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Magnetic electron scattering from deuterium at low-momentum transfer

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The elastic and inelastic cross sections of deuterium for 56.4 MeV electrons scattered at 180°, have been measured up to an excitation energy of 19 MeV. The experimental cross sections are compared with those calculated by Miller, by Durand, and by Arenhövel and Fabian, and also with the sum rules of O'Connell. The results indicate that the contribution of meson exchange currents at this low-momentum transfer is significant.

[NUCLEAR REACTIONS ^{2}H(e,e'); $\theta=180°$, $E=56.4$ MeV; measured σ for $E_x=0$ to 19 MeV. Deduced elastic magnetic form factor.]

I. INTRODUCTION

Although considerable attention has been given in recent years to studies of electron scattering from deuterium at high-momentum transfers,[1,2] there is, nevertheless, an abiding need for low-momentum transfer data. Some earlier electron scattering work[3] at 180° has been done in this momentum region. However, it was of relatively low resolution. The work reported on here[4] constitutes a higher resolution study in which the measured cross sections for elastic and inelastic scattering are compared with theoretical calculations[5-7] and with sum rules.[8] Of particular importance is the comparison with the work of Arenhövel and Fabian[7] which indicates the presence of significant meson-exchange effects at the low-momentum transfer used in this work.

II. EXPERIMENTAL CONSIDERATIONS

The elastic and inelastic spectra of electrons scattered at 180° were obtained using 56.4-MeV incident electrons from the Naval Research Laboratory 65-MeV Linac. The inelastic spectrum was taken up to an excitation energy of 19 MeV. The deuterium target gas was contained in a cylindrical stainless steel chamber 5.08 cm long, 1.90 cm in diameter, and with 12.7 μm thick titanium foil windows, 0.952 cm in diameter, at each end. This chamber, which was in turn inserted into the target vacuum chamber, was cooled to liquid nitrogen temperature and pressurized to 4.4 atm. Under these conditions a target thickness of 14.4 mg/cm^2 could be achieved for the experiment. The details of the 180° electron scattering facility,[9] as well as of the gas target system[10] and its use,[11] can be found in earlier reports.

The collected data were corrected for magnetic spectrometer dispersion and detector efficiency variations. Because the magnetic spectrometer has a finite solid angle of 1.64 msr, charge scattered electrons at angles near 180° will be counted. If multiple scattering is also considered, the effective scattering angle is 178.9°. Also there is background from the gas chamber windows plus and overall background due to some electrons striking the beam pipes, collimators, slits, and other parts of the beam handling system. To subtract this overall background including that due to charge scattering, ^{4}He at the same pressure as ^{2}H was used, since it has no magnetic moment.

Calibration of the gas target system was accomplished by measuring the ^{1}H elastic scattering cross section and comparing it to accepted values in the literature[12] to obtain a correction factor which could then be applied to the ^{2}H cross section measurements. Details of the procedure used in doing this, as well as that used in the radiative unfolding of the spectrum, are given in an earlier report.[11]

III. RESULTS AND DISCUSSION

The radiatively unfolded experimental cross section values for 56.4-MeV electrons scattered at 180° from the above-described gas target are presented in Fig. 1. Shown also is the calculated cross section curve of Miller[5] for the small inelastic region between about 2.4- and 3-MeV excitation, which was based on the impulse approximation calculation of Adler.[13] Above 3-MeV excitation the curve is based on the theory of Durand.[6] In addition, the dashed curve in Fig. 1 presents the results of a recent calculation based on the work of Arenhövel and Fabian[7] which uses a Reid soft-core potential and includes meson-exchange (MEC) and isobar configuration (IC) effects. The latter curve clearly is in much better agreement with the experimental data. The recent high energy experiments of Simon *et al.*[14] when also compared to the calculations of Ref. 7 indicate the presence of MEC and IC effects. Our results show that even at low-momentum transfers, especially the MEC effects can still play a significant role in the interaction.

In an earlier work, Peterson and Barber,[3] using a 41.5 MeV incident beam, also measured the electrodisintegration cross section of ^{2}H at 180°. Their experimental values were compared with the point-nucleus calculation of Jankus.[15] This calculation was found to be about 50% below the experimental points at the higher excitation energies. Although this early experiment was performed with considerably lower resolution than the present work, there is good agreement between the two measurements.

The value of the magnetic form factor, F_{MAG}, for the elastic scattering found in this work is plotted versus q^2 in Fig. 2 along with values measured by other investigators.[16-18] The experimental point contributed by this work is $F_{\text{MAG}} = 0.89 \pm 0.06$ at $q^2 = 0.308$. This was determined by taking the square

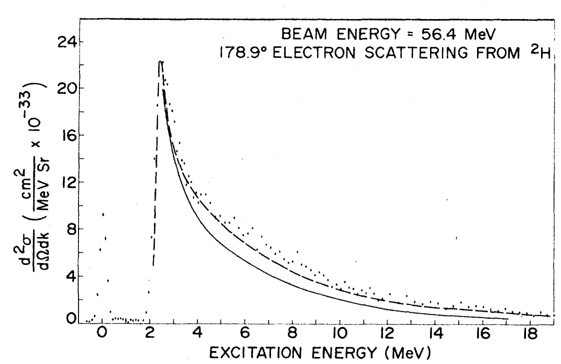

FIG. 1. Cross section values for 56.4-MeV electrons scattered at 180° from ^{2}H. The solid curve is based on the calculation of Miller (Ref. 5) up to 3-MeV excitation and Durand (Ref. 6) above this energy. The dashed curve is the result of a calculation of Arenhövel (Ref. 7) which includes meson-exchange and isobar configuration effects.

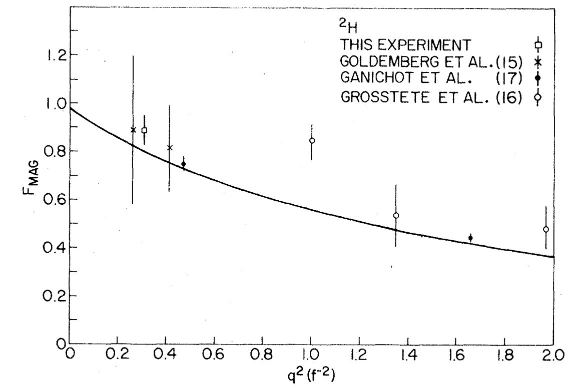

FIG. 2. Magnetic form factors for elastic electron scattering from ^2D from different experiments plotted vs q^2. The solid line is a calculation of F_{MAG} using the Reid soft-core potential with 6.5% D state (Ref. 18).

root of the ratio of the experimental to the Mott cross section values. Shown also is a calculated[19] curve for the form factor using a Reid soft- core potential with a 6.5% D state contribution. Although there is general agreement with the shape of the calculated curve, it is consistently lower than the experimental points. Since the relatively large amount of D state causes the calculated static magnetic moment to be somewhat low, the entire curve is shifted downward, particularly in the low q^2 region.

We compare our experimental results with the sum rule of O'Connell,[8] which is derived for the spatially symmetric part of the 1s shell nuclei. This comparison, along with the details of the theoretical sum rule expressions, also was given in an earlier report.[11] Therefore, it is sufficient here to note that O'Connell's basic expression

$$\int_0^q \left.\frac{d^2\sigma}{d\Omega\, dE}\right|_q dk = \sigma_0(J+M)\,, \tag{1}$$

essentially consists of two terms, J and M. J represents the transverse convection current contribution, while M is the spin magnetization contribution (for the precise definition of all quantities in Eq. (1) see Ref. 11). In Table I are presented the

TABLE I. The factor $J+M$ of the sum rule expression of O'Connell (Ref. 8) is compared with experimental values of the factor corresponding to the elastic, inelastic, and total cross sections. The errors shown on the $J+M$ total are chiefly due to the inelastic part. The experimental sums were taken up to 19-MeV excitation energy.

	Experiment	Theory
	$J+M$	$J+M$
elastic	0.0042	
inelastic	0.0535	
total	0.0577 ± 0.0033	0.078

values of $J+M$ for the elastic, inelastic, and total cross sections to be compared. It will be noted that the experimental value for the total cross section up to 19-MeV excitation is about 74% of the theoretical value which includes all excitation energies. The sum of the inelastic experimental values exhaust 69% of the theoretical sum. This is to be compared with 60% exhausted by the inelastic cross section sum calculated from Arenhövel and Fabian[7] (not included in Table I).

In conclusion it is judged that this work provides a higher resolution low-momentum datum needed in arriving at any overall understanding of deuteron structure. In particular this work shows that meson-exchange effects are present to a significant extent in the interaction at low-momentum transfers.

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[1]F. Martin *et al.*, Phys. Rev. Lett. 38, 1320 (1977).
[2]G. Simon *et al.*, Phys. Rev. Lett. 37, 739 (1976).
[3]G. A. Peterson and W. C. Barber, Phys. Rev. 128, 812 (1962).
[4]For an earlier preliminary report see E. C. Jones, Jr., Ph.D. thesis, American University, Washington D.C., 1973 (unpublished).
[5]H. C. Miller, Ph.D. thesis, the American University, Washington D. C., 1970 (unpublished).
[6]L. Durand III, Phys. Rev. 123, 1373 (1961).
[7]H. Arenhövel *et al.*, contributed paper to *Proceedings of the International Conference on Nuclear Physics with Electromagnetic Interactions, Mainz, 1979* (Springer, Berlin, 1979), p. 7.7; W. Fabian and H. Arenhövel, Nucl. Phys. A314, 253 (1979); and H. Arenhövel, private communication.
[8]J. S. O'Connell, Phys. Lett. 32B, 323 (1970).
[9]L. W. Fagg, Rev. Mod. Phys. 47, 683 (1975).
[10]L. W. Fagg, E. C. Jones, Jr., and W. L. Bendel, Nucl. Instrum. Methods 77, 136 (1970).
[11]E. C. Jones, Jr., W. L. Bendel, L. W. Fagg, and R. A. Lindgren, Phys. Rev. C 19, 610 (1979).
[12]D. J. Drickey and L. H. Hand, Phys. Rev. Lett. 9, 521 (1962); and F. Borkowski, P. Peuser, G. G. Simon, V. H. Walther, and R. D. Wendling, Nucl. Phys. A222, 269 (1974).
[13]R. J. Adler, Phys. Rev. 169, 1192 (1968); more accurate expressions are to be found in J. Hockert *et al.*, Nucl. Phys. A217, 14 (1973).
[14]G. G. Simon, F. Borkowski, C. H. Schmitt, V. H. Walther, H. Arenhövel, and W. Fabian, Nucl. Phys. A324, 277 (1979).
[15]V. Z. Jankus, Phys. Rev. 102, 1586 (1956).
[16]J. Goldemberg and C. Schaerf, Phys. Rev. Lett. 12, 298 (1964).
[17]B. Grossetete *et al.*, Phys. Rev. 141, 1425 (1966).
[18]D. Ganichot *et al.*, Nucl. Phys. A178, 545 (1972).
[19]J. E. Elias *et al.*, Phys. Rev. 177, 2075 (1967).