[a]Present address: Los Alamos Scientific Laboratory, Los Alamos, N. Mex. 87545.
[b]Present address: Department of Physics, University of Virginia, Charlottesville, Va. 22901.
[c]Present address: Fermilab, Batavia, Ill. 60510.
[1]J. Kelly *et al.*, in Workshop on Nuclear Structure with Intermediate Energy Probes, Los Alamos Scientific Laboratory Report No. LA-8303C, 1980 (unpublished).
[2]J. Kelly *et al.*, to be published.
[3]J. R. Comfort *et al.*, Phys. Rev. C 21, 2147 (1980).
[4]A. Ingemarsson, O. Jonsson, and A. Hallgren, Nucl. Phys. A319, 377 (1979).
[5]A. Ingemarsson and J. Källine, Phys. Scr. 2, 191 (1970).
[6]A. K. Kerman, H. McManus, and R. M. Thaler, Ann. Phys. (N.Y.) 8, 551 (1959).
[7]F. Petrovich, in *The (p,n) Reaction and the Nucleon-Nucleon Force*, edited by C. D. Goodman *et al.* (Plenum, New York, 1980), p. 115.
[8]W. G. Love, in *The (p,n) Reaction and the Nucleon-Nucleon Force*, edited by C. D. Goodman *et al.* (Plenum, New York, 1980), p. 23.
[9]F. Petrovich *et al.*, Phys. Lett. 91B, 27 (1980).
[10]J. P. Jeukenne, A. Lejeune, and C. Mahaux, Phys. Rep. 25, 83 (1976), and Phys. Rev. C 16, 80 (1977).
[11]F. A. Brieva and J. R. Rook, Nucl. Phys. A291, 299, 317 (1977), and A297, 206 (1978); H. V. von Geramb, "Table of Effective Density and Energy Dependent Interactions for Nucleons" (unpublished), available from the author at I. Institut für Experimentalphysik der Universität Hamburg, D-2000 Hamburg, Germany.
[12]F. A. Brieva and J. R. Rook, Nucl. Phys. A307, 493 (1978); H. V. von Geramb, F. A. Brieva, and J. R. Rook, in *Microscopic Optical Potentials*, edited by H. V. von Geramb (Springer-Verlag, Berlin, 1979), p. 104.
[13]W. G. Love, Nucl. Phys. A312, 160 (1978); F. Petrovich *et al.*, Phys. Rev. Lett. 22, 895 (1969).
[14]H. Miska *et al.*, Phys. Lett. 83B, 165 (1979).
[15]H. Crannell, Phys. Rev. 148, 1107 (1966).
[16]K. Itoh, M. Oyamada, and Y. Torizuka, Phys. Rev. C 2, 2181 (1970).
[17]C. W. deJager, H. deVries, and C. deVries, At. Data Nucl. Data Tables 14, 479 (1974).
[18]W. Bauhoff, H. V. von Geramb, and G. Pálla, to be published.

Comparison of Pion- and Photon-Induced Reactions on ^{12}C

R. D. McKeown, J. P. Schiffer, H. E. Jackson, M. Paul,[a] S. J. Sanders, J. R. Specht, and E. J. Stephenson[b]
Argonne National Laboratory, Argonne, Illinois 60439

and

R. P. Redwine
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

and

R. E. Segel
Northwestern University, Evanston, Illinois 60201

and

J. Arends, J. Eyink, H. Hartmann, A. Hegerath, B. Mecking, G. Nöldeke, and H. Rost
Physikalisches Institut, Universität Bonn, D-5300 Bonn, West Germany
(Received 8 September 1980)

The proton spectra from pion- and photon-induced reactions on ^{12}C at the $\Delta(\frac{3}{2},\frac{3}{2})$ resonance are found to be very similar in shape, and in their variation with angle. It seems reasonable to assume that these protons arise from a common reaction mechanism (Δ production) for the two projectiles. The absolute cross sections for producing protons with pions and with photons are in roughly the same ratio as the total inelastic pion yield to the total photopion yield.

PACS numbers: 25.80.+f, 25.20.+y

In the energy region of the $\Delta(\frac{3}{2},\frac{3}{2})$ resonance, the interaction of photons with nucleons is dominated by pion production, and the resonant behavior of this cross section indicates that the reaction proceeds through formation of a Δ.[1] The fact that the π interaction on these nuclei also proceeds through the Δ implies that a comparison between pion- and photon-induced reactions could yield interesting information on Δ production and decay in the nucleus. The relaxation between energy and momentum is rather similar for photons and pions because of the relatively small rest mass of the pion.

Inclusive measurements of protons from pion[2]- and photon[3]-induced reactions on ^{12}C have recently been completed. The proton spectra at three angles are compared in Fig. 1 for approximately the same incident total energies, and the similarity is quite evident. The average of π^+- and π^--induced proton yields is plotted; the individual proton spectra have approximately the same shape for both charge states at all angles. The ratio of the proton yields from π^+ to that of π^- is 4.0 ± 0.6 and independent of angle. The angular variation in the shape of the proton spectrum has been interpreted[2] as consistent with pion absorption on 3–5 nucleons.

The strong similarity between pion- and photon-induced proton spectra suggests a common mechanism for production of the final-state protons in these two reactions. A plausible interpretation is to assume that the protons arise from the same decay mode of the Δ in the nucleus. Of course, the yield of protons may depend on the Δ charge state, although the spectrum shape appears almost independent of the charge state of the initial Δ. Averaging the π^+- and π^--induced proton yields is an attempt to remove the charge dependence in the absolute yield. Photons can couple only to the $T_3 = \pm\frac{1}{2}$ substates of the Δ while pions produce the $T_3 = \pm\frac{3}{2}$ states preferentially. However, from charge symmetry it is clear that, by using the π^+-π^- average on a self-conjugate target, the proton spectrum is equivalent to the nucleon spectrum, as it also must be for photons. The ratio of the average proton yields from pions to the yield from γ's is $R_{\pi/\gamma}(p) = 55 \pm 10$.

We can make additional comparisons in ^{12}C by using other available experimental data on this nucleus. The total inelastic pion cross section (including charge exchange) for 220-MeV pions incident on ^{12}C is 300 ± 50 mb.[4] The cross section for inclusive photoproduction of charged pions on ^{12}C is 2.1 ± 0.2 mb.[5] From the free photopion cross section on the nucleon we may estimate the π^0 yield to be about equal to that for charged pions for a total pion yield of 4.2 ± 1 mb. The ratio of pion yields then is $R_{\pi/\gamma}(\pi) = 70 \pm 20$, comparable to the ratio of proton yields.

The fact that the two ratios $R_{\pi/\gamma}(p)$ and $R_{\pi/\gamma}(\pi)$ are comparable in magnitude is likely to be the consequence of ^{12}C being a rather light nucleus. Since nuclear matter is rather transparent to photons and opaque to pions one might have expected some difference. While incident pions would form a Δ near the nuclear "surface," photons would interact uniformly throughout the nuclear volume. The probability for a pion (produced via $\Delta \to N + \pi$) to escape the nucleus would be significantly greater for a Δ on the surface than a Δ in the interior of the nucleus. Thus one might expect $R_{\pi/\gamma}(p) < R_{\pi/\gamma}(\pi)$. It may be very interesting to make such a comparison on heavier nuclei when the photonuclear data become available—it would carry important information on the pion absorption mechanism.

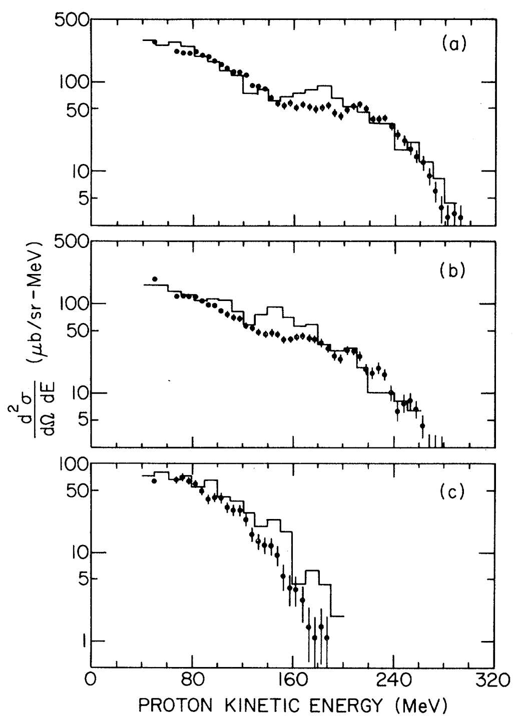

FIG. 1. The proton-energy spectra from 220-MeV incident π^+ and π^- on ^{12}C have been averaged and plotted as solid points. The proton spectra from ^{12}C(γ,p) at $E_\gamma = 343$ MeV have been multiplied by 55 and plotted as histograms. The three plots correspond to three different laboratory angles: (a) $\theta(\pi,p) = 45°$, $\theta(\gamma,p) = 49°$; (b) $\theta(\pi,p) = 60°$, $\theta(\gamma,p) = 73°$; (c) $\theta(\pi,p) = 120°$, $\theta(\gamma,p) = 125°$.

This work was supported in part by the U. S. Department of Energy, the National Science Foundation, and by the Bundesministerium für Forschung und Technologie.

---

[a]Present address: Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem, Israel.

[(b)]Present address: Indiana University Cyclotron Facility, Bloomington, Ind. 47401.

[1]A substantial fraction of the charged-pion photoproduction on the nucleon is nonresonant. However, many of the pions produced in *nuclei* by photons will subsequently interact through Δ formation.

[2]R. D. McKeown, S. J. Sanders, J. P. Schiffer, H. E. Jackson, M. Paul, J. R. Specht, E. J. Stephenson, R. E. Segel, and R. P. Redwine, Phys. Rev. Lett. 44, 1033 (1980), and to be published. Note that the conclusion of that work bears on pion absorption (a Δ-decay mode), whereas we are addressing the common elements of γ and π reactions in this Letter.

[3]J. Arends, J. Eyink, H. Hartmann, A. Hegerath, B. Mecking, G. Nöldeke, and H. Rost, to be published.

[4]D. Ashery, Nucl. Phys. A335, 385 (1980).

[5]J. Arends, J. Eyink, H. Hartmann, A. Hegerath, B. Mecking, G. Nöldeke, and H. Rost, in *Photopion Nuclear Physics*, edited by P. Stoler (Plenum, New York, 1979), p. 275.

Excitation of Helium Atoms by Positron Impact

P. G. Coleman and J. T. Hutton
Center for Positron Studies, The University of Texas at Arlington, Arlington, Texas 76019
(Received 7 July 1980)

Excitation cross sections for positrons of energies up to 10 eV above threshold scattered in the forward direction by helium atoms have been measured directly by use of time-of-flight spectrometry. The results indicate that the scattering is dominated by excitation of the 2^1S state and that there exists a strong small-angle lobe in the angular distribution of the scattered positrons.

PACS numbers: 34.80.Dp, 34.90.+q

The partition of the total scattering cross section for positron collisions with atoms and molecules is of fundamental importance. In addition to the unique positronium-formation process, the cross sections for positron-atom excitation and ionization are of interest because of the difference between them and the equivalent electron cross sections. For example, the excitation of triplet levels through exchange will be absent in the case of positrons. The energy-dependent inelastic cross sections govern the slowing-down process for positrons in gases and knowledge of them is prerequisite to the full interpretation of the features of measured positron-lifetime spectra in gases, such as the positronium-formation fraction. The same knowledge is essential when considering the fate of galactic positrons which may form positronium or excite or ionize gas molecules prior to annihilation and the emission of the characteristic radiation which has been detected on Earth.[1]

Recently Griffith *et al.*[2] determined that at intermediate energies (up to 500 eV) the dominant positron-helium inelastic collision process is ionization, but no direct measurement of a positron inelastic cross section has been reported to date.

In this Letter measurements of cross sections are presented for the excitation of helium by positrons of energies up to 10 eV above threshold (20.6 eV) accompanied by deflection of the positrons through forward angles of up to 70°. In these energy and angular ranges positrons scattered following excitation collisions are readily distinguished from those scattered through elastic, ionization, and positronium-formation channels.

The time-of-flight (TOF) apparatus used for the present measurements has been described elsewhere.[3] Slow positrons, accelerated to the desired mean energy and having an energy spread of about 1 eV, are timed sequentially along a 25.3-cm-long flight path from source to Channeltron detector under the influence of a strong, uniform, axial magnetic field (150 G) in a chamber evacuated in 10^{-7} Torr by two 6-in.-diam diffusion pumps. The initial direction of the accelerated positrons is essentially axial[3,4]; for the current measurements most of the positron's energy is derived from the axial electrostatic field. The timed beam is 3 mm in diameter and of intensity 0.4/sec, found by use of an MgO-coated grid moderator. The intensity was increased to 1.2/sec by replacing the MgO with a 50%-transmission annealed tungsten mesh.[5]

The accumulation of a time spectrum for positrons *in vacuo*, with use of a standard fast-timing electronics (time-to-amplitude converter–

