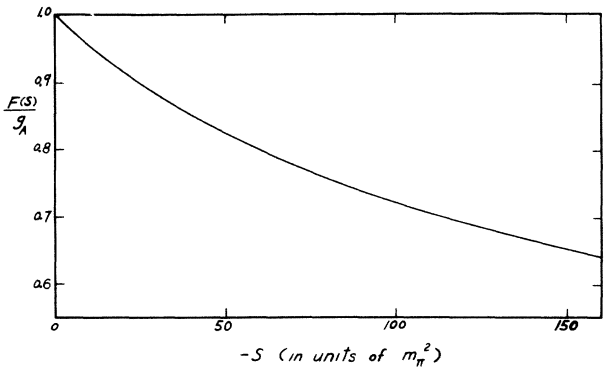

FIG. 2. The axial-vector form factor $F(s)/g_A$ as a function of the square of momentum transfer $-s$.

sidered as an overestimate in view of the neglect of contributions to g_A other than the $\pi\rho$ state.[4] Another remark is that the short cut above the real axis in Fig. 1 gives rise to a marked resonance behavior in the $\pi\rho$ scattering amplitude $M(s)_{22}$ around $s = 65$. There have been considerable interest and discussion as to whether such a resonance in unstable particle scattering can manifest itself in other physical processes by coupling through unitarity.[5] So far the attention is mostly on its effect on production amplitudes; e.g., whether the resonance in πN^* scattering can enhance $\pi N \to \pi N^*$. We have here another place where a similar effect can be looked for, where the physical manifestation, if any, is through the behavior of the form factor. This is because if the resonance in $\pi\rho$ scattering should enhance the $N\bar{N} \to \pi\rho$ amplitude $\lambda^J(s)$ in the low-energy region, by Eq. (17) $\mathrm{Im}\,F(s)$ would also become concentrated in the low-energy region, leading to a faster drop of $F(s)$ with increasing $-s$ than we have found. In our N/D solution no such enhancement in $\lambda^J(s)$ was found because $1/D(s)_{22}$ does not show any marked resonance around $s = 65$, in contrast to the full amplitude $M(s)_{22}$.

The author wishes to thank Professor G. Feinberg for suggesting this investigation, and for many helpful discussions. He also thanks Dr. N. P. Chang, Dr. Herman Chew, Dr. T. Truong, and Dr. Rudolph Hwa for discussions.

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[1]T. D. Lee and C. N. Yang, Phys. Rev. 126, 2239 (1962); G. Danby et al., Phys. Rev. Letters 10, 260 (1963).

[2]There now exists an extensive literature on the treatment of 3-particle intermediate states, particularly when two of them resonate. See R. Blankenbecler, Phys. Rev. 122, 983 (1960); S. Mandelstam et al., Ann. Phys. (N.Y.) 18, 198 (1962); J. S. Ball, W. R. Frazer, and M. Nauenberg, Phys. Rev. 128, 478 (1962); P. G. Federbush et al., Ann. Phys. (N.Y.) 18, 23 (1962); L. F. Cook and B. W. Lee, Phys. Rev. 127, 283 (1962); D. R. Harrington, Phys. Rev. 127, 2235 (1962); R. C. Hwa, Phys. Rev. 130, 2580 (1963).

[3]However, it can be shown that the Born term with N^* exchange does not contribute to the amplitude $\lambda^J(s)$ defined below.

[4]Of course, to determine $B(0)$ this way one must know the value of $\gamma_{\rho N\bar{N}}^2/4\pi$, which we have taken to be ≈ 2.

[5]R. F. Peierls, Phys. Rev. Letters 6, 641 (1961); and references quoted in reference 2.

ANALYSIS OF H^3 AND He^3 FORM FACTORS AND THE DETERMINATION OF THE CHARGE FORM FACTOR OF THE NEUTRON*

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Experiments on the elastic scattering of high-energy electrons from H^3 and He^3 have recently been carried out[1,2] at Stanford University on targets specially prepared by the Los Alamos Laboratory. These results were interpreted in a straightforward manner and provided distributions of charge densities, magnetic moment densities, and sizes of the two mirror nuclei.

It is also possible to make a much more detailed analysis of the appropriate form factors that is able to describe some of the internal dynamics of the nucleons in the ground states of H^3 and He^3. Moreover, by methods we shall describe, the charge form factor of the neutron can be found from the above-quoted experiments. The charge form factor of the neutron has heretofore been an

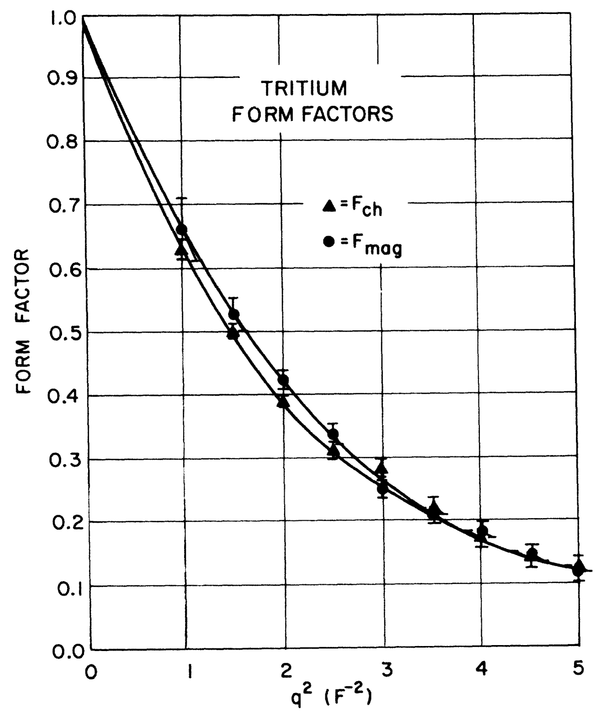

FIG. 1. New values of H^3 form factors.

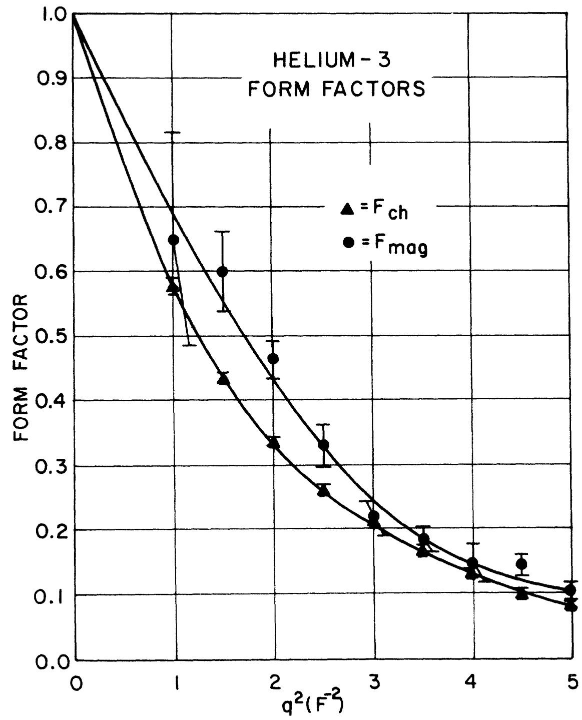

FIG. 2. New values of He^3 form factors.

elusive quantity and has been determined up to now mainly by studying the deuteron. Our present method therefore provides an independent and novel determination of the charge form factor of the neutron, F_{ch}^{n}.

Before describing the theoretical approach to this question, we point out that the data in reference 2 have been thoroughly restudied with the result that error determinations and central values of the form factors in that reference have been very slightly modified and improved. Figures 1 and 2 show the new values used in the present formulation. The analysis of the experimental data which resulted in the new values of the form factors will be described subsequently in a more complete publication.

A phenomenological analysis of the high-energy electron elastic-scattering data on H^3 and He^3 can be made in terms of the wave function for the three-nucleon system. We assume that the total electric charge density and total magnetic-moment density can be expressed without mutual interference as the sum of contributions from each of the three nucleons, together with an exchange magnetic-moment density. The contribution from each nucleon is the resultant of the distribution of its center in space, which is determined by the nuclear wave function, and its own structure, which is assumed to be the same as for the free proton or for the neutron in deuterium.

The principal components of the wave function are believed to be the dominant, fully space-symmetric $^2S_{1/2}$ state (denoted S), the $^2S_{1/2}$ state of mixed symmetry (denoted S'), and the three $^4D_{1/2}$ states (denoted D).[3] The probabilities of the S' and D states are not expected to be more than a few percent,[4] so that the S^2, D^2, and $S'D$ contributions to the form factors are probably too small to observe with present experimental accuracy. The cross term SS' contributes to both the charge and moment form factors, and the SD term only to the moment form factors. Since the moment form factors also contain the unknown exchange moment contribution, it is reasonable to absorb the SD term into the exchange term in analyzing the experimental data. The effect of the Coulomb repulsion between the protons in He^3 is neglected, so that the same wave function is used for both nuclei. It is also assumed that the exchange term has the same structure for both nuclei, even though a small error is probably incurred here owing to the inclusion of the SD contribution.

In this way the following expressions for the form factors, or three-dimensional Fourier transforms, of the charge and moment distributions of the two nuclei may be obtained[5]:

$$2F_{\mathrm{ch}}(\mathrm{He}^3) = 2F_L F_{\mathrm{ch}}^{\ p} + F_O F_{\mathrm{ch}}^{\ n},$$

$$\mu(\mathrm{He}^3)F_{\mathrm{mag}}(\mathrm{He}^3) = \mu(n)F_O F_{\mathrm{mag}}^{\ n} + \tfrac{2}{3}\mu(p)(F_O - F_L)F_{\mathrm{mag}}^{\ p} + [\mu(\mathrm{He}^3) - \mu(n)]F_X,$$

$$F_{\mathrm{ch}}(\mathrm{H}^3) = 2F_L F_{\mathrm{ch}}^{\ n} + F_O F_{\mathrm{ch}}^{\ p},$$

$$\mu(\mathrm{H}^3)F_{\mathrm{mag}}(\mathrm{H}^3) = \mu(p)F_O F_{\mathrm{mag}}^{\ p} + \tfrac{2}{3}\mu(n)(F_O - F_L)F_{\mathrm{mag}}^{\ n} + [\mu(\mathrm{H}^3) - \mu(p)]F_X.$$

Each of the F's is a function of the momentum transfer q, and is normalized to unit value at $q = 0$ (except of course for $F_{\mathrm{ch}}^{\ n}$). The μ's are the static magnetic moments in units of the nuclear magneton, and F_X contains the exchange and SD contributions. We may write $F_1 = \frac{1}{3}(2F_L + F_O)$, $F_1 = (F_O - F_L)$, in which case F_1 arises just from the S state and F_2 from the SS' cross term. Thus F_2 is much more sensitive to the S' state than other observable quantities, such as the binding energy.

Because of the manner in which F_L and F_O appear in the above equations, it is natural to think of F_L as the form factor associated with the spatial distribution of each of the like pair of nucleons (protons in He^3 and neutrons in H^3), and F_O as that associated with the odd nucleon. Indeed, in a preliminary report[6] in which a single S state symmetric only in the space coordinates of the like nucleons was employed, nearly the same equations as those above were obtained. Although such a wave function is inconsistent with charge independence of nuclear forces, the lack of symmetry between the like pair and the odd nucleon has its counterpart in the isotopic spin formalism in the above-mentioned cross term between the two S states of different symmetry.

In this formulation of the three-nucleon problem, we note that there are seven unknowns in the four independent equations, as follows: F_L, F_O, F_X, $F_{\mathrm{ch}}^{\ p}$, $F_{\mathrm{mag}}^{\ p}$, $F_{\mathrm{ch}}^{\ n}$, and $F_{\mathrm{mag}}^{\ n}$. Since, however, $F_{\mathrm{ch}}^{\ p}$, $F_{\mathrm{mag}}^{\ p}$, and $F_{\mathrm{mag}}^{\ n}$ are all well known, only four unknowns remain and therefore the equations may be solved at all values of q^2. Only one of the two sets of solutions is of physical significance, and this is the solution we have chosen. Thus our analysis provides a new and independent method of obtaining $F_{\mathrm{ch}}^{\ n}$. In this way we obtain the data shown in Table I which give the values of $F_{\mathrm{ch}}^{\ n}$, F_X, F_L, and F_O.

The fact that this analysis of the nuclear three-body problem leads to no contradictions, and, on the contrary, to reasonable values of $F_{\mathrm{ch}}^{\ n}$ and the other unknowns, is very satisfactory and adds to our confidence in the method. The values of $F_{\mathrm{ch}}^{\ n}$ found in this paper are in substantial agreement with those reported by other investigators of neutron structure, but our method will permit higher accuracy as the experimental data improve with time.

The internal behavior of the nucleons in H^3 and He^3 may be found from a further analysis of F_L and F_O which involves the wave functions of the various nucleons in each of the mirror nuclei. Three assumptions are made as to the dependence of the S wave function on the internucleon distances: (a) an exponential function of the sum of the three distances divided by the square root of their product; (b) an exponential function of the sum of the squares of the distances; and (c) an exponential function of the square root of the sum of the squares of the distances. These are re-

Table I. Form factors.

q^2 (F^{-2})	$F_{\mathrm{ch}}^{\ n}$	F_X	F_L	F_O
1.0	−0.024 ± 0.162	1.168 ± 2.247	0.649 ± 0.077	0.731 ± 0.237
1.5	+0.091 ± 0.095	2.246 ± 0.778	0.481 ± 0.026	0.479 ± 0.098
2.0	+0.050 ± 0.062	1.696 ± 0.369	0.396 ± 0.016	0.422 ± 0.054
2.5	−0.028 ± 0.069	0.846 ± 0.475	0.343 ± 0.024	0.422 ± 0.060
3.0	−0.006 ± 0.086	0.191 ± 0.455	0.293 ± 0.026	0.380 ± 0.064
3.5	−0.039 ± 0.053	0.244 ± 0.269	0.245 ± 0.016	0.331 ± 0.036
4.0	−0.093 ± 0.083	0.087 ± 0.454	0.219 ± 0.028	0.314 ± 0.059
4.5	+0.015 ± 0.107	0.505 ± 0.215	0.154 ± 0.018	0.207 ± 0.042
5.0	+0.007 ± 0.084	0.266 ± 0.178	0.134 ± 0.015	0.145 ± 0.031

ferred to as the exponential, Gaussian, and Irving[7] wave functions, respectively. F_L and F_O are calculated analytically in each case. The available experimental data show a definite preference for (b) and (c) over (a), and a slight preference for (c) over (b). The size parameters for the Gaussian and Irving wave functions are in good agreement with those obtained from the Coulomb energy of He^3, and the probability of the mixed-symmetry S state is found to be about 4%. Calculational details will be published separately.[5]

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INTERMEDIATE BOSONS: PAIR PRODUCTION CROSS SECTION BY PHOTONS

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If the intermediate boson[1] $W^{\pm}$ particles should exist, in principle, they could be produced in particle-antiparticle pairs by high-energy photons in the proton (or nucleus) Coulomb field. While there seem to exist at the present moment certain experimental difficulties concerning the considerable μ, e pair backgrounds,[2] it is nevertheless hoped that the experiments will eventually be performed. We have therefore made a calculation on such pair-photoproduction cross section of $W^{\pm}$, to the lowest order of the fine structure constant. No discussion is made, in this note, of higher order corrections[3] to this process.

To be more precise, the differential cross section is computed in closed form. For the total cross section, a two-dimensional integration is performed numerically on an IBM 7094. The boson mass M_W and the anomalous magnetic moment[3] κ are taken as parameters. It is seen that, at a given (lab) photon energy, the cross section is quite sensitive to both the anomalous magnetic moment and the boson mass. Therefore, it is hoped that, with sufficient experimental data, the actual values of M_W and κ may be determined from the production experiments.

The calculation is made on the following two processes:

$$\gamma + p \to p + W^+ + W^-, \tag{1}$$

$$\gamma + Z \to Z + W^+ + W^-, \tag{2}$$

and is based on the set of Feynman diagrams shown in Fig. 1. These processes have been