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A COMPARISON OF THE O^{16}(p, t) AND (p, He^3) REACTIONS POPULATING ANALOG FINAL STATES IN O^{14} AND N^{14}†

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A COMPARISON OF THE $O^{16}(p,t)$ and (p,He^3) REACTIONS POPULATING ANALOG FINAL STATES IN O^{14} and N^{14}†

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Detailed comparative measurements of direct interaction transitions from an initial state to analog final states provide a sensitive experimental test of the charge independence of nuclear forces. Since few comparisons of direct transfer reactions to analog final states have been made and none under unambiguous direct reaction conditions, we have investigated the $O^{16}(p,t)O^{14}$g.s.[0+, T = 1] and $O^{16}(p,He^3)N^{14*}$[2.31 MeV, 0+, T = 1] transitions induced by 43.7 MeV protons. Previous two-nucleon transfer investigations of the mass 14 isobaric triad have been reported utilizing the $C^{12}(He^3,n)O^{14}$g.s. and $C^{12}(He^3,p)N^{14*}$(2.31 MeV) reactions at bombarding energies up to 2.6 MeV,[1] 1.8 to 5.5 MeV,[2] and 6-11 MeV.[3] However, rigorous comparison of these low energy measurements is handicapped by the relatively larger Coulomb effects and interference between the compound nucleus and direct reaction contributions to the transitions. A further difficulty arises in comparing the absolute cross-sections since two different detecting systems must be employed.

The (p,t) and (p,He^3) measurements were induced by a beam of 43.7 MeV protons from the Berkeley 88-inch cyclotron. After energy analysis, the protons were brought into a 36-inch scattering chamber and impinged on a gas target. An improved particle-identifier[4] fed by a 40 mg/cm^2 dE/dx - 480 mg/cm^2 E semiconductor counter-telescope distinguished the reaction products. A typical particle-identifier spectrum is shown in Fig. 1. Total energy pulses were fed into a Nuclear Data analyzer which was appropriately gated so that the triton and helium-3 spectra were recorded simultaneously, each spectrum in a 1024 channel group. The deuteron-triton valley and the entire α-particle spectrum of the identifier were also recorded in the analyzer to measure any small but possible loss of the t and He^3 groups in question. The average energy resolution was 190 keV for the tritons and 240 keV for the helium-3.

Figure 2 presents absolute cross-section measurements of the $O^{16}(p,t)O^{14}$g.s. and $O^{16}(p,He^3)N^{14*}$(2.31 MeV) transitions; the (p,He^3) differential cross-sections have been multiplied by the theoretically required factor of 1.88 as will be discussed below. Representative statistics are shown on the figure. Our independent absolute cross-sections should be accurate to ±10 per cent; however, since the spectra were obtained simultaneously, the relative errors should be given primarily by the statistics. Although the differential cross-sections vary by a factor of one hundred over the angular range investigated, only slight departures from exact agreement are apparent.

In Born approximation the ratio of these differential cross-sections is given by

$$\frac{d\sigma(p,t)}{d\sigma(p,\ He^3)} \doteq \frac{k_t}{k_{He^3}} \frac{|M_t|^2}{|M_{He^3}|^2} .$$

Assuming pure i-spin states for all nuclei involved in the transitions and an i-spin conserving interaction, the theoretical ratio of

$$\frac{|M_t|^2}{|M_{He^3}|^2} = \frac{C(t_p T t_t; \tau_p, \tau_t - \tau_p)^2}{C(t_p T t_{He^3}; \tau_p, \tau_{He^3} - \tau_p)^2} = 2$$ (T is the i-spin of the transferred pair). Since the ratio of k_t/k_{He^3} is 0.94, the (p,t) reaction should be favored by a factor of 1.88 over the (p,He^3) reaction.

The above calculation has also ignored the effects of the differing energies and Coulomb scattering in the exit channels and an indication of this is of interest. Dr. N. K. Glendenning has performed a preliminary calculation of these 0+ $\rightarrow$ 0+, L = 0 transitions using his two-nucleon transfer, distorted wave Born approximation code.[5] The fits are also shown in Fig. 2. Identical optical model potentials were used in the incident and exit channels (no i-spin dependent term was included) and both calculations required a cutoff radius of 5.2F; the nucleons were assumed to be picked-up from the $p_{1/2}$ shell. Since at present these theoretical calculations do not give absolute cross-sections, the two curves were normalized to each other at 0° and the $O^{16}(p,t)O^{14}$g.s. fit was normalized to the experimental data at the 30° peak.

The theoretical angular distributions shown in Fig. 2 fit the data very well. It can be seen that a reduction of the $O^{16}(p,He^3)N^{14*}$(2.31 MeV) cross-section relative to the $O^{16}(p,t)O^{14}$g.s. cross-section at the 30° peak is predicted in accord with the experimental results; the fits at the 65° peak agree with the data within our statistics. Further calculation shows that the variation at the 30° peak arises primarily from the difference in energy of the outgoing particles.

The ratio of the integrated cross-sections (11-90°c.m.) for these transitions, after correcting for the phase space and i-spin coupling factors, is $\frac{\sigma(p,t)}{\sigma(p,He^3)} = \frac{0.905\text{mb}}{0.807\text{mb}} = \frac{1.12}{1}$. This excellent agreement between the absolute cross-sections, and the angular distributions, implies a strongly charge-independent interaction operator. Further, the analog states of O^{14} and N^{14} must be extremely similar. In addition to the principal $[(p_{1/2})^2]0+, T = 1$ component in these states, there can be admixtures of 0+ states of $T \neq 1$ and admixtures of other 0+, T = 1 states. Since these amplitudes enter linearly into the matrix elements, though appropriately weighted by transition-dependent factors, the matrix element ratio is a sensitive measure of differing amplitude and phase admixtures in the analog states.

Exact comparison of the O^{14} g.s. and N^{14*}(2.31 MeV) wave functions must await an accurate calculation of the effect of the different energies and Coulomb scattering in the exit channels on the relative cross-sections. For example, however, let us assume that the ratio of the matrix elements depends solely upon differences in the wave functions of the analog states of O^{14} and N^{14}. Also, we will assume that this difference arises only from the unique T = 0 impurity in the N^{14*}(2.31 MeV) state[6] of 2×10^{-3} with a single amplitude and phase of -0.045. The predicted ratio of $\frac{\sigma(p,t)}{\sigma(p,He^3)}$ would then be $\frac{1.10}{1}$, which is comparable to the experimental ratio, even though the admixture is quite small.

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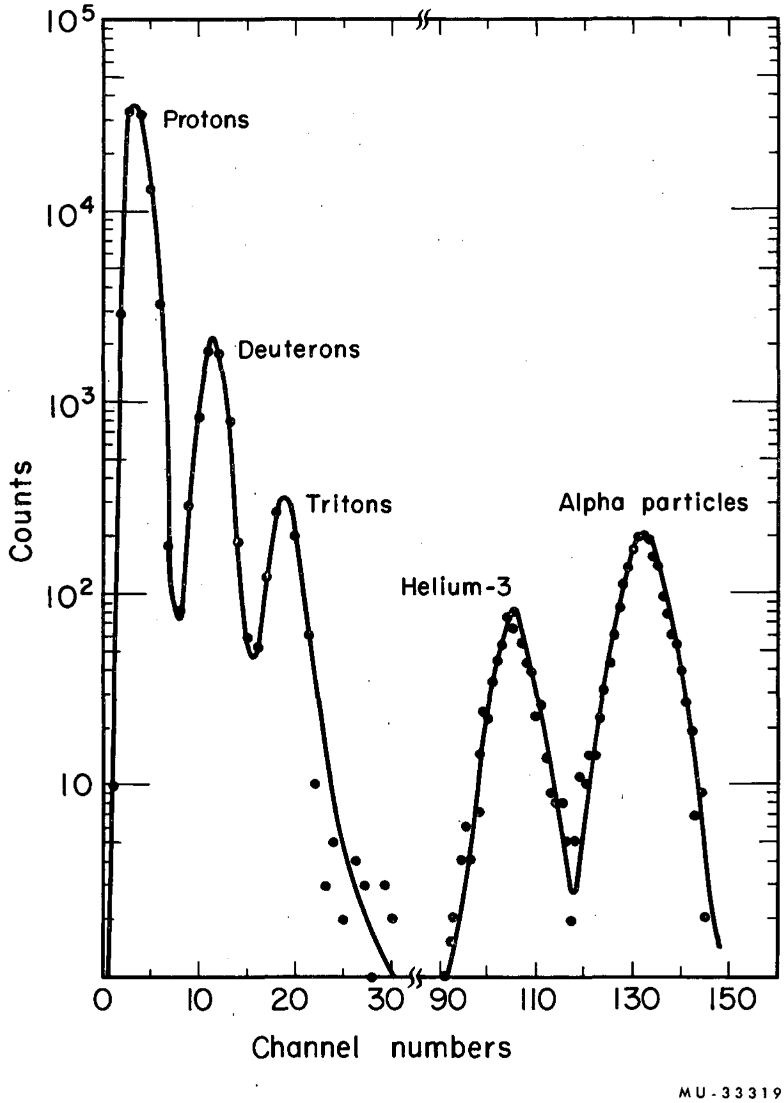
FIGURE CAPTIONS

Figure 1. Particle identifier spectrum from 43.7 MeV protons on O^{16}.

Figure 2. Angular distributions for the $O^{16}(p,t)O^{14}$g.s.[0+,T = 1] and $O^{16}(p,He^3)N^{14*}$[2.31 MeV, 0+, T = 1] transitions; the latter cross-sections have been multiplied by 1.88. The solid and dashed lines are L = 0, two-nucleon transfer DWBA fits to the (p,t) and (p,He^3) transitions, respectively. The optical model parameters for these fits were

	V	W	a	b	r_o	r_1
p	-55	-12	0.6	0.6	1.3	0
t and He^3	-60	-20	0.5	0.5	1.3	1.2



10⁵
10⁴
10³
10²
10
Counts
Protons
Deuterons
Tritons
Helium-3
Alpha particles
0
10
20
30
90
110
130
150
Channel numbers
MU-33319

Fig. 1

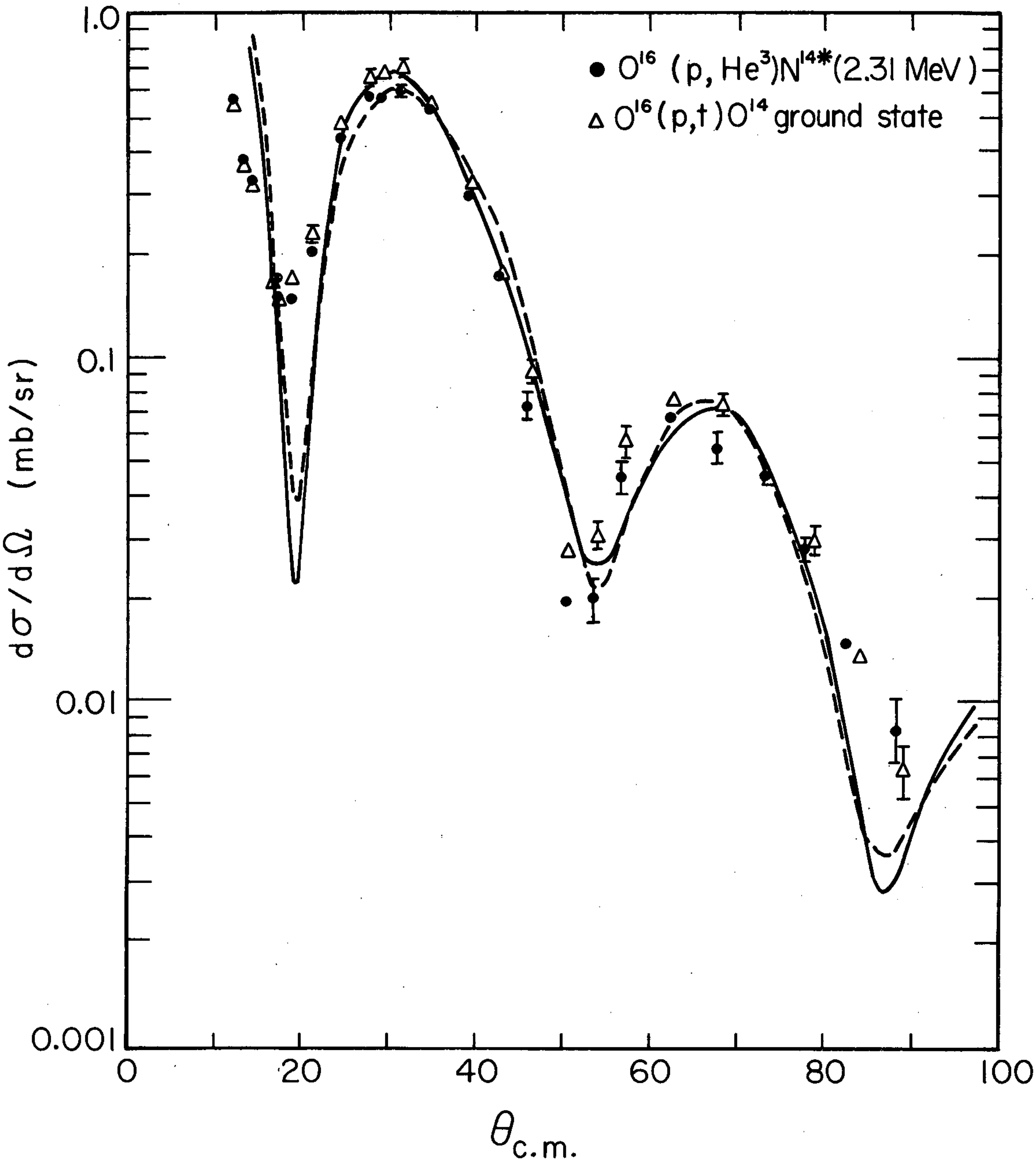


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Fig. 2