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Excitation of positive-parity states in ^{10}B with the ^{13}C(p,α)^{10}B reaction

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The ^{13}C(p,α)^{10}B reaction has been studied at an incident energy of 30.95 MeV. The strong excitation of the positive-parity states is clear evidence of a dominant pickup process in the dynamics of the (p,α) reaction. The experimental relative integrated cross sections are fairly well reproduced by the distorted wave direct pickup calculations using a triton cluster form factor and the shell model spectroscopic strengths of Kurath and Millener.

Our previous (p,α) study on 1p, 2s-1d shell nuclei[1] has shown that the primary reaction mechanism in the dynamics of these reactions is pickup, which strongly dominates over the knockout process. The recent investigation of the ^{14}C(p,α)^{11}B reaction at 41.9 MeV (Ref. 2) has further confirmed the dominance of the pickup process, since only negative parity states are strongly excited. For the ^{13}C(p,α)^{10}B reaction, one should expect the same dominant role of the pickup process with a consequent strong excitation of positive parity states obtained by removing three p nucleons from the ^{13}C target nucleus. On the other hand, in a knockout mechanism one should observe transitions to both types of levels in which the transferred proton can be captured into 1p or 2s-1d orbits. Thus far the ^{13}C(p,α)^{10}B reaction has been investigated at 43.7 and 54 MeV by Maples and Cerny[3] with a limitation of the experimental data to only two states, the 0^+ (0.74 MeV) and 4^+ (6.03 MeV) levels. In order to further investigate the (p,α) reaction mechanism, and to complete the study on carbon isotopes, we performed, at an incident energy of 30.95 MeV, the present ^{13}C(p,α)^{10}B experiment whose results are presented in this Brief Report.

The momentum analyzed beam from the XTU tandem of the National Laboratory of Legnaro provided the source of the proton beam. Self-supporting ^{13}C foils of thickness 60 μg/cm^2 (enriched to 96% in ^{13}C) were used as targets. The scattered alpha particles were detected by two silicon surface barrier detectors mounted on a rotatable platform in a large scattering chamber of one meter diameter. The two detectors, with a thickness of 400 μm sufficient to stop 29 MeV alpha particles, were angularly separated by 5 deg. The elastic proton scattering was obtained by using a 2 mm thick silicon detector in conjunction with a 2.6 mm thick aluminum absorber. Alpha angular distributions were measured from 5° to 90° (laboratory) in 2.5 deg steps, while the elastic proton angular distribution was measured from 5° to 150° (laboratory) in 5 or 10 deg steps. Absolute cross sections were determined by reference to the ^{13}C(p,p)^{13}C optical model fit, and the accuracy of the absolute cross sections thus determined is estimated to be about ±15%. A typical

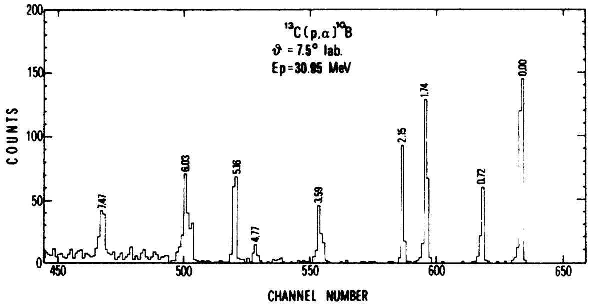

FIG. 1. Alpha spectrum from the ^{13}C(p,α)^{10}B reaction at $E_p = 30.95$ MeV and $\vartheta_{\text{lab}} = 7.5$ deg. The peaks are labeled by the ^{10}B excitation energy expressed in MeV.

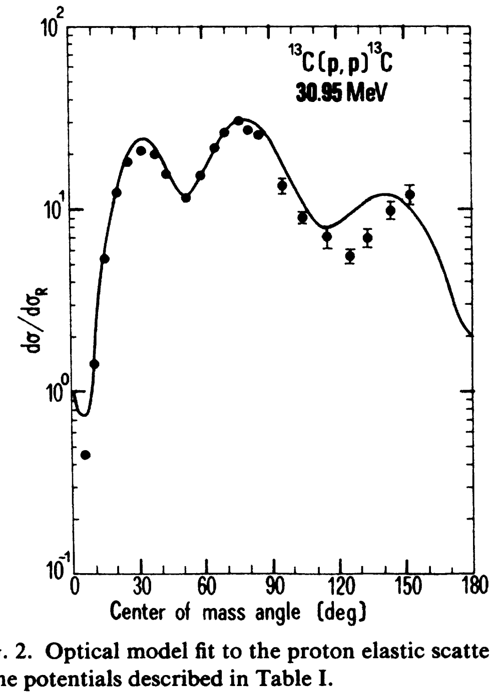

FIG. 2. Optical model fit to the proton elastic scattering data with the potentials described in Table I.

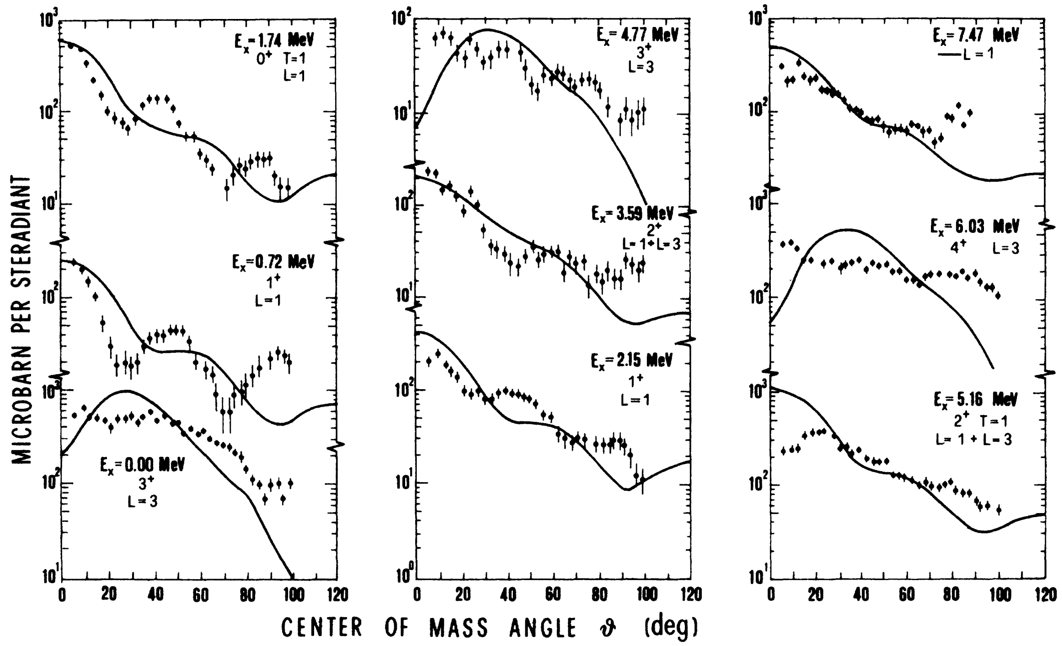

FIG. 3. Experimental angular distributions and distorted-wave predictions in the c.m. system for the ^{13}C$(p,\alpha)^{10}$B reaction at $E_p = 30.95$ MeV.

TABLE I. Optical model parameters used with the code LOLA in the ^{13}C$(p,\alpha)^{10}$B reaction.

Channel	V (MeV)	W (MeV)	W_d (MeV)	$V^a_{\mathrm{s.o.}}$ (MeV)	r (fm)	a (fm)	r' (fm)	a' (fm)	$r_{\mathrm{s.o.}}$ (fm)	$a_{\mathrm{s.o.}}$ (fm)	r_c (fm)
^{13}C$+p$	-53.4		6.045	5.6	1.064	0.623	1.2	0.6	1	0.575	1.25
^{10}B$+\alpha$	-207.1	-26			1.54	0.475	1.54	0.475			1.4
^{10}B$+t$	b				1.3	0.25					1.4
$t+p$	c				1.25	0.6					1.25

[a] The spin-orbit term has been used only for the elastic ^{13}C$(p,p)^{13}$C reaction.

[b] Adjusted to give the transferred triton a binding energy of $-Q(p,\alpha)+19.814$ MeV.

[c] Adjusted to reproduce the $p+t$ separation energy of 19.814 MeV.

TABLE II. Energy levels and spectroscopic factors C^2S_J derived for the ^{13}C$(p,\alpha)^{10}$B reaction. L and J specify the quantum numbers of the transferred triton.

E_x (MeV)		J^π,T	$L=1$		$L=3$	
expt.[a]	calc.[b]		$C^2S_{1/2}$	$C^2S_{3/2}$	$C^2S_{5/2}$	$C^2S_{7/2}$
0	0	$3^+,0$			0.002	1.078
0.72	0.9	$1^+,0$	0.019	0.002		
1.74	1.4	$0^+,1$	0.080			
2.15	2.4	$1^+,0$	0.033	0.077		
3.59	3.3	$2^+,0$		0.054	0.035	
4.77	4.7	$3^+,0$			0.018	0.011
5.16	5.6	$2^+,1$		0.209	0.020	
6.03	5.8	$4^+,0$				0.325

[a] From Ref. 4.

[b] From Ref. 8.

TABLE III. Summary of results from the $^{13}C(p,\alpha)^{10}B$ reaction.

E_x (MeV)[a]	(J^π,T)[a]	L	Integrated cross section expt. (μb)	Integrated cross section calc. (μb)[b]	Angular interval of integration (lab)
0	$3^+,0$	3	2215±222	2215	5–87.5
0.72	$1^+,0$	1	204±50	54	5–87.5
1.74	$0^+,1$	1	448±80	212	5–87.5
2.15	$1^+,0$	1	399±70	295	5–87.5
3.59	$2^+,0$	1+3	257±52	233	5–87.5
4.77	$3^+,0$	3	173±43	70	5–87.5
5.16	$2^+,1$	1+3	1087±110	675	5–87.5
6.03	$4^+,0$	3	1446±145	821	5–87.5
7.47	$(1^+,2^+)$	1	731±88		5–77.5

[a] From Ref. 4.

[b] The calculated cross section has been integrated in the same angular interval as the experimental one using a normalization factor equal to 91.2.

pulse height spectrum is shown in Fig. 1, where the energy resolution of the alpha groups is of the order of 40 keV. It is known[4] that the ^{10}B spectrum has 22 levels up to an excitation energy of 8.07 MeV. Of these we observe only nine peaks, all of positive parity. Between 5 and 8 MeV excitation energy there are six negative parity states.[4] These are populated by the present (p,α) reaction with cross sections 1 or 2 orders of magnitude lower than those of positive parity. As described previously, such an effect suggests a dominant pickup over knockout mechanism with excitation of pure p state levels. In Figs. 2 and 3 the experimental angular distributions with the distorted-wave Born approximation (DWBA) curves are shown. The theoretical calculation for the (p,α) transitions were carried out with finite range DWBA calculations using the code LOLA of DeVries[5] and a triton-cluster form factor. The calculations reproduce the experimental differential angular distributions within the accuracy usually found for (p,α) reactions on carbon isotopes.[2,1] The optical model parameters for the $^{13}C+p$ elastic channel are derived from Ohnuma *et al.*,[6] who studied the differential cross sections and analyzing powers of $^{13}C+p$ elastic scattering at $E_p=35$ MeV. These parameters, together with the ones used for the $^{10}B+\alpha$ and $^{10}B+t$ (Ref. 1) channels, are shown in Table I.

For a (p,α) reaction, the cross section calculated with the code LOLA is related to the experimental one by

$$\left[\frac{d\sigma}{d\Omega}\right]^{L,J}_{\text{expt}}=NC^2S(2L+1)W^2(0\tfrac{1}{2}LJ\mid\tfrac{1}{2}L)\sigma(\vartheta)^{L,J}_{\text{LOLA}}\ ,$$

where N is a normalization factor, L and J specify the quantum numbers of the transferred triton, C^2 is an isospin vector coupling which is equal to 1 or $\frac{1}{3}$ for final isospins $T=0$ and $T=1$, respectively, and S is the spectroscopic factor. Finally, W^2 is the Wigner coefficient[7] which takes into account the different coupling schemes of the transferred triton in the target and in ^4He nuclei. For the calculation of the spectroscopic factors reported in Table II, we have used the parentage amplitudes of Kurath and Millener.[8] The overall normalization constant N was obtained by equating the theoretical integrated cross section to the experimental one for the ground-state transition. The value of N derived in this way is equal to 91.2, and the results are summarized in Table III and shown in Fig. 4. The theory tends to overestimate the ground-state transition since all the other calculated cross sections are somewhat lower than the observed ones. However, the general trend of the (p,α) spectrum is fairly well reproduced by the theory despite the simplified analysis based on a cluster form factor.

In conclusion, the selectivity of the $^{13}C(p,\alpha)^{10}B$ reaction which strongly populates positive-parity states is a further confirmation that the dominant primary reaction mechanism is the pickup process. The analysis, based on a cluster form factor and DWBA calculations using current shell-model wave functions, explains the observed selectivity and the relative yield of the $^{13}C(p,\alpha)^{10}B$ spectrum.

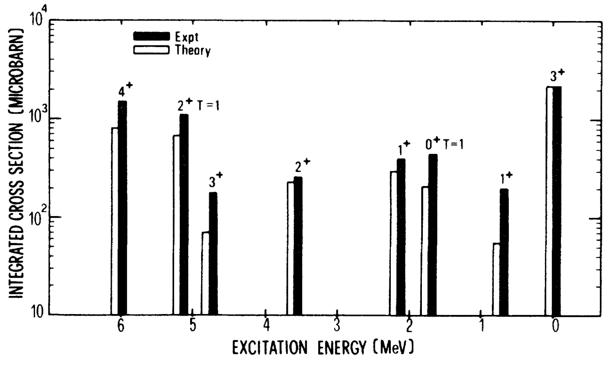

FIG. 4. Comparison of calculated and experimental integrated cross sections for the $^{13}C(p,\alpha)^{10}B$ reaction.

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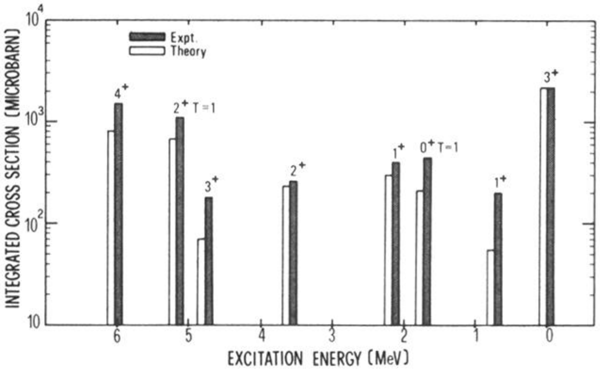

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