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NEW SPECTROSCOPIC MEASUREMENTS VIA EXOTIC NUCLEAR REARRANGEMENT: THE $^{26}Mg(^{7}Li, ^{8}B)^{25}Ne$ REACTION

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NEW SPECTROSCOPIC MEASUREMENTS VIA EXOTIC NUCLEAR REARRANGEMENT: THE $^{26}Mg(^{7}Li,^{8}B)^{25}Ne$ REACTION*

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Abstract:

A 79 MeV ^{7}Li beam and counter telescope techniques were employed to observe the $^{26}Mg(^{7}Li,^{8}B)^{25}Ne$ reaction. The cross-section to the ground state was ~ 350 nb/sr at forward angles and its Q-value was -22.05±0.10 MeV, corresponding to a ^{25}Ne mass excess of -2.18±0.10 MeV. Five excited states were also observed at 1.65±0.05, 2.03±0.05, 3.25±0.08, 4.05±0.08, and 4.7±0.1 MeV.

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Although all of the $T_z = (N-Z)/2 = 5/2$ nuclei from ^{11}Li to ^{35}P (except ^{13}Be) are known to be particle stable, many of their masses are not yet accurately known and no data on the positions of their excited states are available.[1] Knowledge of their masses and energy levels is important because it permits the testing of systematic mass relations and the comparison of experimental with theoretical level schemes for nuclei in a region far from stability. Spectroscopic information on such neutron-excess nuclei has been difficult to obtain via "in-beam" reactions since a large isospin transfer is required in the production process. Unusual heavy-ion rearrangement reactions may then be an excellent means of overcoming this restriction. In this spirit, we have investigated the feasibility of using the (^{7}Li,^{8}B) reaction ($|\Delta T_z| = 3/2$) as a prototype for such studies.

By bombarding ^{26}Mg with a 79 MeV $^7\text{Li}^{2+}$ beam from the Lawrence Berkeley Laboratory 88-inch cyclotron, we have successfully detected ^{8}B nuclei from the ^{26}Mg(^{7}Li,^{8}B)^{25}Ne reaction (Q = ~ -22 MeV), determining the mass of ^{25}Ne and, for the first time, the level structure of a $T_z = 5/2$ nucleus in the very light elements. Reactions yielding ^{8}B nuclei are particularly suitable for the study of neutron-excess isotopes for several reasons. Proton-rich ^{8}B is the lightest, particle-stable $T_z = -1$ nuclide and the fact that both ^{7}B and ^{9}B are proton-unbound simplifies its identification. Further, since all excited states of ^{8}B particle decay, any possible "shadow peak" problems are eliminated.

This reaction was studied utilizing a lithium beam produced with a PIG-type internal ion source.[2] Cathode buttons were employed which consisted of a mixture of 20% LiF and 80% tungsten pressed into a tantalum shell under very high pressure. Erosion of the buttons by the arc maintained a partial pressure of lithium in the source. Additional lithium was supplied by a perforated cylindrical tantalum sleeve loaded with fused LiF which was inserted in the anode. Maximum long-term beam intensities of approximately 200 nA (3+) on target were obtained with a low arc power which slowly vaporized the LiF over a period of ~ 4 hours.

The maximum energy $^7\text{Li}^{2+}$ beam (78.9 MeV) was used to bombard a 99.4% isotopically enriched, self-supporting ^{26}Mg target of thickness 150 μg/cm^2. The energy of the beam was determined using a high-precision analyzing magnet.[3]

Outgoing ^{8}B particles were detected in two counter telescopes, each subtending a solid angle of 0.43 msr, located on opposite sides of the beam. These telescopes consisted of two ΔE detectors (denoted ΔE2 and ΔE1) 15 μ and 11 μ thick, respectively, a 200 μ E detector and a 500 μ reject detector. After a fast coincidence among the first three detectors restricted the origin of all allowed events to a single beam burst, two particle identifications (P.I.) were performed and compared using the signals from the successive ΔE detectors and the E detector.[4] Events in each system with an acceptable ratio of identifications (a stringent comparison eliminated ~ 50%) were sent via an analog-to-digital converter and multiplexer system to an on-line PDP-5 computer. Four parameters for each event (ΔE2, ΔE1, the total E signal, and a P.I. acquired using the summed ΔE pulses) were recorded on magnetic tape for later detailed analysis, and were also sorted on-line to give ^{8}B and ^{10}B energy spectra.

Figure 1 presents a particle identification spectrum showing good separation in the region of the boron isotopes. (This figure also indicates that a few ^{10}C particles were identified. However, the yield and selectivity of the $^{26}Mg(^{7}Li,^{10}C)^{23}F$ reaction were such that no information on ^{23}F could be obtained in these experiments.) To further reduce possible background in the ^{8}B region, a two-dimensional ΔE2 and ΔE1 versus total energy analysis was done off-line. A small percentage of additional events could be eliminated in this manner.

An energy calibration for the ^{8}B data was acquired by concurrently observing ^{10}B particles at θ_{lab} = 10°, 15°, and 20° from the $^{26}Mg(^{7}Li,^{10}B)^{23}Ne$ reaction. Periodic stability checks of the electronics were obtained and linearity was established by utilizing a high-precision pulser, which had been calibrated by alpha-particles from a ^{212}Pb source. In the off-line analysis, corrections were made to individual ^{8}B events to allow for slight gain changes and beam energy shifts. Reactions yielding ^{8}B nuclei from possible ^{12}C and ^{16}O contaminants were not seen. Kinematic shifts (from 10° to 15°) of all the observed peaks were only consistent with reactions induced on ^{26}Mg.

Two independent investigations of the $^{26}Mg(^{7}Li,^{8}B)^{25}Ne$ reaction were made. The ^{8}B data collected at $\theta_{lab} = 10°$ during run 2 are shown in Fig. 2a. Figure 2b is a composite spectrum of these same data plus $\theta_{lab} = 15°$ data taken during both runs 1 and 2 and kinematically corrected to 10°. The cross-sections for population of the ground state at 10° and 15° were similar and were about 350 nb/sr. In addition to the ground state, five excited states of ^{25}Ne can be seen at excitation energies of 1.65±0.05, 2.03±0.05, 3.25±0.08, 4.05±0.08, and 4.7±0.1 MeV. Counts on the high energy shoulder of the 3.25 MeV peak are inconsistent with the observed ^{10}B resolution of ~ 200 keV and are inconclusive evidence for an additional excited state.

Unfortunately, no calculations are available on the level scheme of ^{25}Ne. From simple particle-hole theorems and the spherical shell model one might expect ^{25}Ne to possess a low-lying level structure similar to that of ^{27}Mg (J^{π} g.s. = $1/2^{+}$), whose first two excited states[5] lie at 0.98 MeV ($3/2^{+}$) and 1.70 MeV ($5/2^{+}$). However, even for low excitations, the configuration space needed to describe ^{27}Mg adequately is probably larger than $(\pi d_{5/2})^{-2}(\nu s_{1/2})^{-1}$, as is indicated by some success[5] in applying the Nilsson model to ^{27}Mg. There is, though, a marked similarity[6] between the level spectra of ^{24}Ne and ^{18}O [hence ^{18}Ne] below ~ 4 MeV, which would support describing the lowest levels of ^{25}Ne by the $(\pi d_{5/2})^{2}(\nu s_{1/2})^{1}$ configuration. Using the matrix elements of Kuo and Brown,[7] a $1/2^{+}$ ground state; a 1.3 MeV, $5/2^{+}$ level; and a 2.1 MeV, $3/2^{+}$ level are expected. The calculated ground state spin of $1/2^{+}$ agrees with that preferred by Goosman *et al.*[8] in studies of the β-decay of ^{25}Ne. The significance of the agreement with the observed excitation energies must await more detailed calculations, though one can conclude that the ground state of ^{25}Ne is likely to be well separated from excited states, as observed.

From the energy of the ^{8}B ground state peak, the Q-value for the ^{26}Mg(^{7}Li,^{8}B)^{25}Ne reaction is found to be -22.05±0.10 MeV, corresponding to a mass excess for ^{25}Ne of -2.18±0.10 MeV. This is in good agreement with the two previous experimental results of -1.96±0.30 MeV by Goosman et al.[8] and -2.2±0.3 MeV by Kabachenko et al.[9] (see discussion in Ref. 8), both from β end-point measurements arising in the decay of ^{25}Ne.

Thibault and Klapisch,[10] using the method of Garvey et al.[11] but with more recent data, predict a mass excess for ^{25}Ne of -1.28 MeV. By applying the "transverse" mass relation of Garvey and Kelson (Eq. (1) of Ref. 11) specifically, one obtains:[12]

$^{25}\mathrm{Ne} = {}^{24}\mathrm{Ne} + ({}^{26}\mathrm{Na} - {}^{24}\mathrm{Na}) - ({}^{26}\mathrm{Mg} - {}^{25}\mathrm{Mg}) = -1.36$ MeV. This discrepancy of ~ 800 keV is unusually large;[11] however, in this case it is not clear from a spherical shell model description of the nuclei involved that closer agreement should be expected. Among these nuclei, two of which are odd-odd, differing configurations arise for which the requisite cancellation of the two-body interactions is not obvious. A similar discrepancy appears in the "longitudinal" prediction (Eq. (2) of Ref. 11) for the mass excess of ^{24}Ne:

$^{24}\mathrm{Ne} = {}^{23}\mathrm{Ne} + ({}^{26}\mathrm{Na} - {}^{24}\mathrm{Na}) - ({}^{27}\mathrm{Mg} - {}^{26}\mathrm{Mg}) = -5.22$ MeV,

while experimentally $^{24}\mathrm{Ne} = -5.95$ MeV.

Recently the mass excess of ^{27}Na has been measured[13] (-5.88±0.14 MeV), enabling the longitudinal relation:

$^{25}\mathrm{Ne} = {}^{24}\mathrm{Ne} + ({}^{27}\mathrm{Na} - {}^{25}\mathrm{Na}) - ({}^{28}\mathrm{Mg} - {}^{27}\mathrm{Mg})$

to be used to predict -2.04 MeV for the mass excess of ^{25}Ne. In this instance, this relation also arises from a simple shell model description of these nuclei in terms of $(\pi d_{5/2})^m(\nu s_{1/2})^n$ configurations.[11,14] In order to investigate the approximations in this description, one can evaluate[15] two further equivalent predictions, which employ the remaining appropriate known mass differences:[14]

$$^{25}\mathrm{Ne} = {}^{24}\mathrm{Ne} + ({}^{27}\mathrm{Na} - {}^{25}\mathrm{Na}) - ({}^{29}\mathrm{Al} - {}^{27}\mathrm{Al}) + ({}^{29}\mathrm{Si} - {}^{28}\mathrm{Si}) = -1.86\ \mathrm{MeV}, \text{ and}$$

$$^{25}\mathrm{Ne} = {}^{24}\mathrm{Ne} + ({}^{28}\mathrm{Mg} - {}^{26}\mathrm{Mg}) - ({}^{30}\mathrm{Si} - {}^{29}\mathrm{Si}) = -2.21\ \mathrm{MeV}.$$

There is thus good agreement for the mass excess of ^{25}Ne between the values obtained from a shell model description (-2.04, -1.86 and -2.21 MeV) and the experimental result of -2.18 MeV. Comparison of a large-basis shell model calculation of the expected level scheme of ^{25}Ne with our experimental values therefore may be of particular interest.

FOOTNOTES AND REFERENCES

[*] Work performed under the auspices of the U. S. Atomic Energy Commission.

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15. These shell model relationships can also be used to predict other mass differences involving unknown neutron-excess isotopes of O, F and Ne.

FIGURE CAPTIONS

Fig. 1. A particle identification spectrum resulting from bombardment of ^{26}Mg by ^{7}Li.

Fig. 2. (a) ^{8}B energy spectrum from run 2A at $\theta_{lab} = 10°$.

(b) Composite ^{8}B energy spectrum including data of part (a) plus data taken at $\theta_{lab} = 15°$ from runs 1 and 2, kinematically corrected to $\theta_{lab} = 10°$.

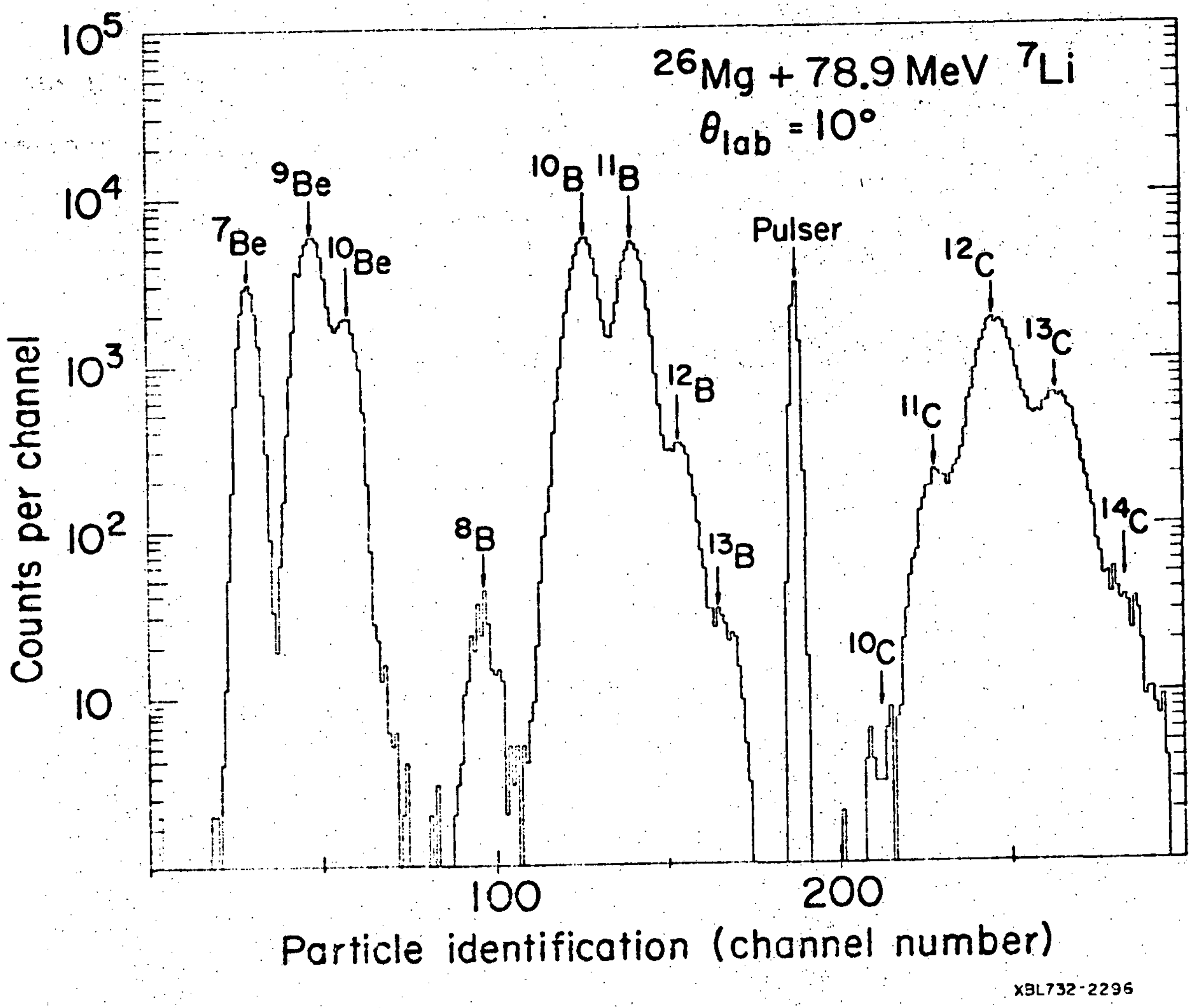
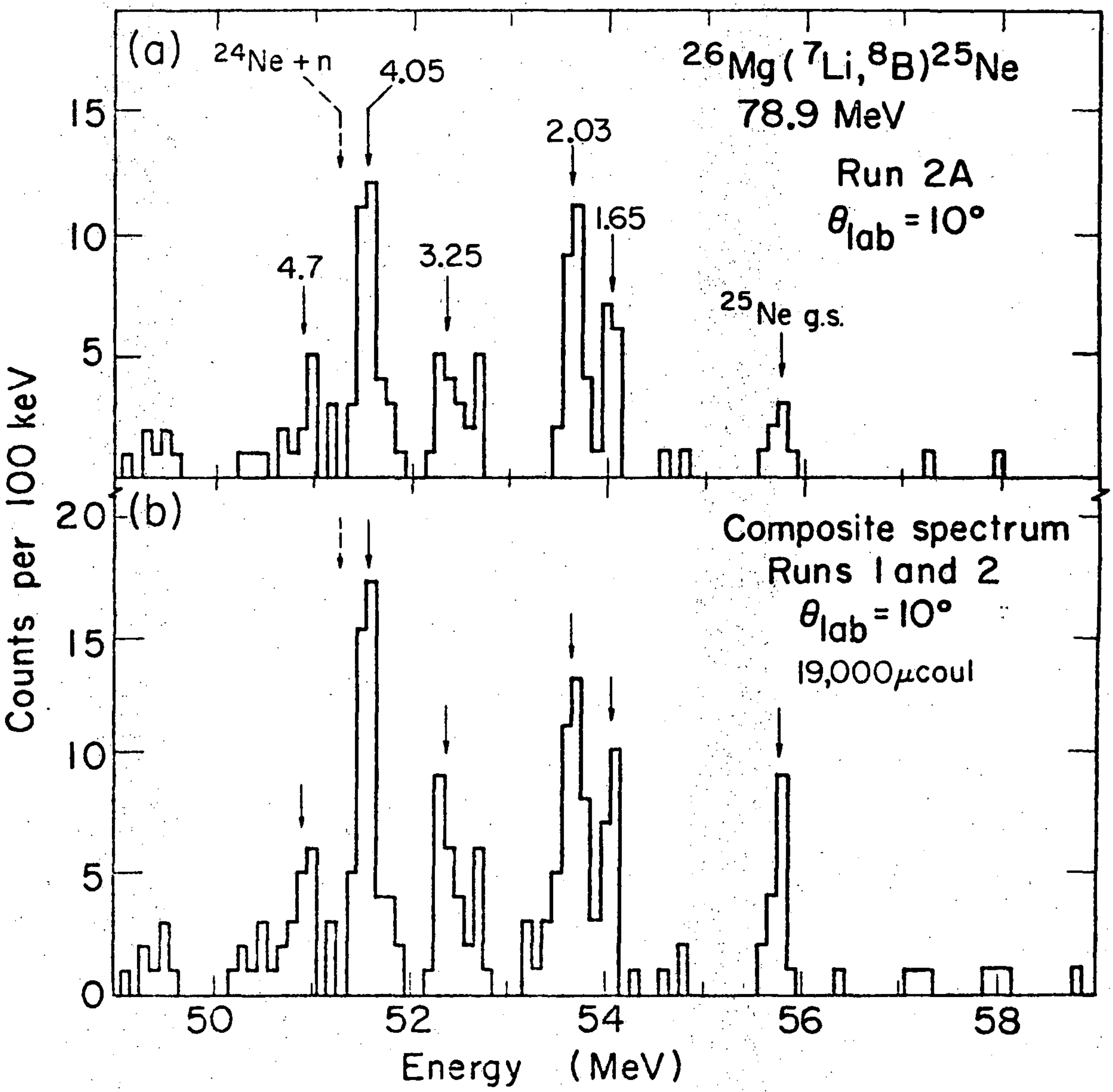

^{26}Mg + 78.9 MeV ^{7}Li
θ_{lab} = 10°
^{7}Be
^{9}Be
^{10}Be
^{8}B
^{10}B
^{11}B
^{12}B
^{13}B
Pulser
^{10}C
^{11}C
^{12}C
^{13}C
^{14}C
10^5
10^4
10^3
10^2
10
Counts per channel
100
200
Particle identification (channel number)
XBL732-2296

Fig. 1



XBL732-2297

Fig. 2

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