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First Observation of the (^{4}He, ^{8}B) Reaction

W.S. Gray and R.S. Tickle
Physics Department, The University of Michigan, Ann Arbor, Michigan, USA

R.D. Bent
Indiana University Cyclotron Facility,* Bloomington, Indiana, USA

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The (^{4}He, ^{8}B) reaction on ^{27}Al and ^{66}Zn targets has been studied at $E_\alpha = 109$ MeV, the first observation of this reaction. Five groups appear in the first 4 MeV of excitation in the ^{23}Ne spectrum, with laboratory differential cross sections ranging from 35 to 384 nb/sr at $\theta_{\mathrm{lab}} = 8°$. Individual levels in ^{62}Co were not resolved in the exposure on the ^{66}Zn target. However, ^{8}B events were observed which are tentatively attributed to the ^{66}Zn(α, ^{8}B)^{62}Co reaction, since contributions from plausible target contaminants can be eliminated on the basis of Q value. The observed yield at 8° indicates a laboratory cross section of 540 nb/sr summed over the first 4.6 MeV of excitation in ^{62}Co.

1. Introduction

One of the methods which has often been used to determine the masses of nuclides away from the line of stability is the direct observation of reactions which remove several nucleons of the same kind from the target. For example, such reactions as (^{3}He, ^{6}He) and (^{4}He, ^{8}He), which involve the transfer of neutrons, have been extensively used to measure the masses of light and medium-weight neutron-deficient nuclides.

For various experimental reasons, much less work has been done using reactions which transfer several protons, although multiple-proton transfer reactions induced by heavy ions have been observed in a few cases [1-3]. Among the possible light-ion induced reactions, the (^{4}He, ^{8}B) reaction, which removes three protons and a neutron from the target, could in principle be used to study several presently unknown neutron-rich nuclides, beginning at $A \simeq 45$. However, the (^{4}He, ^{8}B) reaction suffers from some serious experimental disadvantages as a vehicle for mass measurements. In comparison with the aforementioned neutron-transfer reactions, the contributions to line widths from target thickness are greatly increased by the difference in charge between the projectile and ejectile. This difficulty is exacerbated by the large negative Q values, typically at least -30 MeV on neutron-rich targets. In addition, the transfer of an odd number both of protons and neutrons leads to odd-odd residual nuclei with their more complicated level schemes, when the more abundant even-even targets are used. Still, given a reasonable cross section, the (^{4}He, ^{8}B) reaction might be expected to yield some useful information about certain nuclides which are difficult to reach in any other way.

To our knowledge, the (^{4}He, ^{8}B) reaction has never previously been observed, although an unsuccessful attempt to measure the mass of ^{60}Mn via the ^{64}Ni(^{4}He, ^{8}B)^{60}Mn reaction has been reported [4]. In the present communication, we present some data for the (^{4}He, ^{8}B) reaction on ^{27}Al and ^{66}Zn targets, at a bombarding energy of 109 MeV. Neither of the residual nuclides, ^{23}Ne and ^{62}Co, is of interest from a mass measurement point of view, since each mass is well known. However, the Q values for these reactions (-32.5 MeV and -27.8 MeV for the aluminum and zinc targets respectively) are roughly comparable to those for some neutron-rich targets of interest. In addition, the low-lying level structure of ^{23}Ne is fairly well known, so that some insight may be gained into the selectivity of the reaction. The purpose of this paper is to provide an approximate guide to the yield which might be expected in mass measurement experiments under similar conditions.

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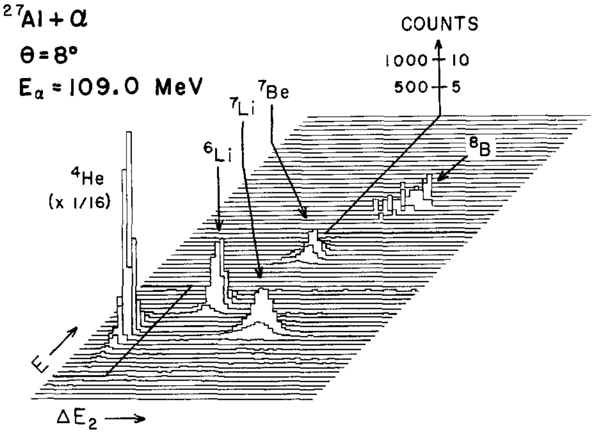

Fig. 1. A two-dimensional display of energy loss (ΔE_2) versus the energy (E) measured at the spectrograph focal plane, for events induced by 109 MeV α particles incident on an ^{27}Al target. Note that relative to the remainder of the figure, the vertical scale in the region containing the ^{8}B group (upper right) is expanded by a factor of 100, while it is compressed by a factor of 16 in the vicinity of the intense ^{4}He group

2. Experimental Procedure

Measurements were made of ^{8}B spectra at $\theta_{\text{lab}} = 8°$, from ^{27}Al and ^{66}Zn targets bombarded with 109.0 MeV alpha particles at the Indiana University Cyclotron Facility. The aluminum target consisted of two stacked, self-supporting foils totaling 413 μg/cm^2 in thickness. The zinc target was fabricated by evaporating ^{66}Zn, 765 μg/cm^2 thick and enriched to 98.8 %, onto a 30 μg/cm^2 carbon backing.

The ^{8}B ejectiles were momentum-analyzed in a magnetic spectrograph and detected in a position-sensing gridded ionization chamber placed at the focal plane of the spectrograph. The solid angle subtended by the spectrograph aperture was 3.3 msr. The design of the ionization chamber was based on one developed at Argonne [5]. The essential feature of such a detector is that the position sensing wire proportional counters and the electrodes used for differential energy loss measurements are all contained in the same gas volume, separated by grids from the region in which the incident ions are stopped. The parameters measured included an initial position measurement (X_1), two sequential differential energy loss measurements (ΔE_1), and (ΔE_2), a second position measurement (X_2), and the energy (E). These parameters were recorded in event mode and simultaneously sorted on-line. The two position measuring elements each consisted of a single-wire proportional counter using a carbon-coated quartz fiber. Positions along the fiber were determined using the Borkowski-Kopp rise-time scheme [6]. A third proportional counter mounted at the rear of the detector was used to veto passing particles.

The measured values of E and either of the ΔE signals, together with knowledge of the spectrograph setting $B\rho$, were sufficient to cleanly and unambiguously distinguish the ^{8}B ions from other species. Redundant information from the other ΔE measurement and the second position measurement X_2 was also available for background rejection; however, a display of ΔE_2 vs. E showed the background in the vicinity of the ^{8}B group to be quite small under actual operating conditions. A two-dimensional display of ΔE_2 vs. E obtained during a run on the aluminum target is shown in Fig. 1.

3. Results and Discussion

3.1. *The* ^{27}Al(^{4}He, ^{8}B)^{23}Ne *Reaction*

In Fig. 2, we show a spectrum from the ^{27}Al(^{4}He, ^{8}B)^{23}Ne reaction at $\theta_{\text{lab}} = 8°$, obtained from the first of the two position measurements (X_1). This spectrum is a composite of two overlapping settings of the spectrograph magnetic field, with events from the second exposure shifted in position to compensate for the different field setting. The range of Q values covered extends from approximately 2.5 MeV above the ground state energy to 4.5 MeV of excitation in ^{23}Ne, or from $Q = -30$ to -37 MeV. Although no special effort was made to calibrate the spectrograph and beam analysis magnets for this particular experiment, the ground state peak appeared within 150 keV of its calculated position, as-

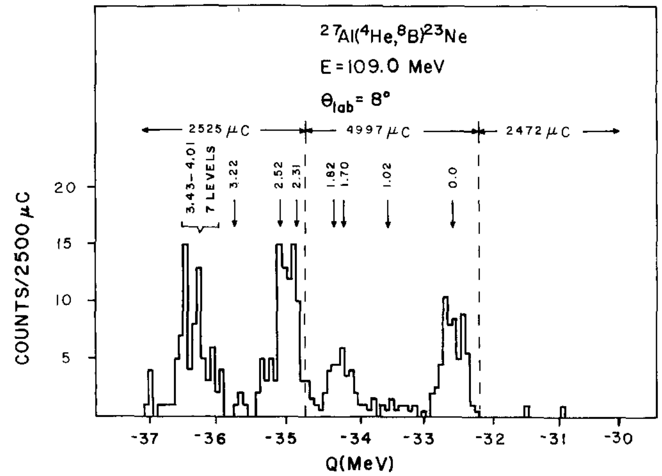

Fig. 2. A spectrum observed for the ^{27}Al(α, ^{8}B)^{23}Ne reaction at 8°. The positions of known states in ^{23}Ne are indicated by arrows. The ordinate represents the number of counts observed per 2,500 μC integrated charge, in order to adjust for differing beam exposure in different parts of the spectrum

Table 1. Differential cross sections measured for the (^4He, ^8B) reaction at $\theta_{lab}=8°$ and $E_\alpha=109.0$ MeV

Residual nucleus	Excitation energy (MeV)	$d\sigma/d\Omega$(lab)[c] (nb/sr)	Q (MeV)
^{23}Ne	0.0	235 ± 22	-32.54
	1.02	35 ± 9	-33.56
	1.76[a]	142 ± 17	-34.30
	2.42[a]	384 ± 40	-34.96
	3.8[a]	351 ± 37	-36.3
^{62}Co	0-4.6[b]	540 ± 91	-27.8-(-32.4)

[a] Probably includes two or more unresolved levels
[b] Spectrum contains a continuum of unresolved levels
[c] Uncertainties given are statistical only

suming the Q value (-32.536 MeV) implied by the mass tabulation of Wapstra and Bos [7]. The expected positions relative to the ground state of known states in ^{23}Ne up to 4 MeV excitation [8] are indicated by arrows in the figure, together with their excitation energies. Note that the portion of the spectrum extending from just above the ground state to about 2.1 MeV excitation was included in both spectrograph exposures, so that the integrated beam current for that part of the spectrum was approximately double that for the rest. The vertical scale in that region has been adjusted by a factor of two in order to avoid distortion of the spectrum as indicated in the figure.

The line width observed for the ground state is approximately 435 keV FWHM, almost entirely determined by target thickness. Thus, only the ground state and the first excited state at 1.02 MeV, for which there is some indication in the spectrum, would have been resolved. There are distinct peaks which appear to correspond to two pairs of levels centered at about 1.75 and 2.4 MeV, as well as another, broader peak which may be due to the several known levels between 3.4 and 4 MeV. Significant contributions to this spectrum from target contaminants are unlikely, since the most plausible sources of appreciable contamination, the stable carbon and oxygen isotopes, are eliminated by more negative Q values.

Differential cross sections for the five groups discernible in the spectrum are given in Table 1. A degree of selectivity is apparent, an undesirable feature for mass measurements where one would like to be sure that the ground state is among the levels populated with detectable intensity. In the present case, the first excited state at 1.02 MeV is populated with only about one seventh the intensity observed for the ground state, and about one tenth that of the groups at 2.4 and 3.7 MeV, which as mentioned before are each probably due to more than one level.

3.2. The $^{66}Zn(^4He, ^8B)^{62}Co$ Reaction

Except for the heavier calcium isotopes, the lightest neutron-rich targets which would be of interest for mass measurements via the (^4He, ^8B) reaction are found in the $A\sim65$-70 region. One possibility, for example, is the $^{64}Ni(^4He, ^8B)^{60}Mn$ reaction, which Cossairt et al. [4] attempted unsuccessfully to observe at a bombarding energy of 116.5 MeV. These investigators found no definite ^8B events within the Q-value range from -33 to -38 MeV, which would have included the ground state and the first few MeV of excitation in ^{60}Mn, and placed an upper limit of 10 nb/sr upon the cross section within this range of Q values. As a supplement to that experiment, we have investigated the $^{66}Zn(^4He, ^8B)^{62}Co$ reaction, which involves a target close in mass to ^{64}Ni but has a Q value (-27.8 MeV) which is somewhat less negative and therefore probably more favorable than the value -34.7 MeV [9] for the ground state transition leading to ^{60}Mn.

The level structure of ^{62}Co is quite complicated [10]. Thus, the thickness of the ^{62}Zn target was chosen not with the intention of resolving individual levels, but rather to maximize the yield in a relatively brief exposure (with the target used, the expected line width for an individual level would be about 600 keV). Accordingly, although a ^8B group could be clearly identified in the ΔE_2 vs. E display obtained with the ^{66}Zn target (Fig. 3), the corresponding position spectrum is consistent with a continuum of events at momenta lower than the expected position of the ^{62}Co ground state. Although the experimental resolution thus precluded the identification of target contaminants via a kinematic shift, in this case con-

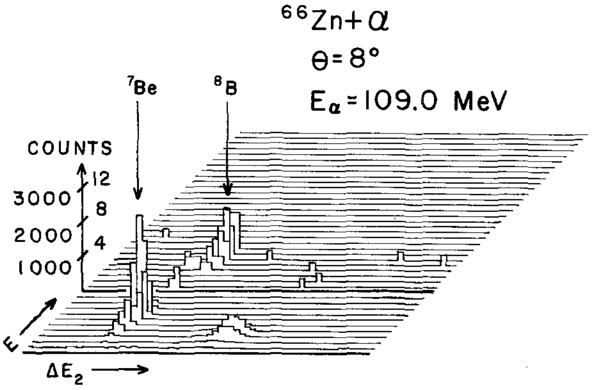

Fig. 3. A two-dimensional display of differential energy loss (ΔE_2) versus the energy (E) measured at the spectrograph focal plane, for events induced by 109 MeV α particles incident on a ^{66}Zn target. The zero in the E direction is suppressed, so that the more intense groups due to ions with $Z<4$ lie off scale. In the energy region above the ^7Be group the vertical scale has been expanded by a factor of 250 as indicated, in order to exhibit the ^8B events

tributions from all the lighter target contaminants which might plausibly be expected are ruled out by their larger negative Q values. Thus, it seems reasonable to assume that the ^{8}B events which are observed arise from the ^{66}Zn(^{4}He, ^{8}B)^{62}Co reaction.

The energy region covered in the exposure on the ^{66}Zn target corresponds to the first 4.6 MeV of excitation in ^{62}Co, ranging in Q value from -27.8 to -32.4 MeV. A total of 35 ^{8}B events were identified within this range, indicating a laboratory cross section of 540 nb/sr, or about 120 nb/sr-MeV. Although the level structure of ^{62}Co is not known over the full 0–4.6 MeV excitation energy range covered in the exposure, the Nuclear Data Sheets list a total of 30 levels below 2.75 MeV [10]. Thus, the measured yield suggests that the cross section for an average level would be in the 5–10 nb/sr range. This is considerably larger than the upper limit obtained in Ref. 4 for the reaction on the nearby nucleus ^{64}Ni, at nearly the same bombarding energy, perhaps partly because of the somewhat more favorable reaction kinematics in the present case.

4. Summary

The data presented here indicate yields for the (^{4}He, ^{8}B) reaction which vary from a few hundred nb/sr for an ^{27}Al target to an average of only a few nb/sr per level in the case of ^{66}Zn. Precise mass measurements using this reaction in the $A \sim 65$ region would thus be difficult, but given intense beams, may provide a feasible means of reaching certain odd-odd nuclei which are inaccessible by other methods.

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W.S. Gray
R.S. Tickle
Physics Department
The Harrison M. Randall
Laboratory of Physics
The University of Michigan
Ann Arbor, Michigan 48109
USA

R.D. Bent
Indiana University Cyclotron Facility
Bloomington, Indiana 47401
USA