Pion-induced nucleon knockout reactions on ^{16}O and ^{18}O

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The (π^+,π^+p), (π^-,π^-p), and (π^-,π^-n) reactions on ^{16}O and ^{18}O were studied at 165 MeV by coincidence measurements of the outgoing particles. The cross sections for the (π^-,π^-n) reaction is larger on ^{18}O than on ^{16}O, whereas those for the (π^+,π^+p) and the (π^-,π^-p) reactions are smaller, most likely because of the coupling between the absorption and the scattering channels.

[NUCLEAR REACTIONS $(\pi^\pm,\pi^\pm p)$ (π^-,π^-n) coin. Measurements on $^{16}O$$^{18}O$ $E=165$ MeV; deduced coupling between the absorption and the scattering channels.]

The coupling between pion-nucleus reaction channels and, in particular, between true absorption and inclusive inelastic scattering, has been discussed by several authors.[1–3] This effect has been observed experimentally[2] in inclusive pion scattering and true absorption measurements on ^{16}O and ^{18}O. It was found that π^+ scattering from ^{18}O is suppressed in comparison to ^{16}O, while true absorption on ^{18}O is larger. Theoretical calculations[3] were able to reproduce this effect quantitatively by assuming that the π^+ absorption at the resonance energy takes place predominantly through intermediate Δ^{++} formation, and that the Δ^{++} spreading potential is proportional to the neutron density. Thus it is larger for ^{18}O and suggests a weaker effective scattering amplitude.

We try in the present work to shed more light on the coupling effect by comparing coincidence measurements of the pion-induced nucleon-knockout reactions $(\pi^\pm,\pi^\pm p)$ and (π^-,π^-n) on ^{16}O and ^{18}O. These measurements provide more detailed information on the Δ^{++} and Δ^0 propagation in the nucleus and the coupling between their reaction channels. The (π^-,π^-p) reaction is expected to proceed through intermediate Δ^0 formation and corresponds to a small fraction of the π^- inelastic scattering. Therefore it cannot be studied by inclusive single-arm measurements. In this particular case coupling between different knockout channels could also be important, since the scattering from the two additional neutrons in ^{18}O may "screen" other scattering channels thus reducing, for instance, the π^-,π^-p channel.

The experiment was done at the $\pi M3$ channel of Swiss Institute for Nuclear Research (SIN) accelerator. Positive and negative pion beams of 165 MeV were used. The targets consisted of $H_2{}^{16}O$ and $H_2{}^{18}O$ (99.06%) in liquid form contained in $50\times50\times10$-mm^3 plastic boxes with 0.5-mm-thick windows. An identical empty box was used for background measurements. The target was mounted in a collimating scintillator with a 50×50-mm^2 hole. The pion beam was monitored by two plastic scintillators positioned on the beam axis. Protons present in the beam were eliminated by degraders positioned inside the beam transport channel. Muon and electron contaminations were measured by time of flight (TOF). The outgoing pions were detected by three plastic scintillator telescopes each with an angular acceptance of 5.2°. With these telescopes, pions were identified and distinguished from protons by their energy loss. The pion energy spectrum was not measured.

Nucleons in coincidence with the pions were detected by a 1-m^2 array of 20 scintillators arranged in two layers. The effective angular resolution for nucleon detection in this array was 5–8° in both horizontal (scatttering) and the vertical planes. Particles were identified by pulse-height and TOF information from each scintillator as well as by a signal from a 1-mm-thick scintillator placed in front of the array to distinguish between charged and neutral particles. This information provided the identification of photons, neutrons, protons, and heavier charged particles (mainly deuterons). The neutron-detection efficiency was calculated with a code, originally written by Kruz,[4] and modified at the University of Karlsruhe.[5] The code reproduced well the previously measured[6] neutron-detection efficiency of the scintillator array. The energy of both protons and neutrons was obtained from TOF measurements. A more detailed description of the experimental setup and the particle identification procedure can be found elsewhere.[7]

For the $\pi^+ p$ angular correlation measurements, pions were detected in the angular range of 90–140° in steps of 10°. The nucleon-detector array was moved so that protons in coincidence with pions were measured in 5° steps from −110 to 5° for the three forward pion angles and from −110 to 30° for the backward pion angles. A vertical angular range of −21 to 21° was covered simultaneously. The $\pi^- p$ and $\pi^- n$ angular correlations were measured for pions detected at 120-130-140°, and the coincident nucleons in the angular range of −70 to 5° in the scattering plane and −21 to 21° perpendicular to the scattering plane. For every pion detection angle, a πN angular correlation was produced by integrating the nucleon yield over the energies of the outgoing nucleons. The low-energy cutoff was 20 MeV for both protons and neutrons set by the TOF information. The general features of the angular correlations of ^{16}O and ^{18}O are the same as those measured for other nuclei.[7] The data show a strong peak centered near the angle corresponding to a pion scattering on a free nucleon with a typical width (full width at half maximum) of 25–40°, consistent with that expected from the Fermi distribution of momenta for the struck nucleon. The $\pi^{\pm} p$ angular correlations show a sharp peak (~ 5°) originating from pion scattering on hydrogen superimposed on a broad peak due to quasifree scattering from oxygen. This pronounced peak makes the determination of the quasifree scattering yield from oxygen rather uncertain in this narrow region of the angular correlation. Hence we will study the differences and ratios of the angular correlations of the two isotopes, omitting the narrow region of the hydrogen peak. The cross section differences

$$[d^2\sigma/d\Omega_\pi d\Omega p]_{H_2{}^{16}O} - [d^2\sigma/d\Omega_\pi d\Omega_p]_{H_2{}^{18}O}$$

for the $(\pi^+, \pi^+ p)$, $(\pi^-, \pi^- p)$, and $(\pi^-, \pi^- n)$ reactions are shown in Fig. 1 as a function of the outgoing nucleon angle, for pions detected at $\theta_\pi = 130°$ and for the nucleon emerging in the reaction plane $(-6° \leq \phi_N \leq 6°)$. The curves are Gaussian fits to the data (with a peak position fixed at the angle of the free πN scattering and with the width and amplitude free to vary). Similarly, the ratio of cross sections for $\pi^+, \pi^+ p$, $\pi^-, \pi^- p$, and $\pi^-, \pi^- n$ reactions on ^{16}O and ^{18}O under the same conditions are shown in

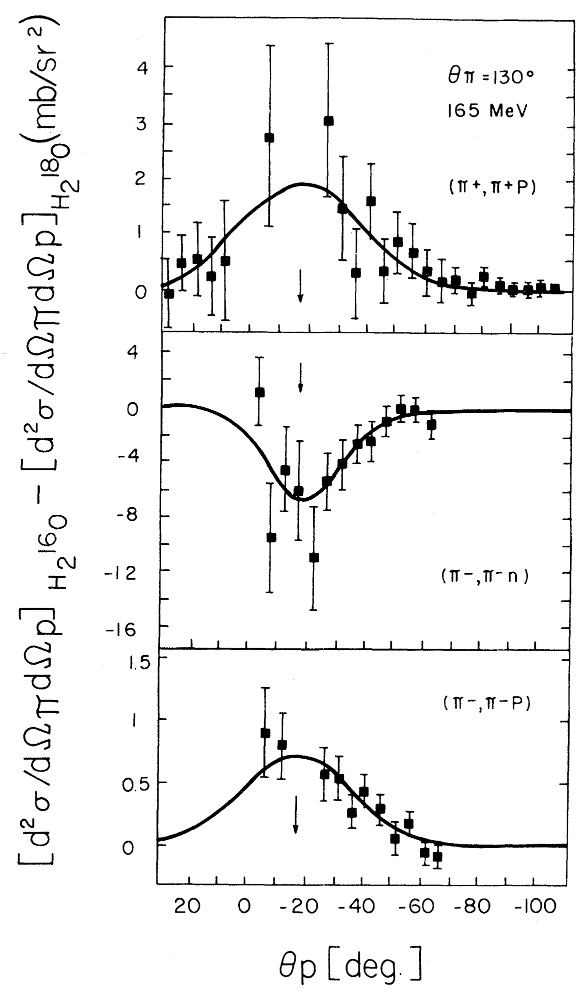

FIG. 1. Cross section differences

$$[d^2\sigma/d\Omega_\pi d\Omega p]_{H_2{}^{16}O} - [d^2\sigma/d\Omega_\pi d\Omega p]_{H_2{}^{18}O}$$

for the (π^+, π^+, p), $(\pi^-, \pi^- p)$, and $(\pi^-, \pi^- n)$ reactions. The pions are detected at a fixed angle $\theta_\pi = 130°$. The nucleons are detected in the reaction plane $(-6° \leq \phi_N \leq 6°)$. The arrows mark the πN free angle.

Fig. 2. The dependence of each ratio on the pion angle, averaged over the outgoing nucleon angle, is shown in Fig. 3 together with the measured[2] and calculated[3] ratio of the pion inelastic scattering cross section on ^{16}O and ^{18}O.

The major features of the results are the following:

(1) The (π^+, π^+p) reaction. The π^+ induced proton-knockout reaction is stronger for ^{16}O. The two additional neutrons in ^{18}O contribute significantly to pion absorption and increase the spread in the scattering amplitude,[2,3] resulting in a similar knockout cross section. Quantitatively, the effect is similar to that observed in the inclusive single-arm measurements at backward angles and is larger at more forward angles. The origin of this angular dependence is not yet clear.

The results may also indicate how the coupling affects the quasifree knockout, as compared to multistep processes. It was previously observed[7] that the central region of πN angular correlations is dominated by the quasifree knockout process, while the shoulder regions are more affected by the multistep mechanisms. If the isotopic effect influences mainly the single scattering quasifree component, one would expect a peak in the angular dependence of the cross section ratios (Fig. 2) at the free πN scattering angle. The measured angular dependence of the ratios does not indicate a significantly different influence either on the single scattering or the multistep components of the knockout cross sections.

(2) The (π^-, π^-n) reaction. The large deviations from zero of the angular dependence of the cross section differences in Fig. 1 and from unity in the ratio angular dependence in Fig. 2 show that the π^- induced reaction is stronger on ^{18}O. Quantitatively, the effect is much larger than the expected A dependence which would suggest a 5% difference. It seems that the two additional neutrons in ^{18}O participate with extra strength in the quasifree scattering. This fact is noteworthy because the coupling to pion absorption would tend to reduce the knockout cross section. The contribution of the two neutrons to the knockout channel seems to more than compensate for this

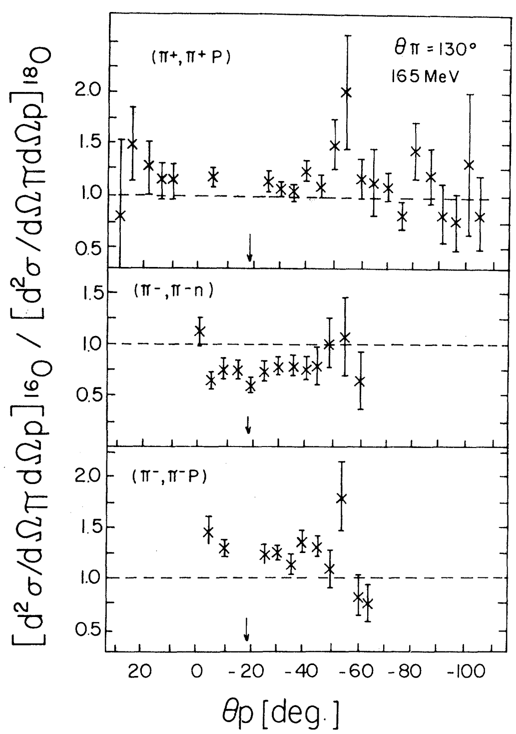

FIG. 2. Ratios of cross sections

$$[d^2\sigma/d\Omega_\pi d\Omega p]_{^{16}O}/[d^2\sigma/d\Omega_\pi d\Omega_p]_{^{18}O}$$

for the (π^+, π^+p), (π^-, π^-p), and (π^-, π^-n) reactions. The pions are detected at a fixed angle $\theta_\pi = 130°$. The nucleons are detected in the reaction plane $(-6° \leq \phi_N \leq 6°)$. The arrows mark the free πN angle.

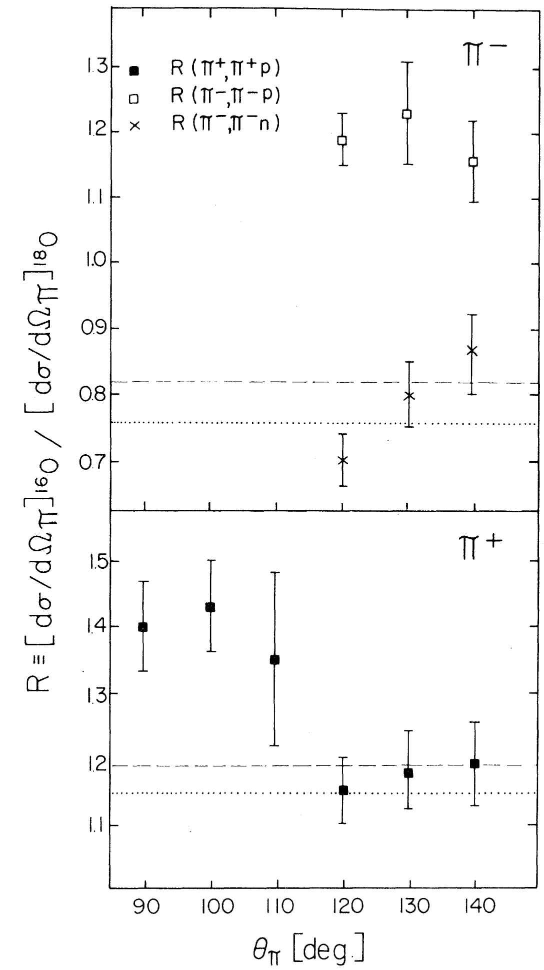

FIG. 3. Ratio of cross sections described in Fig. 2 averaged over the nucleon angle and shown as a function of the pion angle. The dashed (dotted) lines are the results of the measured (Ref. 2) [calculated (Ref. 3)] inclusive inelastic scattering ratios.

reduction. The magnitude of the effect is similar to that observed in inclusive single-arm measurements, but we still do not understand the angular dependence suggested from our results.

(3) The (π^-, $\pi^- p$) reaction. The π^- induced proton-knockout reaction is stronger for ^{16}O. Two different processes can cause this effect. The first is the same coupling to the absorption channel as discussed above for $\pi^+ p$. We note that $\pi^+ p$ and $\pi^- p$ scattering at the resonance energy proceeds predominantly through Δ^{++} and Δ^0 formation, respectively. Even though the Δ^0 can be absorbed on both protons and neutrons, studies of π^- absorption on ^{3}He showed[8] that Δ^0 absorption on a proton is very unlikely. The Δ^0 absorption on a neutron is weaker than that of Δ^{++} by a factor of 3 (from the Clebsch-Gordan coefficients ratio). These arguments then suggest a smaller isotopic effect in the $\pi^- p$ reaction. On the other hand, an increased optical distortion of the π^- in ^{18}O, and particularly the strong role of the two additional neutrons in enhancing the $\pi^- n$ scattering, may reduce the probability for Δ^0 production and hence the $\pi^- p$ knockout process. The measured effect is probably a combination of these two processes.

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