PHYSICAL REVIEW C VOLUME 26, NUMBER 1 JULY 1982

Modified nucleons in nuclei: Test of Noble's hypothesis

Peter D. Zimmerman
Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803
(Received 19 February 1982)

The longitudinal response functions extracted from the deep-inelastic electron scattering data of Altemus *et al.* were shown to be in reasonable agreement with calculations based on J. V. Noble's hypothesis that the nucleon properties are radically altered in nuclear matter. Other data are shown in this work to be much less well fitted.

[NUCLEAR STRUCTURE Quasielastic electron scattering, nuclear properties, momentum distribution.]

The deep-inelastic scattering electron experiment from ^{56}Fe of Altemus and her co-workers[1] indicated that the integral of the longitudinal response function $R_L(q,\omega)$ differed significantly from that expected on the basis of the Fermi gas model of Van Orden.[2] More recent data by Deady and his co-workers[3] (^{40}Ca, ^{48}Ca) and by the Saclay-LSU-Rome-Clermont-Basel collaboration[4] (^{12}C) tended to confirm a certain quenching of $R_L(q,\omega)$ while indicating that the transverse response function $R_T(q,\omega)$ was reasonably well given by the same Fermi gas model. The three-momentum transfer is given by q and the energy transfer by ω.

Noble recently suggested that the nucleon form factor in nuclear matter was altered by an effective mass, while the absolute values of the anomalous magnetic moments of the nucleons declined compared to those of the free particles. The variation of the magnetic moments was derived on the basis of a detailed theory by Noble.[5] This "renormalization" anzatz when applied to the ^{56}Fe data produced remarkable agreement between the measured and calculated values of R_L at three-momentum transfers of 370 and 410 MeV/c. Unfortunately, this approach also quenched $R_T(q,\omega)$, which then dropped well below the measured values. This disagreement between calculated and measured R_T means that Noble's calculation would not give the correct cross section for the Altemus experiment. The discrepancy was attributed by Noble to the presence of meson exchange current contributions.

If m_n^* is the effective mass introduced by Noble, and m_n the free nucleon mass, then with q_μ in units of MeV/c the nucleon form factor would be written

$$F_1^*(q_\mu{}^2)=F_2^*(q_\mu{}^2)=[1-(q_\mu m_n)^2/(855m_n^*)^2]^{-2} \tag{1}$$

with $m_n^*=700$ MeV and q_μ the four-momentum transfer.[5] In all other points of the Van Orden calculation m_n is to be replaced by m_n^* and the adjusted values of the anomalous moments used in place of the free ones. Because Noble's form factor falls off more rapidly with q_μ than does the dipole fit, it may be interpreted as signifying a larger nucleon radius.

Additional data[6] taken at generally larger values of q exist, and Noble's hypothesis should be tested against them. These data consist of isolated spectra from nine nuclei taken at Stanford at a bombarding energy of 500 MeV and a scattering angle of 60°. In Fig. 1 are shown the published data compared to the Van Orden calculation (solid line), and the results obtained using Noble's formulation (dashed line). The Noble hypothesis clearly underestimates the cross section by a very large amount. While the results from only three nuclei (^{12}C, natural Ni, and ^{208}Pb) are shown in this paper, those for the remaining six were also calculated. They do not differ in character in any significant way from those results displayed here. The program used to obtain these numerical results was tested extensively.

The Noble curves were subtracted from the original data points (⧫) to yield the points marked with ×'s (⚹). This "difference curve" gives an estimate of the magnitude and shape of the additional nuclear or mesonic processes needed to bring data and theory into agreement. The difference curves have the characteristic shape which results from the phase space for single-particle knockout and not the shape resulting from the phase space for meson exchange currents, a two body process.[7]

Noble expects his theory to fail for transverse processes, since it only includes single particle knockout. The magnitude of the failure is, however, surprising, particularly since the Whitney measurement[6] was made at a forward angle. In the Van Orden model, at 60°, the longitudinal response function contributes about 44% of the calculated nickel cross section near the quasielastic peak; similar longitudinal contributions are found for the other targets. For comparable three-momentum transfers at the larger angles ($\theta \geq 90°$) where the ^{56}Fe experiment was performed, the contribution from R_L is much less. It seems improbable that meson exchange currents

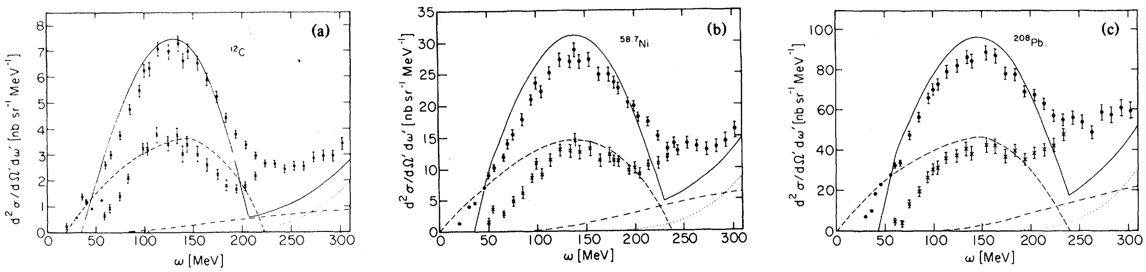

FIG. 1. (a) Deep-inelastic scattering data from ^{12}C. The solid curve is Van Orden's Fermi gas calculation plus MEC and meson production effects. The dashed curve is the cross section calculated using Noble's hypothesis. The dash-dot curve is Van Orden's MEC contribution, and the dotted curve his meson production calculation. Data points indicated with circles are those of Whitney *et al.*; those indicated with ×'s are those of Whitney but with the Noble quasielastic cross section subtracted. $E = 500$ MeV, $\Theta = 60°, k_F = 221$ MeV/c, and $\bar{\epsilon} = 25$ MeV. The average binding energy is $\bar{\epsilon}$ in Van Orden's work. (b) Same as (a), except that the data are from $^{58.7}Ni$ (natural Ni); $k_F = 260$ MeV/c and $\bar{\epsilon} = 36$ MeV. (c) Same as (a), except that the data are from ^{208}Pb; $k_F = 265$ MeV/c and $\bar{\epsilon} = 44$ MeV.

(MEC) could explain this large discrepancy,[2] even if the MEC were calculated with small or zero binding energy as Noble suggests.[5]

Another test which might be applied to Noble's theory is West-Kawazoe "y scaling"[8,9] known to work well for calcium[3,10] and carbon.[11] The variable y is the component of the struck nucleon's momentum parallel to the virtual photon. In the scaling procedure spectra obtained at the different energies and angles are related to one another by the use of a function of the kinematic variables. This function explicitly includes the square of the usual dipole form factor, which is obtained from Eq. (1) by setting $m_n^* = m_n$, rather than Noble's altered form. West-Kawazoe scaling rests on the assumptions that the photon couples to single nucleons, that these nucleons are nearly free, that convection current effects can be neglected and implicitly, that the q_μ dependence of the nucleon form factors is the same as that observed for the free particles. Only if these assumptions are valid will scaling be observed.

It is possible that by permitting the longitudinal and transverse nucleon form factors to be separately modified in nuclear matter, a transverse response function which agreed with the data could have been developed. This, however, would have introduced additional parameters which would have destroyed the simplicity which is the basis of much of the appeal of Noble's idea.

I thank Professor J. W. Van Orden, Dr. T. W. Donnelly, and Dr. C. F. Williamson for important discussions and for encouraging me to make this comparison in the first place. Mr. C. C. Blatchley and Mr. O. E. Pruet assisted with the programming. This work was supported in part by grants from the National Science Foundation and the Research Corporation.

[1]R. Altemus *et al.*, Phys. Rev. Lett. 44, 965 (1980).

[2]J. W. Van Orden, Ph.D. dissertation, Stanford University, 1978 (unpublished); and T. W. Donnelly, J. W. Van Orden, T. DeForest, and W. C. Hermans, Phys. Lett. 76B, 393 (1978).

[3]M. Deady *et al.*, unpublished; M. Deady, Ph.D. dissertation, Massachusetts Institute of Technology, 1981 (unpublished).

[4]P. Barreau *et al.*, Nucl. Phys. A358, 287c (1981).

[5]J. V. Noble, Phys. Rev. Lett. 46, 412 (1981).

[6]R. R. Whitney *et al.*, Phys. Rev. C 9, 2230 (1974).

[7]J. W. Van Orden, private communication.

[8]G. B. West, Phys. Rep. C 18, 269 (1975).

[9]Y. Kawazoe, G. Takeda, and H. Matsuzaki, Prog. Theor. Phys. 54, 1394 (1975).

[10]Peter D. Zimmerman, C. F. Williamson, and Y. Kawazoe, Phys. Rev. C 19, 279 (1979).

[11]Peter D. Zimmerman and C. F. Williamson, Bull. Am. Phys. Soc. 24, 684 (1980) (paper JK 13 using data from paper JK 12).