos^2(\boldsymbol{\mu},\mathbf{p}_i\times\mathbf{p}_f) +\sin^2(\tfrac{1}{2}\theta)\sin^2(\boldsymbol{\mu},\mathbf{p}_i-\mathbf{p}_f). \quad (6)$$

Insertion of (1) in (3) gives the cross sections if the nuclear spin[5] is s. The double scattering cross sections at high energies are obtained from (3) as in reference 1.

The two extreme cases to be considered are $s\rightarrow\infty$ and $s=\frac{1}{2}$. If the nuclear spin is very large, we obtain $\Theta=\Theta_c$, the classical limit calculated in reference 1. For $s=\frac{1}{2}$, on the other hand, $\Theta=1+\sin^2(\frac{1}{2}\theta)$, which is quite independent of the magnetic moment direction. Consequently the single scattering cross secton for unpolarized electrons is independent of the azimuthal angle. This is a consequence of the fact that an azimuthal dependence (for an unpolarized beam) depends only on the alignment of the nucleus. For spin-$\frac{1}{2}$ nuclei, however, equal probability for spin-up and spin-down means complete lack of polarization.[6]

The magnetic moment distribution is determined by measuring

$$\eta=\frac{\sigma_{+0}-\sigma_{-0}}{\sigma_{+0}+\sigma_{-0}}=\frac{\sigma_{0+}-\sigma_{0-}}{\sigma_{0+}+\sigma_{0-}},$$

either via a double scattering experiment, as indicated in reference 1, or via a single scattering experiment using polarized electrons.

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[1] R. G. Newton, Phys. Rev. **103**, 385 (1956).
[2] Similar information is, of course, obtainable from single scattering of longitudinally polarized electrons, which meanwhile were found to be available from nuclear beta decay.
[3] The corresponding cross sections for electrons on protons were calculated by J. H. Scofield (to be published).
[4] Reference 1 contains a sign error in Eq. (15). All subsequent equations are most simply corrected by changing the sign $\boldsymbol{\mu}$ everywhere.
[5] Since the cross section depends on s, it may also be useful for additional evidence for the spin of a nucleus in its ground state.
[6] The azimuthal dependence of the single scattering cross section for unpolarized electrons can also be used for the measurement of a nonsphericity of the charge distribution.

Mass Difference T−He³ and the Mass of the Neutrino*

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THE rest mass of the neutrino has been estimated[1,2] to be between zero and 1 kev from analysis of the shape of the tritium beta spectrum near its end point. These estimates are based on a theory of the nature of the beta-decay process. A purely empirical determination of this rest mass may be obtained from the difference between the mass difference $T-He^3$ and the beta end-point energy.

TABLE I. Mass differences in μMU.

Mass	Doublet	Symbol	Number of determinations	ΔM	Least-squares adjusted values
3	$HD-He^3$	a	18	5899.91±0.07	
4	D_2-HT	b	15	4330.60±0.07	4330.60±0.07
4	D_2-He^4		16	25 611.6±0.6	25 611.5±0.5
4	$HT-He^4$		10	21 280.7±0.8	21 280.9±0.5
28	$C_2H_4-C_2D_2$	c	28	3098.54±0.36	

The mass synchrometer[3] has been used to determine the mass differences of the three doublets $HD-He^3=a$, $D_2-HT=b$, and $C_2H_4-C_2D_2=2(H_2-D)=c$, none of which involves ions formed by molecular dissociation. This eliminates comparison of ions which may have grossly different initial kinetic energy distributions. The measurements were made with the widest practical variation of ion source conditions and rf frequencies and with slits[3] S_1, S_5, and S_7 narrowed to half the value used in all previous work. Thus half-width resolution at mass 28 was raised to about 40 000. Measurements at masses 3 and 4 were made with resolutions varying from 17 000 to 30 000.

The values of a, b, and c are given in Table I together with recently measured values of $HT-He^4$ and D_2-He^4. The latter are consistent with b but less precise because of difficulty in rf tuning with widely spaced doublets. Adjusted values of the three doublets at mass 4 obtained by weighted least squares are also given in Table I. (It is evident that the adjustment has negligible effect on b and hence on the estimate of the neutrino mass). Each error in Table I is the standard error of the mean of the indicated number of independent determinations computed by the formula

$$\sigma=[\sum\delta^2/n(n-1)]^{\frac{1}{2}}.$$

A full account of possible systematic errors will be discussed in a forthcoming report.[4] It must be noted that while undetermined systematic errors may be larger than the indicated error, there is good reason to assume that these effects would tend to cancel in taking the difference of a set of mass differences which are very similar in spacing.

From these measured values we obtain $T-He^3=a-b-\frac{1}{2}c=20.03\pm0.21$ μMU$=18.65\pm0.20$ kev. Subtracting from this result the "best" value of the beta end-point energy selected by King,[5] namely 18.1±0.2 kev, we obtain for the rest mass of the neutrino 0.55±0.28 kev. The result is essentially in agreement with previous estimates,[1,2] and indicates an upper limit of the rest mass of the order of one kev. The lower limit depends very strongly on the accuracy of the synchrometer

TABLE II. Mass defects of T and He^3 in μMU.

	From mass synchrometer	From Q values
T−3	17 007.03±0.29	17 002.95±4.5
He^3−3	16 986.99±0.27	16 983.55±4.5

data and the beta-ray end-point measurements. The latter measurements range from 17.6 to 18.9 kev and this appears now to be the weakest point in the argument for a finite neutrino rest mass. The present data would not justify setting a nonzero lower limit.

By combining the measured values of a, b, and c with the value $H-1=8145.39\pm0.11$ μMU obtained from other recent synchrometer measurements,[4] we obtain the values of the mass defects of T and He^3 shown in Table II. These are in agreement with data obtained by a least-squares computation of Mattauch *et al.*,[6] which uses Q values of 14 reactions involving T and He^3.

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Annihilation Method for Measuring Transverse Polarization of Energetic Positrons*

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In recent months several different methods have been successfully used to measure longitudinal polarization (denoted P_p) of energetic positrons: the bremsstrahlung method,[1] in μ^+ decay[2]; annihilation in flight (to be abbreviated AF) against unpolarized electrons,[3] in Ga^{66} decay[4] and N^{13} decay[5]; a third method, using AF with polarized electrons, has been used by Frankel and co-workers.[6] On the other hand, for analysis of transverse polarization of energetic positrons (denoted P_s), very few real possibilities appear to be known. Mott scattering[7] especially for positrons would be rather ineffective for energies exceeding one or two Mev. In bremsstrahlung, the photon intensity for example could conceivably show some left-right asymmetry, but perhaps not very much.[8] Against polarized electrons, AF used in the manner of reference 6 (ideally this method rests on conservation of angular momentum about the line of collision) has sensitivity to P_s decreasing sharply with energy.[9] Again, use of AF *versus* polarized electrons where one observes total annihilation cross section or azimuthal distribution of the plane of the reaction, depending on energy, has been discussed.[3] The prospects for direct measurement of P_s at high energies were commented upon recently by Kinoshita and Sirlin.[10] Finally, thoughts of constructing a spin-precessor[11] for use above one Mev may not be entirely appealing from an engineering standpoint.

Since some value may attach to P_s measurement (see, for example, reference 10), it seems reasonable to examine the AF cross section[12] to ascertain optimum conditions for converting transverse particle polarization into circular photon polarization (to be called P_k). It is found that the efficiency for the conversion can be quite large and sustained up to rather high energies for an *unpolarized* electron target, assuming *one* of the photons to be analyzed for P_k. Against the background of continued P_k measurements[1,2,4,5,13,14] this latter requirement should probably not inhibit some discussion of this possible approach to the problem.

Let a positron be incident on an electron along the $\theta=0$ direction. If one of the particles were polarized, say only transversely, then on physical grounds both annihilation photons ought to partake in general of the spin angular momentum of this particle plus that of its usually-parallel partner.[15] In any case, denoting by θ the center-of-mass angle of one of the photons, ψ the polar angle of the positron's spin with respect to its momentum, and ϕ the azimuthal angle of this photon (where the positron's spin defines zero azimuth), one finds[16] that the photon would be polarized by an amount

$$\epsilon(\theta,\phi,\psi)=\frac{2\beta^2\{\sin^3\theta\cos\phi\sin\psi+[\gamma\sin^2\theta\cos\theta+(1/\beta\gamma)]\cos\psi\}}{\gamma(1-\beta^4+2\beta^2\sin^2\theta-\beta^4\sin^4\theta)}. \quad (1)$$

That is, the differential cross section for the photon to be like a right-hand screw is $(1+\epsilon)/(1-\epsilon)$ times that for the left-hand screw. If γ_0 stands for total energy of the positron in the laboratory in units of mc^2, the electron being assumed at rest, then $\beta^2=(\gamma_0-1)/(\gamma_0+1)$, $\gamma=[\frac{1}{2}(\gamma_0+1)]^{\frac{1}{2}}$. Taking $\sin\theta=1$ and $\cos\phi=1$ to maximize the desired effect, we have, for $\cos\psi=0$,

$$\epsilon_s=\epsilon(90°,0°,90°)=2\beta^2/\{\gamma[1+2\beta^2(1-\beta^2)]\}.$$

The quantity ϵ_s may be regarded as the conversion efficiency from P_s to P_k. Physically and algebraically $\epsilon(90°,180°,90°)=-\epsilon_s$. A plot of ϵ_s against positron kinetic energy is made in Fig. 1. A plot is also given (curve D) of the usual differential cross section[12] per