Phys. (Kyoto) 35, 798 (1966).
[2]L. Rosen, J. G. Beery, A. S. Goldhaber, and E. H. Auerbach, Ann. Phys. (N.Y.) 34, 96 (1965).
[3]R. L. Hutson, S. Hayakawa, M. Chabre, J. J. Kraushaar, B. W. Ridley, and E. T. Boschitz, Phys. Letters 27B, 153 (1968).
[4]J. B. A. England, R. G. Harris, L. H. Watson, D. H. Worledge, and J. E. Evans, Phys. Letter 30B, 476 (1969).
[5]D. M. Patterson and J. G. Cramer, Phys. Letters 27B, 373 (1968).
[6]J. W. Luetzelschwab and J. C. Hafele, Phys. Rev. 180, 1023 (1969).
[7]W. S. McEver, T. B. Clegg, J. M. Joyce, E. J. Ludwig, and R. L. Walter, Phys. Letters (to be published).
[8]D. D. Armstrong, L. L. Catlin, P. W. Keaton, Jr., and L. R. Veeser, Phys. Rev. Letters 23, 135 (1969).
[9]N. R. Roberson, R. V. Poore, F. Seibel, and J. M. Joyce, in *Proceedings for the Conference on Computer Systems in Experimental Nuclear Physics* (Columbia Univ., New York, 1969), p. 276.
[10]H. T. Fortune, T. J. Gray, W. Trost, and N. R. Fletcher, Phys. Rev. 173, 1002 (1968).
[11]S. I. Warshaw, A. J. Buffa, J. B. Barengoltz, and M. K. Brussel, Nucl. Phys. A121, 350 (1968).
[12]We would like to thank Dr. F. G. Perey for use of this code.
[13]W. J. Thompson and J. L. Adams, Tandem Accelerator Laboratory, Florida State University, Technical Report No. 10 (unpublished).

ELASTIC SCATTERING OF 580-MeV PROTONS FROM ^{3}He

M. Blecher and K. Gotow
Virginia Polytechnic Institute,* Blacksburg, Virginia 24061

and

E. T. Boschitz,† W. K. Roberts, and J. S. Vincent
National Aeronautics and Space Administration, Lewis Research Center, Cleveland, Ohio 44135

and

P. C. Gugelot
University of Virginia, Charlottesville, Virginia 22903

and

C. F. Perdrisat
College of William and Mary, Williamsburg, Virginia 23185
(Received 4 March 1970)

The elastic differential cross section for p-^{3}He scattering has been measured at 580 MeV. The data are compared with a Glauber model calculation.

In the past few years there has been much experimental and theoretical interest in the scattering of medium- and high-energy particles from light nuclei. The observation has been made regarding the scattering of protons[1,2] and pions[3] from deuterons that a diffraction minimum in the differential cross section was absent in contrast to the shape of the cross section for spin-zero nuclei (^{4}He, ^{12}C, ^{16}O). A number of explanations for this observation have been given: (1) the momentum dependence of the phases of the π-N or N-N scattering amplitudes, (2) the spin dependences in these amplitudes, and (3) effects due to the D state of the deuteron. Detailed theoretical studies[4] have then shown that a phase variation cannot explain the p-d and p-^{4}He data simultaneously. The spin dependence in the elementary amplitudes can partially account for the difference in shape of the p-d and p-^{4}He cross sections.[5] The main effect is due, however, to the D-state wave function in the deuteron.[6] In view of these results proton scattering from ^{3}He is interesting because of the ^{3}He spin and of the fact that the ^{3}He ground state contains components of angular momentum greater than that of the symmetric S state. In the present communication we are reporting our results on p-^{3}He scattering at 580 MeV.

The experimental arrangement was similar to the one used earlier.[7] A beam of 582-MeV protons was focused to a (1×4)-cm spot on a 15-cm-diam gaseous ^{3}He target (165 lb/in.^{2} for scattering angles greater than 21° and 30 lb/in.^{2} for smaller scattering angles). The walls of the cylindrical targets were 0.0075- and 0.0025-cm Havar, respectively, which was thin enough to permit the penetration of the recoiling ^{3}He for all angles studied. Since the energy spread in the incident beam was greater than the binding energy of ^{3}He, the elastic proton scattering was defined as a coincident event between the scattered proton and the recoiling ^{3}He nucleus, both with the correct mean range. The proton range telescope was identical to the one used in the p-^{4}He experiments.[7] For detecting the ^{3}He recoil a two-element conjugate counter telescope was used. During the experiment random events were monitored continuously and corrections were applied to the data. The monitoring of the beam intensity, determination of the number of incident protons, and the beam alignment were done as in Ref. 7. The angular resolution was 0.75° (full width at half-maximum) for angles less than 28°, and 2.0° for larger angles.

The laboratory cross section plotted against the squared momentum transfer $-t$ is shown in Fig. 1. The errors shown for each data point

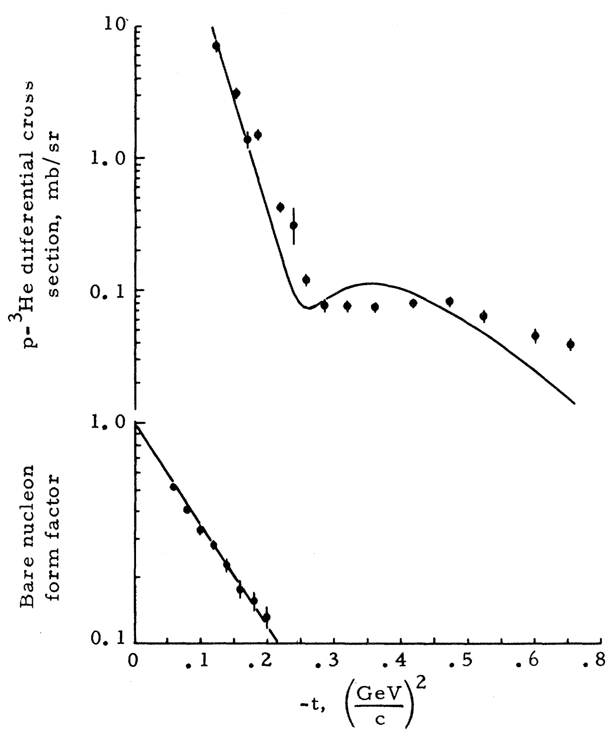

FIG. 1. The upper portion is the differential cross section for p-^{3}He elastic scattering at 580 MeV. The curve is a Glauber approximation calculation. In the lower portion of the figure the points represent the bare form factor for ^{3}He from Srivastava (Ref. 8), which is defined by

$$F_B = [2F_E(^3\text{He}) + F_E(^3\text{H})]/3[F_E(p) + F_E(n)],$$

where the F_E are the experimental electromagnetic form factors. The curve corresponds to the form factor calculated from the wave function used for the p-^{3}He cross section, $F_B = \exp(tR^2/6)$.

are the standard deviations of the relative cross section. The error in the absolute cross section due to uncertainties in the efficiency of the proton range telescope, the number of incident protons, the pressure in the target vessel, and the solid angle defined by two scintillation counters is estimated to be less than ±10%. The principal feature of the data is the shallow minimum near 0.35 (GeV/c)^2, whose depth is between those of the break in the 600-MeV p-d cross-section curve at 0.45 (GeV/c)^2 and of the pronounced minimum in the p-^{4}He data at 0.25 (GeV/c)^2.

In Fig. 1 the upper theoretical curve is a calculation using the Glauber approximation in its simplest form.[9] The nucleon-nucleon amplitude was approximated by

$$f_{p,n}(p,\delta) = [(i + \alpha_{p,n})/4\pi]p\sigma_{p,n}\exp(-\tfrac{1}{2}\beta\delta^2),$$

where δ is the four-momentum transfer, and the variables $\alpha_{p,n}$, $\sigma_{p,n}$, and β were taken as 0.43 and 3.9 fm^2, and 4.3 (GeV/c)$^{-2}$, respectively, as in Ref. 7. The wave function for ^{3}He was a simple Gaussian:

$$|\psi|^2 = \rho_0 \prod_{j=1}^{3} \exp(-r_j^2/R^2),$$

where R is the rms radius of the nucleon centers in the system where

$$\sum_{j=1}^{3} r_j = 0.$$

The curve is for $R = 1.6$ fm, with variations of 0.1 fm not appreciably changing the predicted cross section.[10] The lower curve of Fig. 1 is the corresponding form factor of the nucleon centers which is compared with a representation of electron scattering data due to Srivastava.[8] Both the cross section and the form factor are reasonably described in these simple approximations. Using very similar parameters, Baier and Samaranayake[11] have repeated the above calculation. They have also investigated the effect of adding a small admixture of D state to the ^{3}He wave function, but neglecting the spin-dependent terms in the nucleon-nucleon amplitude. Contrary to the case of p-d scattering, they find that this admixture does not result in a large change in the predicted cross section. In conclusion it would be very useful to include the full spin-dependent N-N amplitude in the theory. The results of such a calculation plus form-factor data at larger momentum transfers should contribute greatly to the understanding of the p-^{3}He cross section.

The authors wish to thank the staff of the Space Radiation Effects Laboratory for their cooperation during the experiment.

*Work supported in part by U. S. National Aeronautics and Space Administration Grant No. NGL 47-003-044.

†Present address: Institut für Experimentelle Kernphysik, Universität Karlsruhe, Karlsruhe, Germany.

[1]G. W. Bennett, J. L. Friedes, H. Palevsky, R. J. Sutter, G. J. Igo, W. D. Simpson, G. C. Phillips, R. L. Stearns, and D. M. Corley, Phys. Rev. Letters 19, 387 (1967).

[2]J. S. Vincent, E. T. Boschitz, W. K. Roberts, K. Gotow, P. C. Gugelot, C. F. Perdrisat, and L. W. Swenson, Bull Am. Phys. Soc. 13, 872 (1968).

[3]F. Bradamante, S. Conetti, C. Fidecaro, M. Fidecaro, M. Giorgi, A. Penzo, L. Piemontese, F. Sauli, and P. Schiavon, Phys. Letters 28B, 191 (1968).

[4]R. J. Glauber, in Proceedings of the Symposium on the Use of Nimrod for Nuclear Structure Physics, Rutherford High Energy Laboratory Report No. RHEL/R-166, 1968 (unpublished), p. 41.

[5]V. Franco, Phys. Rev. Letters 21, 1360 (1968).

[6]V. Franco and R. J. Glauber, Phys. Rev. Letters 22, 370 (1969).

[7]E. T. Boschitz, W. K. Roberts, J. S. Vincent, K. Gotow, P. C. Gugelot, C. F. Perdrisat, and L. W. Swenson, Phys. Rev. Letters 20, 1116 (1968).

[8]B. K. Srivastava, Phys. Rev. 133 B545 (1964).

[9]W. Czyż and L. Leśniak, Phys. Letters 24B, 227 (1967).

[10]Considering the average radius of the nucleon to be 0.70 fm would yield a ^{3}He rms matter radius of $[(1.6)^2 + (0.70)^2]^{1/2} = 1.75$ fm: R. Hofstadter, *Electron Scattering and Nuclear and Nucleon Structure*, edited by R. Hofstadter (Benjamin, New York, 1963), p. 315.

[11]H. Baier and V. K. Samaranayake, Nucl. Phys. B15, 67 (1970).

^{49}Fe: A NEW $T_Z = -\frac{3}{2}$ DELAYED-PROTON EMITTER*

Joseph Cerny,† C. U. Cardinal,‡ H. C. Evans,§ K. P. Jackson, and N. A. Jelley
Nuclear Physics Laboratory, University of Oxford, Oxford, England
(Received 7 April 1970)

Iron-49 with a half-life of 75 ± 10 msec was produced by the reaction ^{40}Ca(^{12}C, $3n$)^{49}Fe using 65-MeV carbon ions; beta-delayed protons with an energy of 1.96 ± 0.05 MeV probably originating from the lowest $T = \frac{3}{2}$ state in ^{49}Mn were observed.

Although the series of $A = 4n+1$, $T_Z = \frac{1}{2}(N-Z) = -\frac{3}{2}$ beta-delayed proton emitters is known[1] from ^{9}C through ^{41}Ti, no technique for forming higher A nuclei of this type has been demonstrated and, in fact, almost no nuclei with $Z > N$ above the titanium isotopes can be considered as reliably established. We wish herein to report the observation of ^{49}Fe following carbon-ion bombardment of ^{40}Ca.

A pulsed beam of 65-MeV ^{12}C ions (4$^+$) from the Harwell variable-energy cyclotron was used to irradiate targets of ^{24}Mg, ^{28}Si, and ^{40}Ca. Beam intensities incident on the target averaged 0.5 μA. Reactions on these targets produced both the known delayed-proton emitters ^{33}Ar and ^{37}Ca as well as the new nuclide ^{49}Fe; the first two nuclides were studied to investigate the systematics of (^{12}C, $3n$) reactions on $T_Z = 0$ targets.

As indicated later, relatively low-energy protons (≈1.9 or 2.6 MeV) were expected in the decay of ^{49}Fe. In order to detect these protons reliably in a high β background, a semiconductor telescope consisting of two surface-barrier detectors—a 23-μ ΔE detector followed by an E detector depleted to 250 μ—was used. The targets were placed at an angle of 25° to the beam, and the telescope was mounted approximately perpendicular to the targets, subtending a solid angle of 0.13 sr.

Beam pulsing was achieved by modulating the voltage on the cyclotron dees. Signals from a repetitive ramp generator triggered the beam "on" for a chosen interval appropriate to the half-life being studied as well as triggering a shutter which dropped in between the target and the ΔE counter for a period overlapping the "beam-on" interval. Summed coincidence pulses between the ΔE and E detectors, further discriminated by requiring that their product ($\Delta E \times E \cong MZ^2$) be appropriate for a proton, were stored in a two-parameter analyzer as a function of time. Protons between 1.3 and 5.7 MeV could be linearly detected with this system. An ^{241}Am α source and a calibrated pulser established the energy scale. Normally 512 energy channels by 8 time channels, the latter covering 2 to 5 half-lives, were recorded.

A proton spectrum from ^{33}Ar produced via the (^{12}C, $3n$) reaction on a 2.8-mg/cm^2 natural Mg target is shown in Fig. 1(a). The overall energy