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Differential Cross Sections for the $^{13}C(^{3}He, p_0)$ and $^{15}N(^{3}He, p_0)$ Reactions at 15 MeV

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Abstract

The angular distributions of the ground state proton groups from ^{3}He-induced reactions with ^{13}C and ^{15}N targets have been measured at a bombarding energy of 15 MeV. The DWBA program DWUCK has been used to fit the differential cross sections with no free parameters. The optical model parameters for the proton–residual nucleus channel were taken from the literature, and the ^{3}He–target nucleus channel parameters were obtained by fitting the ^{3}He elastic scattering differential cross sections.

Introduction

Recently, a considerable amount of attention has been given to the two-nucleon transfer reaction, and to its ability to provide spectroscopic data concerning the residual states populated in the reaction (Hodgson 1971). This paper reports on studies of (^{3}He, p) reactions, with ^{13}C and ^{15}N targets, leading to the ground states of the final nuclei. A comparison of these two reactions is of interest, for the $^{13}C(^{3}He, p_0)^{15}N$ reaction involves two-nucleon transfer completely within the $1p_{1/2}$ subshell, while the $^{15}N(^{3}He, p_0)^{17}O$ reaction requires the two-nucleon transfer to take place 'across' a closed shell. The (^{3}He, p) reaction has been studied for other light nuclei by Schiffer *et al.* (1956), but their analysis was of limited scope. The work of Glendenning (1965) has pointed up the difficulty of obtaining results that can be related to the spectroscopic factor.

The present experiment consisted of measuring differential cross sections for the ground state proton group in both the $^{13}C(^{3}He, p_0)^{15}N$ and $^{15}N(^{3}He, p_0)^{17}O$ reactions at a bombarding energy near 15 MeV. At these energies, a direct reaction mechanism is assumed. The differential cross sections were analysed using the DWBA code DWUCK (P. D. Kunz, personal communication). To enable this analysis to be made, ^{3}He elastic scattering differential cross sections were also measured and fitted, thus yielding ^{3}He optical model parameters.

Experiment

The Melbourne University variable energy cyclotron was used to provide a beam of $^{3}He^{2+}$ ions of energy 15·05 MeV. This beam bombarded targets of ^{13}C, in the form of a 99·5% pure ^{13}C self-supporting foil of thickness 60 $\mu g\,cm^{-2}$, and of ^{15}N, in the form of a gas of 99% purity contained in a gas cell at a pressure of 190 mmHg ($\sim 2·5 \times 10^{4}$ Pa). The gas cell pressure was maintained constant to within 1% for each run.

The large Q values for both these reactions (10·67 MeV for $^{13}C(^3He, p)$ and 8·55 MeV for $^{15}N(^3He, p)$) lead to some problems in the detection of the required proton groups. To detect the high energy protons produced, an E–dE/dx detector telescope was used. The E detector consisted of two 2000 μm thick fully-depleted silicon surface barrier detectors in series. A 42 μm thick silicon detector, also fully depleted, was used to give the ΔE pulse. This thin detector was placed in front of the two that made up the E detector. Both the E and ΔE pulses were fed through preamplifier–amplifier systems to a PDP-9 computer which used a particle identification program (Hudson 1970) to sort the particles emitted from the reactions and to record the spectrum of each particle type separately.

To obtain absolute cross section data for the reactions in the solid ^{13}C target, the geometrical and target thickness normalizations were deduced from a comparison of elastic proton scattering from ^{13}C with published absolute data (Guratzsch *et al.* 1969). In the case of the ^{15}N target, the gas cell geometrical corrections were obtained as described by Crinean *et al.* (1975). Both of these comparisons are estimated to give the $(^3He, p)$ cross sections within 15% error.

Data Analysis

As noted above, the differential cross sections for elastic ^3He scattering from ^{13}C and ^{15}N were measured. These differential cross sections were then fitted, using the optical model search program SMITH (Smith 1970). The potential fitted by this program is of the form

$$U = V(r) + V_{so}(r)\,\boldsymbol{l}.\boldsymbol{\sigma} + \mathrm{i}\{W(r) + W_s(r)\} + V_c(r)\dots, \tag{1}$$

where

$$V(r) = -V(1+e^x)^{-1} \quad \text{with} \quad x = (r - r_0 A^{\frac{1}{3}})/a,$$

$$V_{so}(r) = V_{so}(\hbar/m_\pi c)\, r^{-1}\, d(1+e^x)^{-1}/dr,$$

$$W(r) = -W(1+e^y)^{-1} \quad \text{with} \quad y = (r - r_g A^{\frac{1}{3}})/b,$$

$$W_s(r) = 4T\, d(1+e^y)^{-1}/dy,$$

$$\begin{aligned} V_c(r) &= Z_a Z_A e^2/r && \text{for} \quad r \geqslant r_c A^{\frac{1}{3}}, \\ &= (Z_a Z_A e^2/2r_c A^{\frac{1}{3}})(3 - r/r_c A^{\frac{1}{3}}) && \text{for} \quad r \leqslant r_c A^{\frac{1}{3}}. \end{aligned}$$

The search was carried out over all parameters. The ^3He elastic scattering data for ^{13}C and ^{15}N targets are shown in Figs 1*a* and 1*b*, together with the fits obtained as described. The parameter sets used are displayed in Table 1*a*.

The proton spectra from ^3He-induced reactions in ^{13}C and ^{15}N were also measured at (laboratory) angles between 25° and 150° in 5° steps. The differential cross sections for proton groups leading to population of the ground states of ^{15}N and ^{17}O are shown in Figs 2*a* and 2*b*.

Both sets of $(^3He, p_0)$ data were compared with a DWBA calculation of the differential cross section using the computer program DWUCK. The calculation contained no free parameters, as the ^3He optical model parameters were obtained from elastic scattering data as described above, and the proton optical model parameters were obtained from published fits to proton elastic scattering data: the $^{15}N+p$ data were from Snelgrove and Kashy (1969) and the $^{17}O+p$ data from Crinean *et al.* (1975).

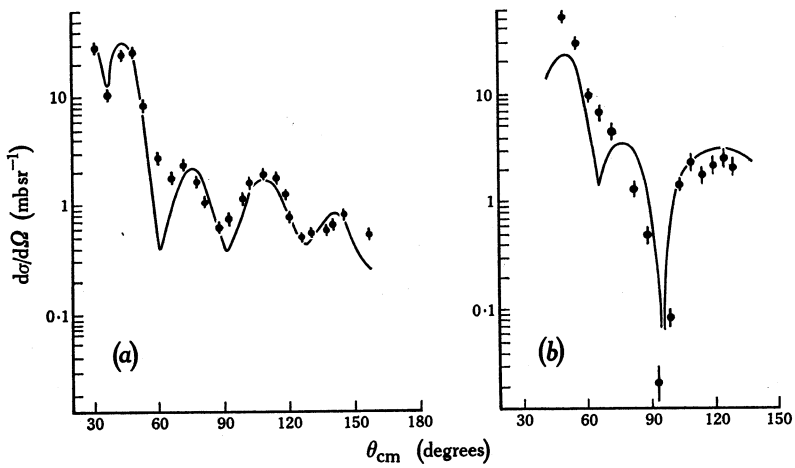

Fig. 1. Differential cross sections $d\sigma/d\Omega$ for the elastic scattering of ^3He by (*a*) ^{13}C and (*b*) ^{15}N, together with optical model fits obtained using the parameters given in Table 1*a*.

Table 1. Optical model parameters

Nucleus	V (MeV)	W (MeV)	W_s (MeV)	V_{so} (MeV)	r_0 (fm)	a (fm)	r_g (fm)	b (fm)	r_c (fm)
(*a*) *From Elastic Scattering of* ^3He									
^{13}C	125	14·0	18·5	0	1·16	0·79	1·14	0·90	1·40
^{15}N	161	21·0	0	4·2	1·32	0·60	1·25	0·57	1·30
(*b*) *From Elastic Scattering of Protons*									
^{15}N	44·0	4·54	11·6	8·0	1·13	0·66	1·42	0·48	1·15
^{17}O	46·5	0	23·2	20·4	1·25	0·66	1·25	0·34	1·25

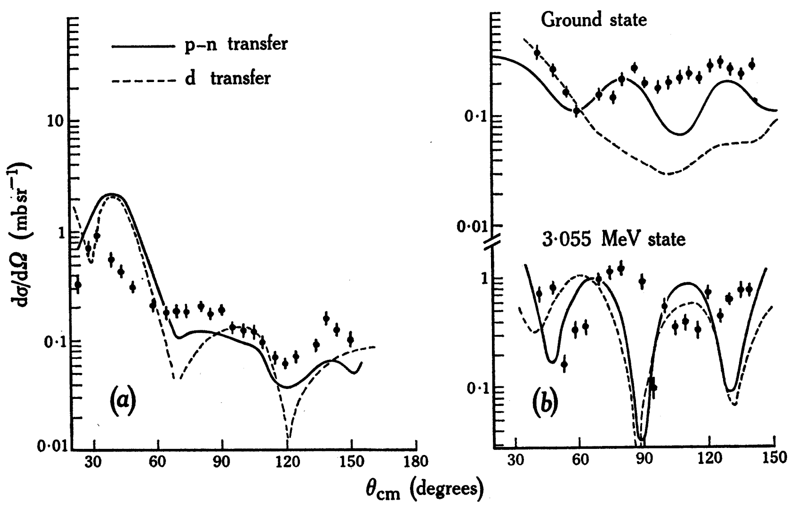

Fig. 2. Differential cross sections $d\sigma/d\Omega$ for (*a*) $^{13}C(^3He, p_0)^{15}N$ and (*b*) $^{15}N(^3He, p_0)^{17}O$ and $^{15}N(^3He, p_2)^{17}O^*$, together with DWBA fits using the parameters of Table 1 for both independent proton–neutron transfer and 'lump deuteron' transfer.

Discussion

The program DWUCK allows the facility for testing whether the two nucleons captured in the reaction are transferred as a 'lump deuteron' or as an independent proton–neutron pair. While the calculations postulating either transfer do not agree particularly well with experiment, that for the independent neutron–proton transfer gives a noticeably better account of the data. The comparisons are shown in Fig. 2 and the proton optical model parameters used are given in Table 1*b*.

The conclusion that the reaction proceeds via independent nucleon transfer is supported further by the observation that the probabilities of populating the ground and first excited states of ^{17}O in the $^{15}N(^{3}He, p)^{17}O$ reaction are almost as large as the probability of populating the second excited state of ^{17}O at 3·055 MeV. The ground and first excited states of ^{17}O are predominantly described as a single nucleon outside a ^{16}O core, while the dominant component of the 3·055 MeV state is a two-particle–one-hole configuration. The two former configurations cannot be populated by 'lump deuteron' transfer but the latter can be populated in this way.

Further evidence to support independent nucleon transfer comes from the observation that there is no preferential population of a small group of states in the $(^{3}He, p)$ reaction. Such preferential population has been observed in (α, d) reactions (Lu *et al.* 1969).

Unfortunately, the relatively poor quality of the fits to the $(^{3}He, p_0)$ differential cross sections rules out any attempt that might be made to derive quantitative nuclear spectroscopic information from them.

References

Crinean, G. B., Wild, L. W. J., and Spicer, B. M. (1975). Proton reactions with oxygen-17. I. Elastic and inelastic scattering reactions. *Nucl. Phys.* (in press).

Glendenning, N. K. (1965). *Phys. Rev.* B **137**, 102.

Guratzsch, H., Hofmann, G., Müller, H., and Stiller, G. (1969). *Nucl. Phys.* A **129**, 405.

Hodgson, P. E. (1971). 'Nuclear Reactions and Nuclear Structure' (Clarendon: Oxford).

Hudson, G. M. (1970). *Nucl. Instrum. Methods* **77**, 197.

Lu, C. C., Zisman, M. S., and Harvey, B. G. (1969). *Phys. Rev.* **186**, 1086.

Schiffer, J. P., Bonner, T. W., Davis, R. W., and Prosser, F. W., Jr (1956). *Phys. Rev.* **104**, 1064.

Smith, W. R. (1970). *Comput. Phys. Commun.* **1**, 198.

Snelgrove, J. L., and Kashy, E. (1969). *Phys. Rev.* **187**, 1259.

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