change the constants to bring the theoretical curve into closer agreement with experiment. Work is being done on the problem at this laboratory.

The theoretical discussions, mentioned above, have often used conclusions taken from meson-nucleon scattering data.[5] Another valid solution to the same data (Yang) has been shown possible and would strongly affect the theoretical photomeson arguments.[6] It seems reasonable that the photo-meson results could be used to choose the correct solution of the meson-nucleon scattering data.

We wish to thank Rod Byrns for his help with the high-pressure target and the crew of the synchrotron for their assistance. Joe Lepore and Steve Gasiorowicz were helpful in discussing some of the theoretical aspects of the subject. A more detailed report will follow.

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Recent Experimental Results on *S* Particles*

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In an examination of recent cloud-chamber films we found several additional examples of *S* particles which throw new light on the mode of decay of these particles. Previous results[1–4] are consistent with the assumption that the secondaries from *S* particles all have the same range of about 66 g cm^{-2} Pb and consequently that the decay of *S* particles is a two-body process. The new evidence appears to contradict this assumption. Indeed, in two of our recent events the decay particle traverses more than 66 g cm^{-2} of lead before going out of the chamber. In the first case the visible range of the particle is 73 g cm^{-2} of lead, and moreover, since the ionization still appears to be minimum after the particle traverses the last plate, the range of the particle (assumed to be a meson) must be greater than 80 g cm^{-2} of lead. In the second case the visible range is 85 g cm^{-2} of lead. The momentum of a π meson with a range exceeding 85 g cm^{-2} of lead is greater than 240 Mev/c and that of a corresponding μ meson is greater than 209 Mev/c.

In addition we have observed four decay events in which related electron cascades appear (see example in Fig. 1). We can interpret these events by assuming that the *S* particle decays into a charged meson and a photon, or possibly into a charged and a neutral meson. In two events the cascade starts in the plate adjacent to the one in which the *S* particle stops and decays. In these cases the direction of the photon is opposite to that of the charged decay product within 5°. This seems to favor the assumption that the neutral decay product is a photon rather than a π^0 meson (the decay photons of π^0 mesons with a momentum of the order of 200 Mev/c are emitted at an average angle of about 30°). In the remaining two cases the photon materializes in the plate in which the decay occurs. Here the direction of the photon cannot be determined accurately and one can only say that it lies within 15° of the direction opposite to that of the charged decay product.

To date we have found a total of twenty examples of *S* particles. Among these, only the four mentioned above contained electron cascades. In order to test the assumption that all *S* particles undergo a two-body decay process in which a photon is produced, we have computed the probability that among our twenty examples four or fewer electron cascades should have been observed. For a photon energy greater than 150 Mev we have obtained for this probability a conservative upper limit of 10^{-5}. One should, of course, consider the possibility that we may have missed some

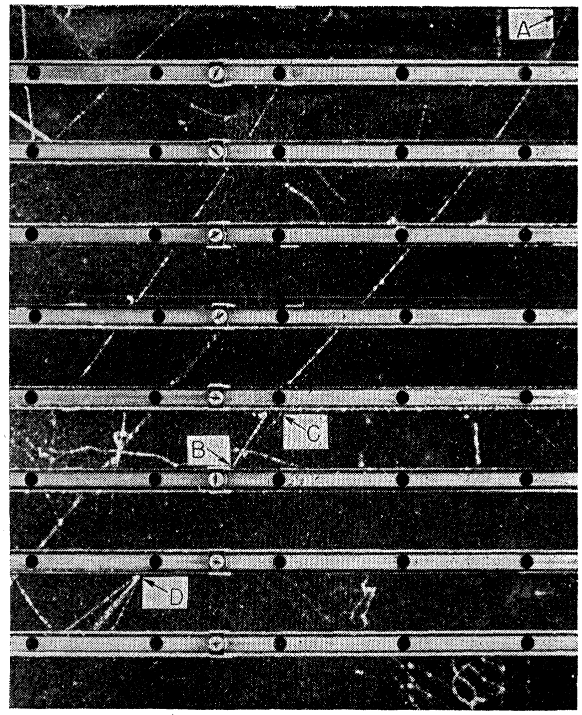

Fig. 1. Example of an *S*-particle decay in which there is a related electron cascade. *AB* is the track of the *S* particle, *BC* is the section of track of the charged decay product which is visible in the illuminated region, and *D* is the point of origin of the electron cascade.

decay processes accompanied by electron cascades. However, even if there had been eight such processes in our sample instead of the four actually detected, a similar computation would yield a probability of about one percent.

Thus, although photons are certainly produced in the decay of some *S* particles, we consider it unlikely that the decay process always gives rise to photons of energy greater than 150 Mev.

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Angular Distributions of Protons from $Na^{23}(d, p)Na^{24}$

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The angular distributions of the protons from the $Na^{23}(d, p)$-Na^{24} reaction has been observed, using a multiple nuclear plate technique.[1] A thin NaI target evaporated in vacuum on a thin silver foil was mounted at the center of the chamber and was bombarded by a 1.15-Mev deuteron beam collimated to 3 mm diameter from the Tohoku electrostatic generator. The proton group corresponding to the Na^{24} ground state was clearly resolved, and its angular distribution is shown in Fig. 1. The distribution shown in Fig. 2 is that of the sum of the two groups corresponding to the 0.472- and 0.564-Mev levels of Na^{24}.[2] It was obtained in a single plate at each angle.

The intensity ratio at 90° of the ground state group to the sum of the groups corresponding to the two excited states is about 1:2.2, in reasonable agreement with the value 1:(0.7+1.4) given

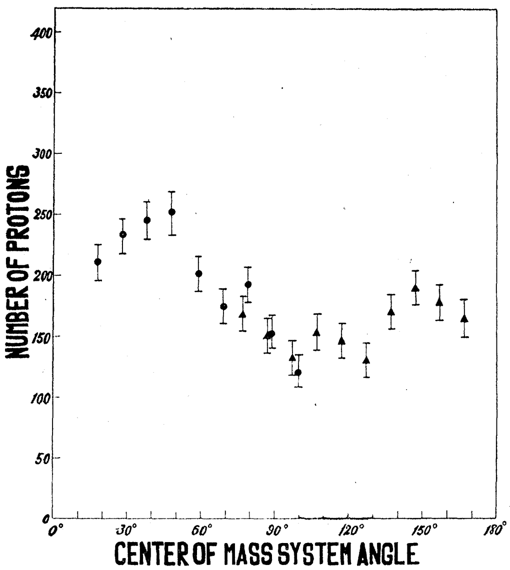

FIG. 1. Angular distribution of ground-state proton group from the reaction $Na^{23}(d, p)Na^{24}$.

by Sperduto and Buechner, taking the possible energy dependence[3] into account.

If the forward maximum in Fig. 1 is considered as the peak corresponding to the deuteron stripping process,[4] the l_n value in this case will be 2, and indeed, the experimental peak agrees well with the calculated one. Since Na^{23} and Na^{24} have the ground-state spin values $\frac{3}{2}$ and 4, respectively,[5] the angular momentum conservation

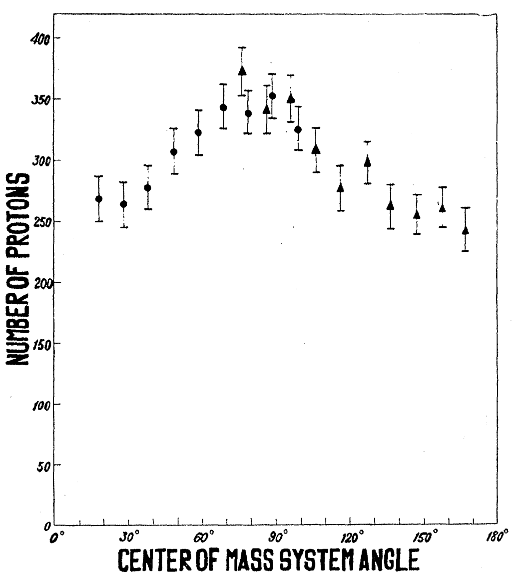

FIG. 2. Angular distribution of 0.472-Mev and 0.564-Mev excited-state proton groups.

law allows l_n values of 2 to 6, while the shell model seems to require a value of 2. Since the Na^{23} ground-state parity is even, the Na^{24} ground-state parity will be even, in agreement with the shell model prediction. Then, the beta decay of the Na^{24} ground state to the second excited state of $Mg^{24}(4, +)$[6] may be an allowed transition, but has rather a large ft value ($\log ft = 6.11$).[7] With respect to these conclusions, however, observations at higher bombarding energies are desirable. Further investigations are now in progress.

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Inner Bremsstrahlung and the Magnetic Moment of the Neutrino*

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IN A recent letter,[1] Hellund proposes the possibility of detection of a neutrino magnetic moment by its contribution to inner bremsstrahlung. There are difficulties with his calculation, since the intensity is derived as inversely proportional to the square of the neutrino rest mass. It is shown here that a complete and relativistic calculation results, in fact, in an expression that is finite in the limit of zero rest mass.[2]

The coupling of the neutrino with the electromagnetic field is accomplished through the addition to the Dirac Hamiltonian for a particle of charge zero, of the relativistic Pauli term,[3]

$$\lambda\gamma_\mu\gamma_\nu F_{\mu\nu}.$$

The Pauli term can be written in the equivalent, more usual form,

$$\lambda(\boldsymbol{\sigma}\cdot\mathbf{H}-i\boldsymbol{\alpha}\cdot\mathbf{E}),$$

where **H** and **E** are the field vectors of the radiation field. In the extreme relativistic case the two terms are of the same order of magnitude. In fact, taken alone each would contribute terms inversely proportional to the square of the neutrino rest mass. Taken together these terms cancel, leaving a result finite in the limit of zero rest mass.

The calculation is easily carried through with the Feynman methods. The relevant part of the S matrix is

$$(-i/\hbar c)^2 G\lambda \int \bar{\psi}_p(x_1)\mathbf{O}\psi_N(x_1)\bar{\psi}_e(x_1)\mathbf{O}\tfrac{1}{2}S_\nu(x_1-x_2) \times\frac{(\gamma_\mu\gamma_i-\gamma_i\gamma_\mu)}{2}\left(\frac{\partial A_i}{\partial x_\mu}-\frac{\partial A_\mu}{\partial x_i}\right)\psi_\nu(x_2)d^4x_1d^4x_2,$$

where ψ_p and ψ_N are the proton and neutron operators, ψ_e is the electron operator, ψ_ν the neutrino operator, S_ν the Feynman function for the neutrino, A_i the vector-potential of the radiation field, **O** the beta interaction, and G the beta-coupling constant. Confining ourselves henceforth to allowed spectra, and introducing the Fourier transforms, a matrix element H_{fi} is deduced,

$$|H_{fi}|=\left|\frac{G\lambda}{\hbar c}\left[\int\bar{\psi}_f\mathbf{O}\psi_i(x)d\tau\right] \times\left[\bar{\psi}_e(p_e)\mathbf{O}\frac{i\gamma(q+k)-\mu}{(q+k)^2+\mu^2}k_\mu A_i(k)(\gamma_i\gamma_\mu-\gamma_\mu\gamma_i)\psi_\nu(q)\right]\right|,$$

where ψ_i and ψ_f are the initial and final nuclear wave functions, and p_e, q, k are, respectively, the electron, neutrino, and photon wave numbers. Using $q^2+\mu^2=0$ and $k^2=0$ and the transverse nature of photons in the form $k_i=0$, by standard manipulations $|H_{fi}|$ is transformed into

$$|H_{fi}|=\left|\frac{G\lambda}{\hbar c}\left[\int\bar{\psi}_f(x)\mathbf{O}\psi_i(x)d\tau\right] \times\left[\bar{\psi}_e(p_e)\mathbf{O}\frac{2i(\gamma\cdot k)q_i-2i(q\cdot k)\gamma_i-2\mu\gamma_i(\gamma\cdot k)}{q\cdot k}\psi_\nu(q)\right]\right|.$$

It is easy to see directly that $\int|H_{fi}|^2d\omega$ is finite as $\mu\rightarrow 0$, where $d\omega$ corresponds to the angle between neutrino and photon.