SCALAR NUCLEON FORM FACTOR $F_1^n + F_1^p$*

Norman K. Glendenning and Gustav Kramer†
Lawrence Radiation Laboratory, University of California, Berkeley, California
(Received October 23, 1961)

All meson-theoretic derivations of nucleon-nucleon potentials agree that the outer region should behave like the one-pion exchange potential (OPEP). The inner region cannot be calculated unambiguously, however, and is therefore usually treated phenomenologically.

The modification of the inner region in such a way as to fit the low-energy n-p data is the subject of a forthcoming work.[1] There we discovered that the integrals that enter the deuteron electromagnetic form factor G^2 are very insensitive to the inner region of the potential for $q \lesssim 3\ \mathrm{f}^{-1}$, and are therefore determined by the well-established OPEP tail. This fact can be used to extract the sum of the neutron and proton charge form factors $F_1^p + F_1^n$ with practically no uncertainty arising from our imperfect knowledge of the n-p force. The sum $F_1^p + F_1^n$ is obtained from the expression[2]

$$G_{\mathrm{exp}}^2 = (F_1^p + F_1^n)^2 (G_0^2 + G_2^2) + [2\tan^2(\theta/2) + 1] G_{\mathrm{mag}}^2, \qquad (1)$$

where G_0, G_2, G_{mag} are, respectively, the contributions from the spherical and quadrupole charge distributions and the magnetic moment.[3] In addition to F_1^p and F_1^n, G_{mag} contains also the magnetic parts of the nucleon form factors F_2^p and F_2^n. Since G_{mag} is almost everywhere at least two orders of magnitude less than $G_0^2 + G_2^2$, its value will effect at most the third figure of $F_1^p + F_1^n$ (except at large angles, which we avoid). Since the already published neutron form factors of Hofstadter et al.[4] should allow us to compute G_{mag} to at least one significant figure, we shall use the published values of the nucleon form factors in G_{mag}.

We have used the experimental cross section for elastic electron-deuteron scattering of Friedman, Kendall, and Gram[5] to find $G_{\mathrm{exp}}^2 = (d\sigma/d\Omega)_{\mathrm{exp}}/(d\sigma/d\Omega)_0$, where $(d\sigma/d\Omega)_0$ is the cross section for electron scattering from a spinless point charge.

Drawing a smooth curve through a recent experimental measurement[6] of the proton charge form factor F_1^p, we obtained values for this quantity which we subtracted from our value of $F_1^p + F_1^n$ to get the neutron charge form factor. Our results are tabulated in Table I. The upper and lower limit on $F_1^n + F_1^p$ come both from the experimental uncertainty in G_{exp}^2 and the slight uncertainty in the integrals appearing on the right side of Eq. (1) arising from our imperfect knowledge of the nucleon force at small distances.

As can be seen from the table, it is consistent with the existent data to say that the neutron charge form factor F_1^n is zero, at least up to a momentum transfer $q = 3\ \mathrm{f}^{-1}$. However, most of the data suggest a very small negative value of the form factor.

Our results do not agree with those of the Stan-

Table I. Upper and lower limits on the scalar nucleon form factor $F_1^n + F_1^p$ and the neutron form factor F_1^n deduced from the experimental proton and deuteron form factors F_1^p and G are shown. We obtain F_1^p by drawing a smooth curve through the experimental points of reference 6.

q (f^{-1})	θ (deg)	G^2 exp	$F_1^n + F_1^p$ Lower	$F_1^n + F_1^p$ Upper	F_1^p exp	F_1^n Lower	F_1^n Upper
0.99	60.0	0.266 ±0.025	0.781	0.877	0.901	−0.120	−0.024
1.07	70.0	0.241 ±0.023	0.789	0.890	0.889	−0.100	0.001
1.36	90.0	0.151 ±0.015	0.779	0.897	0.839	−0.060	0.058
1.51	105.0	0.101 ±0.009	0.716	0.824	0.809	−0.093	0.015
1.79	43.0	0.0496 ±0.0048	0.638	0.751	0.748	−0.110	0.003
1.99	48.5	0.0290 ±0.0027	0.574	0.685	0.706	−0.132	−0.021
2.22	55.0	0.0225 ±0.0022	0.610	0.744	0.658	−0.048	0.086
2.41	61.0	0.0107 ±0.0009	0.489	0.600	0.619	−0.130	−0.019
2.61	67.5	0.00733 ±0.00077	0.467	0.598	0.578	−0.111	0.020
2.82	75.0	0.00422 ±0.00042	0.413	0.537	0.538	−0.125	−0.001

ford[4] and Cornell[7] groups who analyzed the inelastic (deuteron breakup) process. However, no analysis of the inelastic process to date has accounted for the presence of the D state in the deuteron, nor all of the final-state interactions, except in a rough manner.[2,8]

There is some uncertainty introduced into our results by unknown relativistic and meson-current effects. Nevertheless we feel that these effects will be small in the region of low momentum transfer considered here.[9]

---

*Work supported by the U. S. Atomic Energy Commission.

†On leave from the University of Heidelberg, Heidelberg, Germany.

[1]N. K. Glendenning and G. Kramer, Lawrence Radiation Laboratory Report UCRL-9904 (to be published). The potentials were required to yield the deuteron binding energy and quadrupole moment and give a scattering phase shift at zero energy consistent with the known scattering length. In addition, the phase shifts at higher energies were calculated and they agree roughly with the analysis of the experimental data at 95 Mev by M. H. MacGregor, Phys. Rev. 123, 2154 (1961), and with two of the solutions in the energy range up to 300 Mev of M. H. Hull, K. E. Lassila, H. M. Ruppel, F. A. McDonald, and G. Breit, Phys. Rev. 122, 1606 (1961).

[2]V. Z. Jankus, Phys. Rev. 102, 1586 (1956).

[3]R. Hofstadter, Ann. Rev. Nuclear Sci. 7, 231 (1957).

[4]R. Hofstadter, C. de Vries, and R. Herman, Phys. Rev. Letters 6, 290 (1961); R. Hofstadter and R. Herman, Phys. Rev. Letters 6, 293 (1961). We used Eqs. (9) through (12) in the second of these references.

[5]J. I. Friedman, H. W. Kendall, and P. A. M. Gram, Phys. Rev. 120, 992 (1960).

[6]F. Bumiller, H. Croissiaux, E. Dally, and R. Hofstadter, Phys. Rev. 124, 1623 (1961).

[7]D. N. Olson, H. F. Schopper, and R. R. Wilson, Phys. Rev. Letters 6, 286 (1961). R. M. Littauer, H. F. Schopper, and R. R. Wilson, Phys. Rev. Letters 6, 141 (1961); 6, 144 (1961).

[8]L. Durand, III, Phys. Rev. Letters 6, 631 (1961); Phys. Rev. 123, 1393 (1961).

[9]R. Blankenbecler, thesis, Stanford University, 1958 (unpublished), has studied relativistic corrections, using a simplified model of the deuteron (two bosons, one of which is charged, bound by a separable potential). In this model the corrections can give rise to a 25 to 30% reduction in the cross section at $q = 3\ \mathrm{f}^{-1}$ which would mean that the scalar charge form factor would be larger by as much as 15%. Whether the corrections would be as large in a realistic model is not clear. However, suppose that this is the correction that obtains at $q = 3\ \mathrm{f}^{-1}$. Then if we applied a correction that is 15% at $q = 3\ \mathrm{f}^{-1}$ and goes linearly to zero as $q \to 0$, the limits we place on $F_1{}^n$ would lie one above and one below the zero value for all values of q listed in our table except at $q = 2.2\ \mathrm{f}^{-1}$, where both limits are positive.

ERRATA

RESONANCE IN THE $\Lambda\pi$ SYSTEM. Margaret Alston, Luis W. Alvarez, Philippe Eberhard, Myron L. Good, William Graziano, Harold K. Ticho, and Stanley G. Wojcicki [Phys. Rev. Letters 5, 520 (1960)].

Due to a typographical error, a sentence in the second paragraph on page 523, line 26, is incorrect and should read: "We find the ratio of events with $|\xi| < 0.5$ to all events is 0.355." The conclusions of the paragraph remain unchanged.

π-π RESONANCE IN π^--p INTERACTIONS AT 1.25 Bev. E. Pickup, D. K. Robinson, and E. O. Salant [Phys. Rev. Letters 7, 192 (1961)].

Due to a computational error, the mean value of the $\pi^-\pi^0$ and $\pi^-\pi^+$ cross sections at the maximum of the resonance was incorrectly stated as $\sigma_{\pi-\pi} = 95$ mb. The correct value is 65.0 ± 7.5 mb. The values of the ordinate in Fig. 3 should be multiplied by 0.68.

LIFETIME EFFECTS IN CONDENSED FERMION SYSTEMS. A. Bardasis and J. R. Schrieffer [Phys. Rev. Letters 7, 79 (1961)].

It has been pointed out by P. Nozières that a more accurate estimate of the damping coefficient α for He^3 can be made with the aid of the theoretical expression for the thermal conductivity given by Abrikosov and Khalatnikov.[1] Our original assumption that the thermal conductivity relaxation time is given by

$$\tau = \hbar/2\alpha(kT)^2,$$

leads to $\alpha = 9.1 \times 10^{16}\ \mathrm{erg}^{-1} \simeq 37.6/E_F$. The more refined estimate using $m^* = 2.82\ m$ gives $\alpha = 4.27 \times 10^{15}\ \mathrm{erg}^{-1} \simeq 1.77/E_F$. With this value one finds that damping effects reduce the transition temperature $T_c{}^0$, predicted in the absence of damping, to

$$T_c \simeq 0.32\ T_c{}^0.$$

[1]A. A. Abrikosov and I. M. Khalatnikov, Reports on Progress in Physics (The Physical Society, London, 1959), Vol. 22, p. 329.