A further check of the thickness measurement has been accomplished by weighing circles punched from the films. The accuracy of this method is restricted to ±5 percent, but within these limits there is agreement with the optical measurements and the assumption concerning density.

There is indication that polystyrene has a stopping power slightly less than that of acetylene. The difference is less than one percent, and this is probably smaller than the present limits of accuracy of the measurements. Since this condition was found to exist throughout the alpha-range, it is concluded that the relative stopping power of gas and solid is independent of alpha-energy.

* This document is based on work performed for the AEC.
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Scattering of Protons by the Loosely Bound Neutron in Beryllium

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A STUDY is being made of the energy distribution of neutrons emitted by various targets when bombarded with a nominally 112-Mev internal proton beam (38-in. radius) of the Harvard cyclotron. This letter reports results observed with Be and C. Bodansky and Ramsey[1] have previously reported such data obtained in the forward direction at a slightly higher energy.

The ejected neutrons, after passing through the tank wall, were collimated by slits cut into a lead shield (28-in. thick) at angles of 0°, 5°, 10°, 16°, and 28° with respect to the proton beam. The neutrons were observed using a scintillation counter telescope to measure the energy distribution of recoil protons from a CH_2-C subtraction. Three points of the differential range spectrum were obtained simultaneously. The observed proton spectrum was converted into the original neutron spectrum by interpolating the results of Hadley *et al.*[2] for the angular dependence of the $n-p$ cross section and the more recent measurements[3] of total scattering cross section.

To obtain absolute cross sections, the proton beam was monitored by the activity induced in thin polystyrene foils placed against the targets.

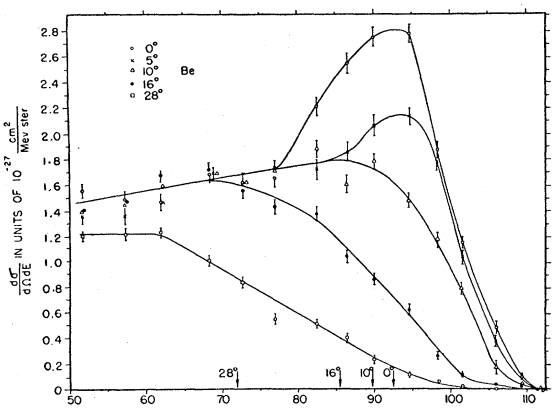

Fig. 1. Energy distribution of neutrons emitted from a 0.125-inch Beryllium target at several angles. The angles are measured with respect to the direction of the incoming proton beam. Arrows indicate the energy corresponding to 92.5 $\cos^2\theta_n$ Mev.

Figure 1 shows the results observed with a Be target. The standard deviations shown are due to counting statistics only. The high energy peak observed at 0° decreases rapidly with increasing angle. No such peak is observed in the neutrons emitted from C as shown in Fig. 2.[4] The angular dependence is not very pronounced at the smaller angles. These results suggest that the loosely bound neutron in Be^9 is responsible for the observed peak,[5]

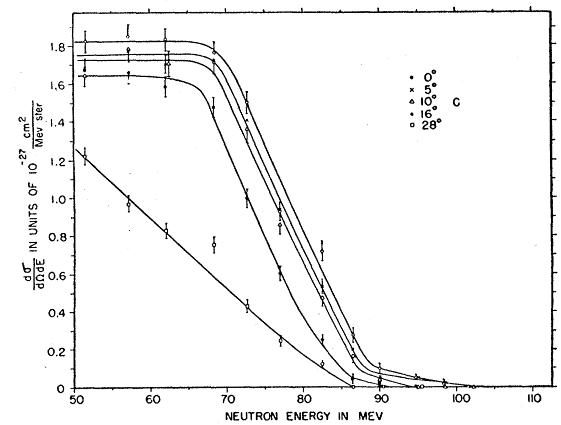

Fig. 2. Energy distribution of neutrons emitted from a 0.196-inch C target at several angles.

while the inner core corresponding to Be^8 might behave very much like the carbon nucleus.[6] A good estimate of the contribution of Be^8 to the observed spectrum from Be^9 might be the C^{12} spectrum multiplied by $(8/12)^{2/3}$. This factor follows from the observed A-dependence of high energy neutron yield measurements[7] and is also suggested by the theoretical considerations of Mandl and Skyrme.[8]

The results of this subtraction are shown in Fig. 3. It is believed that the shape of the peak obtained at 0° reflects primarily the energy distribution of the incident protons.[1] This depends on the position of the target (i.e., the effective thickness presented to the beam); to insure consistency in this respect the target was not moved during the course of a complete set of measurements. Other variables such as the ion source position could also affect the energy spread and it was not possible to keep these constant; this is estimated to introduce an additional 5 percent uncertainty into the measurements. The width of the peaks increases with the angle of observation.

If our interpretation is correct, then the area under the peaks in Fig. 3 represents the differential scattering cross section for the

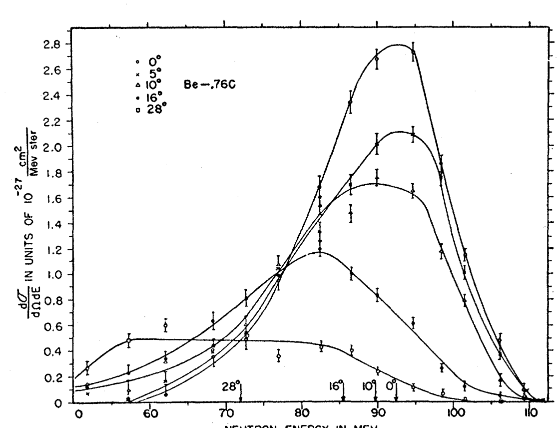

Fig. 3. Energy distribution of neutrons emitted by Be^9 after contributions from the "inner core" have been subtracted.

proton interaction with the loosely bound neutron in Be. The results given in Table I represent the average of two measurements (except for 16° where only one measurement was taken) and errors are estimated with respect to the 0° result only. The cross section scale could be off by as much as 20 percent. Cross sections based on two different measurements[2,9] of the free n-p scattering at 90 Mev are also given. It appears within the relatively large experimental uncertainties that the absolute differential cross section for bound n-p scattering is lower than in the free case, and this tendency is increased at the larger angles of observation. This is to be expected since some of the outgoing neutrons will undergo collisions with the inner core of the Be nucleus. This secondary interaction becomes more important the lower the neutron energy, and thus accounts for the decreased cross section and the broadening of the neutron energy spectrum at the larger angles. In addition, since the bound n-p scattering takes place in a potential well, it should be compared with free n-p scattering at about 120 Mev.

TABLE I. Differential cross section in units of 10^{-27} cm²/sterad for n-p scattering in the laboratory system.

		Free n-p (90 Mev)	
θ_n	n-p in Be	Hadley *et al.*	Fox
0°	55.9	67.8	~50
5°	49.7 ±2.6	51.3	49.2
10°	41.5 ±2.1	44.7	39.9
16°	30.4 ±2.2	35.2	
28°	17.7 ±0.9	21.8	

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An Argument Against the Majorana Theory of Neutral Particles

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IT is well known that the Majorana theory[1,2] describes spin 1/2 neutral particles by means of self charge-conjugate fields, so that particles and antiparticles are described by identical half-fields[3] and the distinction between them ceases to be significant—or, as is more currently stated, a Majorana particle coincides with its antiparticle. In particular, it has been till now an open question whether the neutrino is a Dirac or a Majorana particle; the latter alternative has been invoked as a possible explanation of double beta-decay phenomena (whose actual occurrence, however, is still far from certain. For an exhaustive discussion of this point, see reference 3.) A decision on this matter is also of interest when investigating the possibility of a universal Fermi-type interaction among any four fermions, because such interaction would be incompatible with Majorana neutrinos.[4–6]

We prove here that the condition of self charge-conjugation is incompatible with the usual invariance requirements; identity of a field with its charge-conjugate is impossible, because they transform differently under space reversal. Clearly, this suffices to rule out the Majorana theory. What follows is merely an alternative and perhaps more rigorous proof of a statement already contained in reference 6, to which the reader is referred for further details, references, and discussion.

Let ψ and ψ^c represent a spin 1/2 field and its charge conjugate, I_S the operator which reverses the sign of all space coordinates. When $\mathbf{x}\rightarrow-\mathbf{x}$, it is known that $\psi\rightarrow\rho_S\gamma^4\psi$, $\psi^c\rightarrow\bar{\rho}_S\gamma^4\psi^c$.[3,6,7] The phase factor (type) ρ_S can have one of the values ±1, $\pm i$ with, eventually, different determinations for different particles. It is then clear that, as is well known, a Majorana theory is compatible only with the choices $\rho_S=\pm i$, or, which amounts to the same, $I_S^2=-1$. Our proof consists in showing that the only allowed possibilities are $\rho_S=\pm1$, i.e., $I_S^2=+1$. (See reference 6 for a simple proof of the fact that the square of any inversion operator, $+1$ or -1, must have always the same value regardless of the nature of the fermion field on which it acts, contrary to what was thought before[3,7] to be the case.)

The operator I_S is the product, in a given fixed order, of the operators I_h corresponding to reversal of only one of the spatial coordinates x^h, say $I_S=I_1I_2I_3$. We use the standard form of the Dirac equation, with imaginary time coordinate and Hermitean γ^μ's. One finds immediately, in a purely algebraic manner, the explicit expressions for the I_h's and their commutation properties: $I_h=\rho_h\gamma^h\gamma^5$; $I_hI_k+I_kI_h=2\delta_{hk}I_h^2$; so that $I_S^2=(\rho_S\gamma^4)^2=(I_1I_2I_3)^2=-I_1^2I_2^2I_3^2$. It will suffice, therefore, to prove that $I_h^2=-1$ (any h), i.e., that the phase factors ρ_h, which can again be restricted to have only the values ±1, $\pm i$, must all be real.

The reason for introducing four types as *a priori* possible under space reversals lies in the discontinuous nature of these operations, as well as in the singularity at the origin peculiar of spinorial functions and transformations, which shows up in their characteristic double-valuedness. One cannot thus decide *a priori* whether the square of an inversion must be $+1$ or -1. It is possible, however, to analyze the singularity and to eliminate the discontinuity in a quite simple manner by considering—as is certainly allowed and is standard procedure in algebraic geometry—the physical four-dimensional world as a manifold imbedded in a five-dimensional space, with an added space-like coordinate x^5 (to which is associated γ^5, which duly anticommutes with the γ^μ's). In this enlarged world, I_h becomes a rotation of $\pm\pi$ in the (x^hx^5)-plane. We are, therefore, reduced to the study of rotations (that is, of continuous operations) in the five-dimensional space. The infinitesimal rotation in the plane $(x^\lambda x^\nu)$, as determined from the condition

$$\gamma^\mu T^{\lambda\nu}-T^{\lambda\nu}\gamma^\mu=\delta_{\lambda\mu}\gamma^\nu-\delta_{\nu\mu}\gamma^\lambda, \tag{8}$$

must be of the form $T^{\lambda\nu}=\frac{1}{2}\gamma^\lambda\gamma^\nu+\Delta_{\lambda\nu}\cdot1$, with $\Delta_{\lambda\nu}=-\Delta_{\nu\lambda}$ pure numbers ($\lambda\neq\nu$). The terms $\Delta_{\lambda\nu}$ are in reference 8 put$=0$ by imposing Sp $T^{\lambda\nu}=0$. This we are not allowed to do here because, when passing to finite rotations, the $\Delta_{\lambda\nu}$'s give rise to arbitrary phase factors; this is exactly the problem at hand, so that care must be taken of not introducing unjustified restrictions in the proof. It is, however, just as easy to see directly that all $\Delta_{\lambda\nu}$ must be$=0$. The proof of this statement—which is not trivial in our case, since a new coordinate has been introduced—follows simply from Lie's second fundamental theorem, which states that

$$[T^{\lambda\nu}, T^{\rho\sigma}]_-=\Sigma_{\alpha\beta}\, c_{\lambda\nu,\,\rho\sigma,\,\alpha\beta}T^{\alpha\beta},$$

where the c's are constant coefficients. With $\lambda=\rho$, $\nu\neq\sigma$ this yields

$$[T^{\lambda\nu}, T^{\lambda\sigma}]_-\equiv[\tfrac{1}{2}\gamma^\lambda\gamma^\nu, \tfrac{1}{2}\gamma^\lambda\gamma^\sigma]_-=\tfrac{1}{2}\gamma^\sigma\gamma^\nu=T^{\sigma\nu},$$

so that $\Delta_{\sigma\nu}=0$, q.e.d.

It follows then, clearly, that a rotation of $\pm\pi$ in the (x^hx^5)-plane is represented by $I_h=\exp(\pm\frac{1}{2}\pi\gamma^h\gamma^5)=\pm\gamma^h\gamma^5$, so that $\rho_h=\pm1$, $I_h^2=-1$, $I_S^2=+1$, and our statement is proved. Although the case of time inversion requires quite different considerations,[6] we remark here that one finds, for both the Wigner and the Pauli type of time inversion, $I_4^2=-1$, as here with I_h^2.