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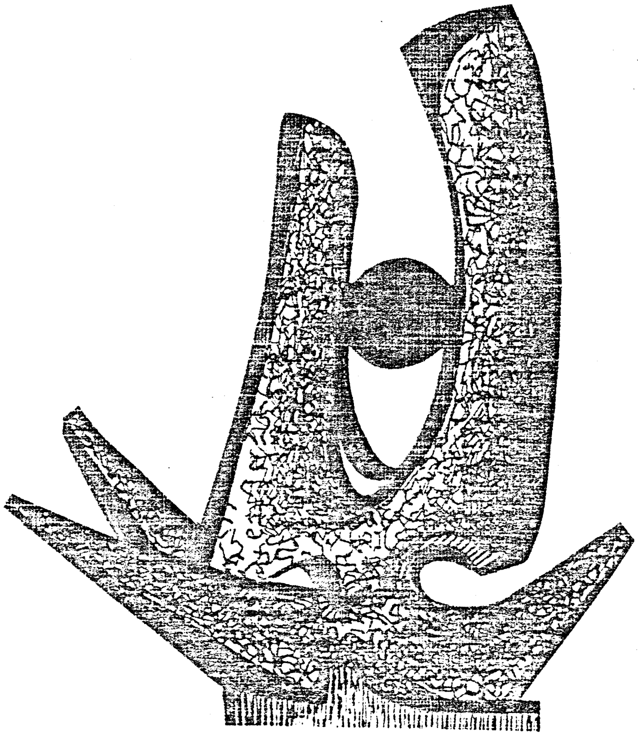

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Comparison of Alpha-Spectroscopic Factors on ^{24,26}Mg: The (^{14}N,^{10}B) Reaction

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Abstract

Cross sections for states populated in the ^{24}Mg(^{14}N,^{10}B)^{28}Si and ^{26}Mg(^{14}N,^{10}B)^{30}Si reactions at 83 MeV were measured. Equal strengths for population of ^{28}Si and ^{30}Si ground states were observed, in contrast to (^{16}O,^{12}C) and (^{12}C,^{8}Be) reactions, but in agreement with (^{6}Li,d) results and with theoretical predictions.

[Nuclear Reactions ^{24}Mg(^{14}N,^{10}B), ^{26}Mg(^{14}N,^{10}B), E=83MeV; measured $\sigma(\theta)$.]

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I. Introduction

Several measurements of alpha-spectroscopic factors between the ground states of ^{24}Mg-^{28}Si and ^{26}Mg-^{30}Si have been carried out in the past few years with widely varying results. Measurements of the ratio of spectroscopic factors via the (α,2α) reaction[1] are in good agreement with shell model predictions[2] but in poor agreement with (^{12}C,^{8}Be)[3] and (^{16}O,^{12}C)[4] reactions. Unpublished results[5] for ^{26}Mg (^{6}Li,d)^{30}Si at E_{Li}=36 MeV observe the ground state spectroscopic factor (and peak cross section) to be nearly equal to that from the ^{24}Mg (^{6}Li,d)^{28}Si reaction at the same incident energy[6] - a result which is in good agreement with the shell model predictions. In order to try to pin down this discrepancy and, in particular, to look for substantive problems in the description of the different reactions as one-step direct alpha transfer, we have investigated the relative ground-state yields to ^{28}Si and ^{30}Si via the (^{14}N,^{10}B) reaction on ^{24,26} Mg. The ^{26}Mg(^{14}N,^{10}B)^{30}Si reaction has been shown[7] to be adequately described by Distorted Wave Born Approximation (DWBA) calculations at 70 MeV, giving an indication that the reaction mechanism is direct. An earlier study of the relative ground state yields for the two reactions at 70 MeV proved inconclusive due to insufficient statistics.[8]

II. Experimental Procedure and Results

Beam currents of up to 1.5μA of 83 MeV ^{14}N were obtained from the Texas A & M 88" cyclotron and were used to bombard ~ 100 μg/cm^2 targets of isotopically enriched (>99%) ^{24}Mg and ^{26}Mg on thin carbon backings. Reaction products were observed in the focal plane of an Enge split-pole spectrograph using a 1.2 m detector[9] with mass and charge identification derived from energy loss information and particle rigidity. Transfer reaction cross sections were measured at 8°, 9°, and 10°. The ^{12}C(^{14}N,^{10}B)^{16}O reaction[10] was used for calibration. The backing on the Mg targets provided reference peaks since the cross sections are a factor of ten larger than for either Mg isotope. Unfortunately, the mass resolution was insufficient to completely resolve ^{10}B from ^{11}B. This did not prove a problem with the ^{24}Mg target, where the ^{11}B yields were less than half those for ^{10}B. However, this introduced large backgrounds with the ^{26}Mg target which produced ^{11}B's at a rate ten times that of the ^{10}B's. The large leak-through of ^{11}B's resulted in considerable uncertainty in yields for the ^{26}Mg target and prohibited extraction of yields for ^{30}Si excited states.

Relative cross sections were obtained by using the dead time corrected charge integration. Repeated runs showed a reproducibility of better than 3%. The products of target thickness and solid angle needed for calculating absolute cross sections were obtained by measuring elastic scattering cross sections and simultaneously fitting the normalization and the optical model parameters with the code ECIS.[11] Different parameter sets [7,12] were compared to establish the uncertainties of the procedure. The overall normalization is estimated to have an uncertainty of $\pm$ 40%, although the uncertainty in the cross section for ^{28}Si relative to ^{30}Si is 25% since possible errors in the optical model normalization largely cancel.

Levels in ^{28}Si were observed up to an excitation energy of $\sim$ 12 MeV. However, the simultaneous population of ^{10}B levels and ^{28}Si levels and the many levels populated in ^{16}O allowed extraction of yields for only the ^{28}Si 2^+ level at 1.78 MeV and the ^{10}B 1^+

(0.72 MeV) built on the ^{28}Si 2^+ level.

The cross sections for ^{24,26}Mg(^{14}N,^{10}B)^{28,30}Si ground state transitions are shown in the left hand side of figure 1, and the cross sections for the 1.78(2^+) and the ^{28}Si(2^+)-^{10}B(1^+) levels are to the right. Error bars represent uncertainties arising from background substraction, statistics and charge integration. The absolute cross sections for the ^{26}Mg(^{14}N,^{10}B) transitions are consistent with the excitation function systematics of ref. 7.

III. Discussion

Table 1 lists the ratios of cross sections (or ratios of spectroscopic factors) for several reaction systems on ^{24,26}Mg, together with the present data. Since there is little difference in the Q values or angular momentum matching between the reactions on ^{24}Mg and ^{26}Mg the dynamics of the two reactions should be the same if they are direct, thus ratios of cross sections should correspond to ratios of spectroscopic factors. It is seen that only the (^{6}Li,d) and the (^{14}N,^{10}B) reaction have ratios as predicted by theory[1] and consistent with (α,2α) work.[2] Recent ^{28}Si(p,pα)^{24}Mg work[13] supports both the (α,2α) and (^{6}Li,d) work on ^{24}Mg. The (^{12}C,^{8}Be) and (^{16}O,^{12}C) reactions seem to be the only ones in disagreement. One possible explanation is very different angular momentum mismatches inhibiting the reactions. Table 1, however, shows there is no correlation between mismatch and ratios of cross sections, although the (^{6}Li,d) and (^{14}N,^{10}B) reactions are more mismatched than the other channels.

We thus find the (α,2α), (p, pα), (^{6}Li,d) and (^{14}N,^{10}B) data to be consistent with each other and with theory. The (^{12}C,^{8}Be) and (^{16}O,^{12}C) are in disagreement with everything else. We are left with a choice between two possibilities, 1) the first four reactions are direct and the last two are not, and 2) none of the reactions are predominantly direct. The latter choice is somewhat implausible based simply on the agreement of the results for the four reactions. However, a careful examination of the evidence for or against the reactions being direct is needed. Such an examination for the four heavy ion studies follows.

At 70 MeV reasonable DWBA fits to the ^{26}Mg(^{14}N,^{10}B)^{30}Si angular distributions were obtained,[7] while compound nucleus, Hauser-Feshbach (HF), calculations underpredicted the forward angle cross sections by two orders of magnitude. Semi-classical analysis of the ^{16}O(^{14}N,^{10}B)^{20}Ne reaction at 155 MeV, also presents evidence for a direct mechanism.[14] Only in the ^{12}C(^{14}N,^{10}B)^{16}O reaction at 53 MeV were good fits obtained with HF calculations.[10] The presence of many ^{10}B excited states from both the Mg targets and the ^{12}C backing prevented identification of T=1 states, the presence of which would be indicative of multi-step processes.

There is considerable evidence that the (^{6}Li,d) reaction proceeds by single step transfer on many nuclei in the mass range 20-40.[5,15] Only in the ^{16}O(^{6}Li,d)^{20}Ne reactions is there some evidence for compound nuclear and multi-step processes. At 32 MeV, HF calculations for the ground state transition are 20 times too small at forward angles but are in good agreement at backward angles, although the complete angular distribution is very poorly described[16] by the HF calculations. Multi-step calculations produced only marginally better fits to the data than the DWBA.[17] Only at 20 MeV were the HF calculated strengths at forward angles below the experimental points by a factor of four.[18]

Good DWBA fits have been observed for the (^{12}C,^{8}Be) reactions on ^{24}Mg at 50 MeV,[3] on ^{40}Ca at 45 MeV[19] and on ^{28}Si at 42 MeV.[20] Additionally, the excitation function for the ^{28}Si(^{12}C,^{8}Be)^{32}S ground state transition does not exhibit any resonance-like structure in the range $23 \leq E_{c.m} \leq 29$ MeV.[20] Therefore, there is evidence that (^{12}C,^{8}Be) is direct with no data to the contrary.

At 56 MeV the ^{24}Mg(^{16}O,^{12}C)^{28}Si reaction is well described by the DWBA calculations.[21] In the energy range $40 \leq E_{lab} \leq 80$ MeV many successful DWBA and Legendre Polynominal fits have been made.[22,23] However, it is well known that the ^{24}Mg(^{16}O,^{12}C)^{28}Si shows strong resonance features[22] over this 40 MeV bombarding energy range. It is possible that some enhancement of the cross section from the ^{24}Mg target compared to ^{26}Mg has occurred because of this resonance behavior thereby invalidating any comparison of spectroscopic factors for (^{16}O,^{12}C) on Mg isotopes. In a study of (^{16}O,^{12}C) on ^{28}Si, Berg et al,[24] observed that the reaction does not populate a T=1 state which is not accessible *via* a direct "α-cluster" transfer, indicating the reaction is direct.

It would seem that there is considerable evidence that all the heavy ion α-transfer reactions discussed are essentially single step processes on at least some sd-shell nuclei and that evidence for competing mechanisms is scarce, with the exception of the ^{24}Mg(^{16}O,^{12}C)^{28}Si reaction. However, the cross sections for (^{12}C,^{8}Be) and (^{16}O,^{12}C) on ^{26}Mg are small, on the order of 1-10 μb/sr, and represent the major inconsistency between the other reactions and between the theory. With such small cross-sections the possibility of reaction mechanisms contributing differently to each reaction is more likely and makes a detailed comparison between these channels difficult. The agreement of the (^{14}N,^{10}B) and (^{6}Li,d) results with light ion work suggests that these channels proceed via a single step mechanism and that (^{16}O,^{12}C) and (^{12}C,^{8}Be) reactions have contributions from other mechanism, at least on the Mg isotopes

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Figure Caption

Fig 1. Cross sections for states populated in the $^{24,26}Mg$ $(^{14}N, ^{10}B)$ $^{28,30}Si$ reactions at 83 MeV. Subscripts refer to the excitation energy in MeV of the levels in Si and ^{10}B.

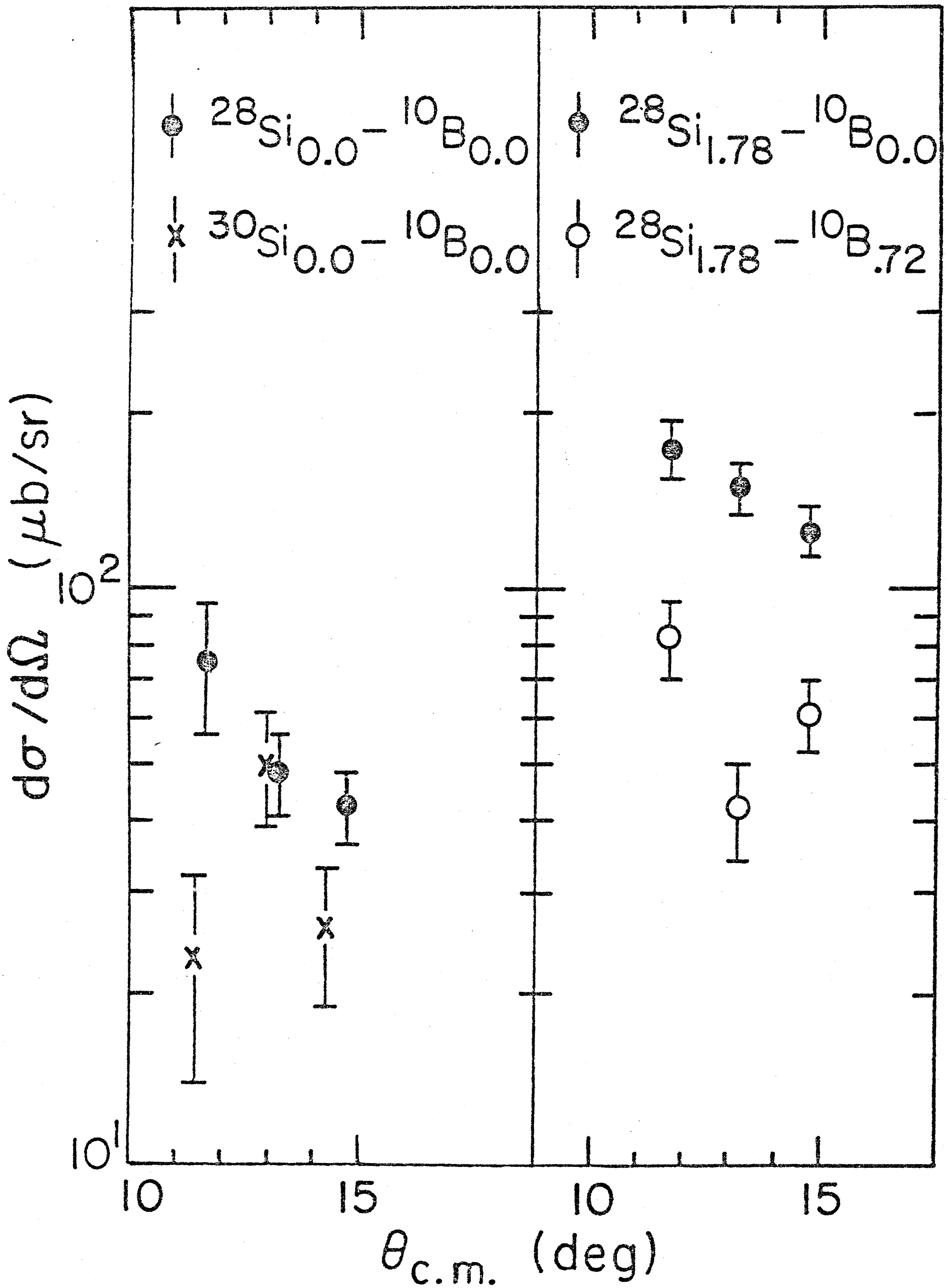
Table 1

Cross Section Ratios for $^{24,26}Mg$ Reactions

Reactions	E_{Lab} (MeV)	$\left.\frac{d\sigma}{d\Omega}\right\|_{^{26}Mg} \Big/ \left.\frac{d\sigma}{d\Omega}\right\|_{^{24}Mg}$	$\Delta\ell$	ref.
$(^{16}O, ^{12}C)$	42	0.029	2	4
$(^{12}C, ^{8}Be)$	50	$<0.02^{a}$	2	3
	65	$<0.1^{a}$	3	
$(^{6}Li, d)$	36	$1.0 \pm .3$	6	5,6
$(^{14}N, ^{10}B)$	83	$0.68 \pm .31$	4	this
Theory^{b}		0.88		1

(a) The authors of ref. 3 report that the ground state of ^{30}Si was not observed at any energy or angle. The 50 MeV ratio is that of the strongest state observed. The 65 MeV ^{30}Si state is the lowest cross section observed (assumed upper limit).

(b) Ratio of spectroscopic factors.


$^{28}Si_{0.0} - ^{10}B_{0.0}$
$^{30}Si_{0.0} - ^{10}B_{0.0}$
$^{28}Si_{1.78} - ^{10}B_{0.0}$
$^{28}Si_{1.78} - ^{10}B_{.72}$
$d\sigma/d\Omega$ (μb/sr)
10^2
10^1
10
15
10
15
$\theta_{c.m.}$ (deg)