Grants Commitee.

[1]R. J. Blin-Stoyle, Phys. Rev. 120, 181 (1960).
[2]K. Amos, M. Fox, and I. Morrison, to be published.
[3]H. Grawe, F. Heidinger, and K. Kändler, Z. Phys. A280, 271 (1977).
[4]M. A. Box, A. J. Gabric, and B. H. J. McKellar, Nucl. Phys. A271, 419 (1976). Equation (35) of this reference should read $A = \frac{1}{6}(2H + K)$ and $D = \frac{1}{6}(H - K)$ and the entries in the columns headed A and D in Table I should be divided by 2. Entries in Tables 2 and 4 except for ϵ should be multiplied by 2. The final results are correct only for the Cabibbo potential.
[5]J. B. McGrory and B. H. Wildenthal, Phys. Rev. C 7, 974 (1973).
[6]A. P. Zuker, Phys. Rev. Lett. 23, 983 (1969).
[7]N. Cabibbo, Phys. Rev. Lett. 10, 531 (1963).
[8]M. Gari and J. Reid, Phys. Lett. 53B, 237 (1974).
[9]J. F. Donoghue, Phys. Rev. D 13, 2064 (1976).
[10]M. A. Box, A. J. Gabric, K. R. Lassey, and B. H. J. McKellar, J. Phys. G 2, L107 (1976). The parameters quoted here are those given by B. H. J. McKellar in Proceedings of the Second International Conference on the Nucleon-Nucleon Interactions, Vancouver, British Columbia, June 1977 (to be published). They have been updated to include new data.
[11]M. A. Box, B. H. J. McKellar, P. Pick, and K. R. Lassey, J. Phys. G 1, 493 (1975).
[12]K. A. Snover, R. von Lintig, E. G. Adelberger, H. E. Swanson, T. A. Trainor, A. B. McDonald, E. D. Earle, and C. A. Barnes, Phys. Rev. Lett. 41, 145 (1978).
[13]C. A. Barnes, M. M. Lowry, J. H. Davidson, R. E. Marrs, F. B. Morinigo, B. Chang, E. G. Adelberger, and H. E. Swanson, Phys. Rev. Lett. 40, 840 (1978).
[14]R. A. Brandenburg, B. H. J. McKellar, and I. Morrison, to be published.

Observation of Isospin Dependence on Analyzing Powers in Proton Inelastic Scattering

K. Hosono, M. Kondo, T. Saito, N. Matsuoka, and S. Nagamachi
Research Center for Nuclear Physics, Osaka University, Suita, Osaka 565, Japan

and

S. Kato
Laboratory of Nuclear Studies, Faculty of Science, Osaka University, Toyonaka, Osaka 560, Japan

and

K. Ogino and Y. Kadota
Department of Nuclear Engineering, Kyoto University, Kyoto 606, Japan

and

T. Noro
Department of Physics, Kyoto University, Kyoto 606, Japan
(Received 13 June 1978)

Differential cross sections and analyzing powers in inelastic scattering of 65- and 50-MeV polarized protons exciting the 1^+ states at 12.71 MeV ($T=0$) and 15.11 MeV ($T=1$) in ^{12}C have been measured. There is a marked difference between the analyzing powers of the two states, which show an out-of-phase pattern in angular distribution. The exchange effect was found to contribute essentially to the isospin dependence from the results of distorted-wave Born-approximation calculations.

Studies of proton inelastic scattering to pair levels of different isospins with same spins and parities are described in this Letter. Here so-called spin-flip 1^+ states at 12.7-MeV ($T=0$) and 15.11-MeV ($T=1$) excitations in ^{12}C were chosen as representative of such levels.[1] These states are well known to have a similar configuration described as single-particle excitations upon the ground state of ^{12}C within the p shell.[2] The excitation of these states by proton inelastic scattering at about 60-MeV incident energies can be described by a simple direct-reaction process. Therefore this reaction is suitable to search for the importance of an isospin-dependent term in the two-body interaction potential in direct reactions.[3] There is also a possibility of determining the importance of noncentral terms or exchange effects in distorted-wave Born-approximation

(DWBA) calculations by fitting the experimental cross sections and analyzing powers simultaneously.[4]

The angular distributions of cross sections and analyzing powers of proton inelastic scattering to these states were measured with 65- and 50-MeV polarized protons. The polarized protons from an atomic-beam-type polarized ion source[5] were accelerated by the Research Center for Nuclear Physics azimuthally varying field cyclotron. The experimental arrangement has been shown elsewhere.[6] Polarized protons up to 30 nA were delivered onto the target with polarization of 50–60%. The direction of polarization was frequently changed by reversing the magnetic field of the ionizer of the ion source by control signals from the beam-current integrator. The beam polarization was monitored by a ^{12}C polarimeter[7] continuously during the measurements. The scattered protons were detected by a pair of counter telescopes positioned at symmetric angles to beam. Each telescope consisted of a 1-mm-thick transmission-type Si detector and a 15-mm-thick high-purity Ge detector cooled by liquid nitrogen. The particle identification was made with ΔE and E signals. The overall energy resolution was less than 200 keV full width at half-maximum (FWHM), the major part of which came from energy spread of the incident beam. The typical pulse-height spectrum is illustrated in Fig. 1.

Angular distributions of the cross sections and the analyzing powers for inelastic scatterings to the 12.71- and 15.11-MeV states at 65-MeV incident energy are shown in Fig. 2. The errors indicated in Fig. 2 are overall ones including errors caused from subtraction of overlapping peaks and background in addition to statistical ones.

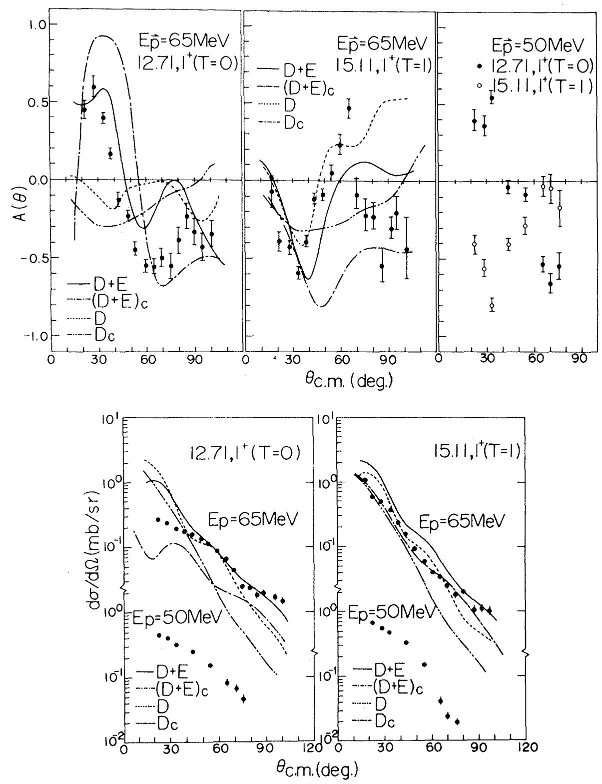

FIG. 2. The experimental data and calculated curves of the differential cross sections and analyzing powers for the inelastic scattering to the 12.71-MeV 1^+, $T=0$ and 15.11-MeV 1^+, $T=1$ states in ^{12}C at 65- and 50-MeV incident energies. The notations D, D_c, $D+E$, and $(D+E)_c$ labeling the calculated curves are described in the text. Errors in the figure are overall ones.

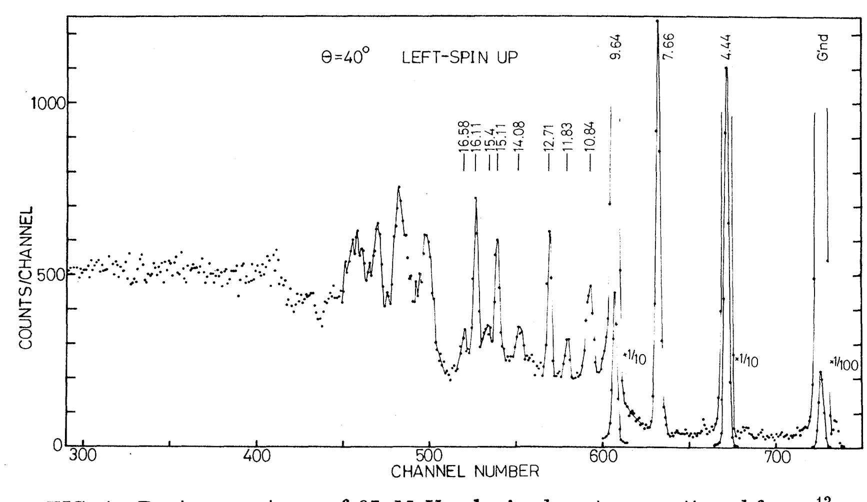

FIG. 1. Proton spectrum of 65-MeV polarized protons scattered from ^{12}C.

There are some differences between the angular distributions of the cross sections. The cross sections of the $T=1$ state increase rapidly at forward angles. The most interesting feature of the data is the strong isospin dependence in the angular distributions of analyzing powers. The two analyzing powers show out-of-phase patterns in the angular distributions. At lower incident energies up to 30 MeV, the cross sections and analyzing powers to the 12.71-MeV level were found to vary rapidly with the incident energies.[8] To ascertain that such resonance effects did not contribute to the scatterings in the present energy region, the cross sections and analyzing powers were also measured at 50-MeV incident energy. Though there are some differences in the cross sections and analyzing powers between 65 and 50 MeV, the out-of-phase pattern of analyzing powers still remains at 50 MeV as shown in Fig. 2. So in this energy region two-step resonance effects[8] can be neglected.

To explain the remarkable features, calculations have been made using an antisymmetrized microscopic DWBA code. The code used is DWBA-74 programmed by Raynal.[9] The parameters of the optical potential were determined using the cross sections and polarizations of the elastic scattering obtained in this experiment at 65 and 50 MeV and are listed in Table I. The parameters at 65 and 50 MeV were used for entrance and exit channels, respectively. In these calculations the values of the spectroscopic amplitudes[8] obtained from the calculations of Cohen and Kurath were used, but the configurations except for $(p_{3/2})^{-1}(p_{1/2})^1$ were omitted because of their small contribution to the cross sections and analyzing powers.

The effective interaction potential between two nucleons was taken as

$$\begin{aligned} V(r) = {} & V_C(r) + V_0(r) + V_\sigma(r)(\vec{\sigma}_1\cdot\vec{\sigma}_2) \\ & + V_\tau(r)(\vec{\tau}_1\cdot\vec{\tau}_2) + V_{\sigma\tau}(r)(\vec{\sigma}_1\cdot\vec{\sigma}_2)(\vec{\tau}_1\cdot\vec{\tau}_2) \\ & + [V_{LS}(r) + V_{LS\tau}(r)(\vec{\tau}_1\cdot\vec{\tau}_2)]\vec{L}\cdot\vec{S} \\ & + [V_T(r) + V_{T\tau}(\vec{\tau}_1\cdot\vec{\tau}_2)]S_{12}, \end{aligned}$$

where the suffixes 1 and 2 refer to the two interacting nucleons and V_C to the Coulomb potential. The radial dependence of each potential was taken to be Yukawa form (except for V_C), $V(r) = V \times \exp(-r/\mu)(r/\mu)^{-1}$, with different range parameters in each potential.[3] The parameter values of the interaction are listed in Table II. The DWBA calculations at 65-MeV incident energy are presented in Fig. 2. Efforts were exerted to fit the theoretical curves to the experimental data for the cross sections and analyzing powers for the two levels simultaneously. In this figure, D and E represent the direct and exchange processes, respectively. The suffix c indicates the calculation containing only central potential and D and $D+E$ without suffix express the results including both central and noncentral interactions in the potential between two nucleons. We failed to obtain a good fit to the analyzing powers without any exchange effect in spite of the wide range of parameters searched. For the 15.11-MeV 1^+, $T=1$ state, the theoretical curves labeled as $D+E$ are qualitatively in good agreement with both the experimental cross sections and analyzing powers simultaneously. For the 12.71-MeV 1^+, $T=0$ state, both angular distributions are fitted by the curves labeled $D+E$ and $(D+E)_c$. From the above analysis it is concluded that the out-of-phase pattern in analyzing powers can be explained by taking into account the exchange process. The noncentral interactions are also important to fit the experimental data.

We also observed the angular distributions of cross sections and analyzing powers leading to 4.44-MeV 2^+, 15.4-MeV 2^+,[10] and $T=1$, 16.11-MeV 2^+ states[1] at 65-MeV incident energy, which are shown in Fig. 3. The 15.4-MeV state is a broad level with a level width of about 2 MeV (FWHM). It is also interesting that the angular distribution of analyzing power to the 15.4-MeV state is also out of phase with that to the 16.11-MeV state.

In summary, we found isospin dependence of the analyzing powers in inelastic scatterings to the states with the same configuration. An ex-

TABLE I. Optical-model parameters for $^{12}C(\vec{p},p)^{12}C$ scattering at 65 and 50 MeV. $r_C = 1.3$ fm; $r_W = r_D$, $a_W = a_D$.

E (MeV)	V (MeV)	r_0 (fm)	a_0 (fm)	W (MeV)	W_D (MeV)	r_W (fm)	a_W (fm)	v_{S0} (MeV)	r_{S0} (MeV)	a (fm)
65.0	25.39	1.244	0.712	2.841	2.320	1.469	0.390	6.790	1.041	0.532
50.0	38.91	1.147	0.641	4.878	4.050	1.405	0.336	5.896	1.038	0.445

TABLE II. Parameters of two-nucleon interaction potential.

V_0 (MeV)	−16.2
V_σ (MeV)	5.5
V_τ (MeV)	26.2
$V_{\sigma\tau}$ (MeV)	1.55
μ (fm)	1.0
V_{LS} (MeV)	−1.25
$V_{LS\tau}$ (MeV)	23.75
μ (fm)	0.7
V_T (MeV)	−7.75
$V_{T\tau}$ (MeV)	6.75
μ (fm)	0.80

change process plays an essential role in explaining the isospin dependence of analyzing power in ^{12}C. Further measurements are planned in other nuclei to pursue the persistence of the isospin dependence in proton inelastic scattering.

The authors wish to thank to Professor S. Yamabe for his continuous encouragement. We are indebted to Dr. F. Sugiura for his helpful advice on DWBA code and to Professor M. Sano for valuable discussions. We are also grateful to the cyclotron crew for operation of the cyclotron.

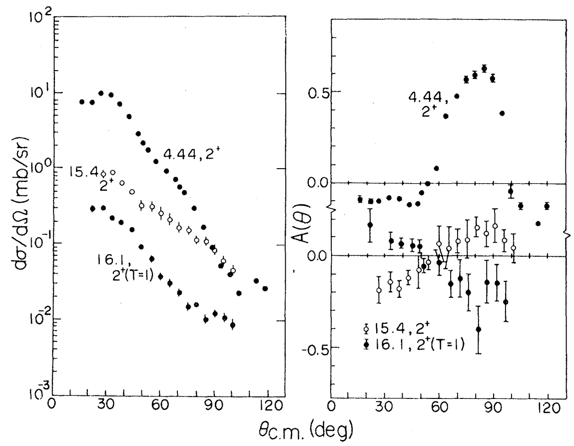

FIG. 3. The experimental data of the differential cross sections and the analyzing powers for the inelastic scattering to the 4.44-MeV 2^+, 15.4-MeV 2^+ and $T=1$, 16.11-MeV 2^+ states in ^{12}C at 65-MeV incident energy. Errors in the figure are overall ones.

[1]F. Ajzenberg-Selove, Nucl. Phys. A248, 1 (1975).

[2]S. Cohen and D. Kurath, Nucl. Phys. A101, 1 (1967).

[3]S. M. Austin, in *The Two-Body Force in Nuclei*, edited by S. M. Austin and G. M. Crawley (Prenum, New York, 1972), p. 285.

[4]W. G. Love and G. R. Satchler, Nucl. Phys. A159, 1 (1970).

[5]K. Imai, N. Tamura, and K. Nisimura, Research Center for Nuclear Physics Annual Report, 1976 (unpublished), p. 23.

[6]M. Nakamura *et al.*, J. Phys. Soc. Jpn. Suppl. 44, 41 (1978).

[7]E. Egawa *et al.*, in *Proceedings of the International Conference on Nuclear Structure, Tokyo, 1977*, edited by The Organizing Committee (International Academic Printing Co. Ltd., Tokyo, 1977).

[8]K. A. Amos, H. V. Geramb, R. Sprickman, J. Arivеux, M. Buenerd, and G. Perrin, Phys. Lett. 52B, 138 (1974).

[9]J. Raynal, private communication to Dr. F. Sugiura and Professor T. Sawada who provided us the code and directions for its use.

[10]M. Buenerd, P. Martin, P. De Saintignon, and J. M. Loiseaux, Nucl. Phys. A286, 377 (1977); K. T. Knöpfle, G. J. Wagner, A. Kiss, M. Rogge, G. Mayer-Böricke, and Th. Bauer, Phys. Lett. 64B, 263 (1976).