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Experimental Study of the Reaction ^{7}Li(π^+, π^0)^{7}Be in the (3, 3) Resonance Region

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Angularly integrated cross sections for the reaction ^{7}Li(π^+, π^0)^{7}Be* (429 keV) were measured over the energy range of 90 to 210 MeV by a selective "prompt-γ" detection method. These results, combined with the summed cross sections to the ground state and excited state, yield the cross section for the ground state alone. The excitation function for the excited state is flat with cross sections of about 0.3 mb. For the ground-state transition the cross sections are between 1.2 and 1.9 mb. The data are compared with theoretical calculations.

Results of recent pion single-charge-exchange experiments[1] have been the subject of much theoretical activity.[2-4] The only experiment performed to date in which the cross section for the population of a single final state was measured is for the isobaric analog transition ^{13}C(π^+, π^0)^{13}N.[1] For the reaction ^{7}Li(π^+, π^0)^{7}Be, the summed angularly integrated cross section to two final states was measured[1]: the isobaric-analog ground state ($\frac{3}{2}^-$) and the first excited state (429 keV, $\frac{1}{2}^-$). The various calculations carried out for the reaction ^{13}C(π^+, π^0)^{13}N,[2-4] where mainly the monopole transition contributes, give too small cross sections and do not reproduce the shape of the excitation function.[5] For the reaction ^{7}Li(π^+, π^0)^{7}Be both monopole and quadrupole transitions are allowed when spin flip is included. In this case, reasonable agreement could be obtained for the sum of the two states by attributing a fair fraction of the cross section to the population of the excited state and to excitation modes other than the simple monopole transition.[2] Therefore, it became interesting to measure the ^{7}Li(π^+, π^0)^{7}Be cross section to each state separately. So far no experimental information is available for a transition to a single nonanalog state.

In this Letter we report the results of the ^{7}Li(π^+, π^0)^{7}Be* cross-section measurement to the 429-keV, $\frac{1}{2}^-$ excited state. In addition we present cross sections for the ground-state transition, which were obtained by subtracting the measured excited-state values from the summed cross sections.

The experiment was carried out at the $\pi M3$ channel of the Schweizerisches Institut für Nuklearforschung accelerator at bombarding energies of 90, 130, 170, and 210 MeV. The cross section for the excited state of ^{7}Be was measured by observing the 429-keV γ decay to the ground state. The γ spectrum was measured with a 50-cm^3 Ge(Li) detector, positioned at 90° relative to the beam. The angular distribution of these γ rays is isotropic (due to the spin $\frac{1}{2}$ of the excited state) and the integration over the sphere is thus straightforward. The γ rays were detected in coincidence with a plastic scintillator placed in the pion beam. The expected cross section for this reaction is relatively small compared to typical values of a few millibarns usually measured by this technique. In addition, the 429-keV line is Doppler broadened because of the short lifetime of the 429-keV state. It was therefore essential to reduce drastically the background normally present in the γ spectrum. Most of this background is caused by reactions in the target, often followed by charged particles leaving the target. In contrast, the 429-keV γ ray associated with the (π^+, π^0) reaction is not accompanied by an outgoing charged particle. In order to eliminate this part of the background, we surrounded the target with plastic scintillators covering all angles except in the backward direction. The γ spectrum was recorded in two modes: in coincidence and in anticoincidence with a charged-particle signal in the surrounding detectors. Figure 1(a) shows the latter spectrum while Fig. 1(b) shows the sum of the two recorded spectra, which is equivalent to eliminating the effect of the surrounding detectors. A comparison of the two figures clearly demonstrates the effectiveness of this selective γ counting. The background was reduced by one order of magnitude. Actually no useful results would have been obtained without this technique because the energy region of interest in Fig. 1(b) contains additional γ lines which do not show up in Fig. 1(a).

We used natural Li targets which were 1.2 g/cm^2 thick and 10.6 cm in diameter. The average beam intensity was 1.5×10^6 pions/sec with a momentum spread of $\pm 1\%$. The beam profile had approximately a Gaussian shape with 4×4 cm^2 full width at half-maximum (FWHM). The macro duty cycle was 100%. In addition to pions the beam contained muons and positrons. Protons were eliminated from the beam by magnetic deflection and absorbers to a level of $<5\times10^{-5}$ protons/pions. The pion flux was determined by a plastic counter placed in the beam combined with a time-of-flight measurement of the beam composition which was carried out at low beam intensity. The positrons and muons in the beam do not contribute to the measured reaction. Protons produced by pion reactions in the target, followed by the (p,n) reaction, do contribute to our measured cross section. An estimate of this effect is described in Ref. 1. These secondary reactions are estimated to contribute $(20\pm10)\%$ to the summed cross section and $(15\pm8)\%$ to the excit-

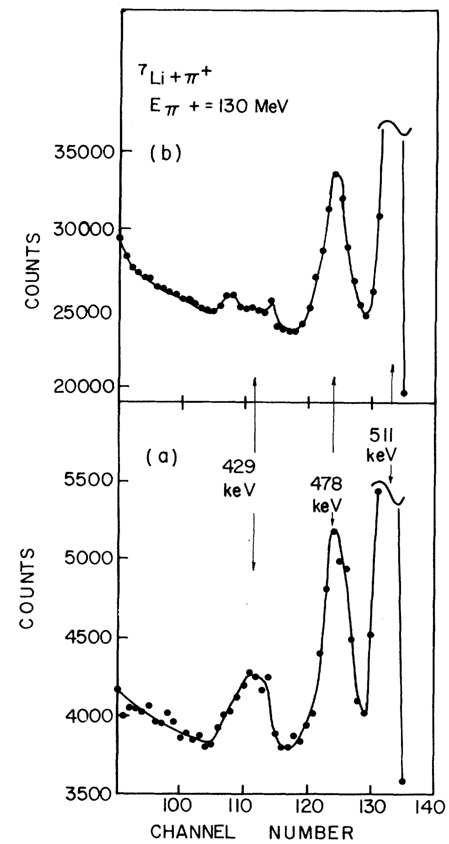

FIG. 1. (a) The γ spectrum recorded in anticoincidence with a charged-particle signal in the surrounding detectors. (b) Sum of spectrum (a) and the spectrum in coincidence with surrounding detectors. The spectrum is equivalent to eliminating the effect of the surrounding detectors.

ed-state cross section. These amounts were subtracted from our measured cross sections.

After the irradiations, the 478-keV γ line following the ^{7}Be decay was measured with a shielded 65-cm^3 Ge(Li) detector. The long half-life of ^{7}Be (53.28 days) enabled us to count the activity in a low-background area far from the accelerator. In this way we measured the sum of the reaction cross sections to the analog state and to the excited state in the same manner as described in Ref. 1. Figure 2(a) shows our results for the charge-exchange cross section to the sum of the two states, together with the previously published results.[1] There is excellent agreement between the two sets of data. Figure 2(b) shows the cross sections for the ground state alone which were deduced by subtracting the excited-state cross sections from the summed values of Fig. 2(a). The solid lines are the results of a calculation by

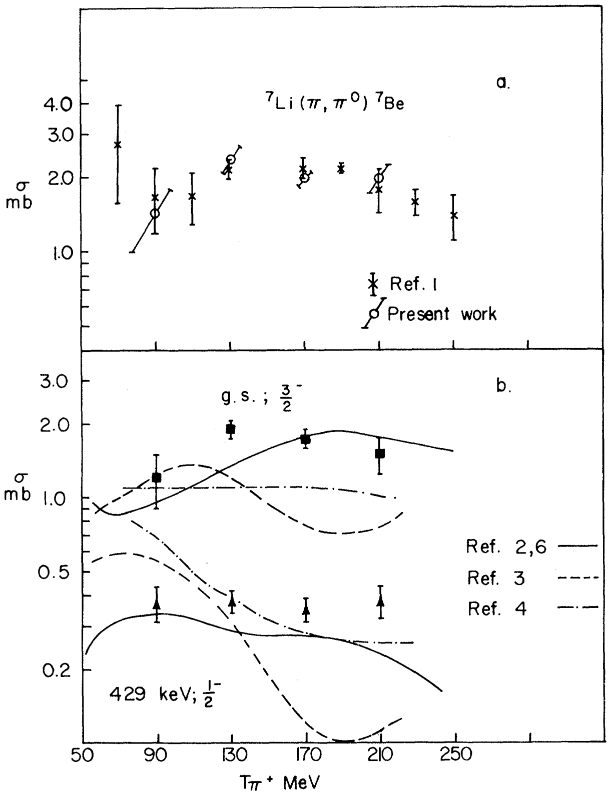

FIG. 2. (a) The circles are the present cross sections for the sum of the two states in ^{7}Be: the ground state ($\frac{3}{2}^-$) and first excited state (429 keV, $\frac{1}{2}^-$). The crosses are the results of Ref. 1. (b) The triangles are the cross sections for the excited state; the squares represent the cross sections for the ground state obtained by subtracting the excited-state cross sections from the averaged values of Fig. 1(a). The solid lines represent calculations of Refs. 2 and 6; the dashed lines, those of Ref. 3; and the dash-dotted lines, those of Ref. 4.

Gibbs and co-workers[2,6] based on a Foldy-Walecka[7] multiple-scattering formalism. In particular, it includes some multiple-step processes of the type discussed by Eisenberg and Gal,[8] which have the effect of increasing the cross sections calculated in first order only. The calculated values have the correct order of magnitude but do not yet follow the shape of the excitation functions in detail. Results of distorted-wave impulse-approximation calculations made by Warszawski and Auerbach[3] and by Sparrow[4] are also shown in the figure. Each of these calculations used different shell-model parameters and different off-shell extrapolations of the (πN) t matrix, and they are extensively discussed by Warszawski, Gal, and Eisenberg.[9] The agreement between the results of these calculations and the data is poor.

In conclusion, the experimental information of the (π^+, π^0) reaction to a single final state is now composed of three measured excitation functions in the (3, 3) resonance region: (a) the ^{13}C$(\pi^+, \pi^0)^{13}$N(g.s.)—$\Delta T = 0$, $\Delta I = 0$, mainly monopole transition; (2) the ^{7}Li$(\pi^+, \pi^0)^7$Be(g.s.)—$\Delta T = 0$, $\Delta I = 0$, monopole plus quadrupole transitions; and (3) the ^{7}Li$(\pi^+, \pi^0)^7$Be*(429 keV)—$\Delta T = 0$, $\Delta I = 1$, monopole plus quadrupole transition.

It is important to note that the calculation by Gibbs and co-workers,[2] when applied to ^{13}C, did not agree with the data in magnitude nor in shape. The question of whether this different behavior is due to nuclear-structure effects or to a lack of understanding of the pion-nucleus interaction remains to be resolved.

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