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EXOTIC REACTIONS IN THE LIGHT ELEMENTS*

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I. Introduction

In this talk I have been asked to concentrate on recent in-beam experiments with heavy ions leading to mass measurements and spectroscopic studies of light nuclei very far from the region of beta-stability. Mass measurements of new highly n-excess or n-deficient nuclei provide important tests of the various theoretical relations used to predict the limits of nuclear stability and the onset of new nuclear decay modes. Complex, low-yield heavy-ion reactions afford an increasingly utilized method of studying such nuclides, possibly even beginning with the multi-neutron system, as I will indicate below. Since the mechanism of reactions similar to several of those that I wish to cover has been discussed by earlier speakers, particularly Kovar and Volkov, I will not consider it here.

As will be discussed first, another possible "exotic" type of heavy ion reaction consists of directly observing resonant-state products in nuclear reactions. Although at present such studies are largely confined to the detection of ^{8}Be nuclei for α-transfer investigations, Robson [1] has pointed out many other interesting resonant particles which can possibly be detected as reaction products, and the potential also exists for employing such reactions as a tool in the study of nuclei far from stability.

II. Detection of Resonant Particles as Low-Yield Reaction Products

At the present time, by far the most investigated particle-unstable reaction product is the ^{8}Be ground state ($\tau_{1/2} \sim 10^{-16}$ sec). Reactions such as (^{12}C,^{8}Be) and (α,^{8}Be) are employed in several laboratories to study various aspects of α-particle transfer phenomena; there are a number of papers on the former reaction contributed to this conference from Heidelberg and Munich in which the α-particles are detected in 4 and 8 counter arrays. We have been interested in developing a general-purpose counter telescope technique for studying resonant particles as reaction products and have initially employed it to study the (α,^{8}Be) reaction, which typically possesses an order of magnitude lower cross section and more severe background problems than the (^{12}C,^{8}Be) reaction.

Figure 1 presents a schematic drawing of our counter telescope approach to ^{8}Be detection. The basic system employs a divided collimator, twin transmission ΔE detectors with pileup rejection, and a position-sensitive E detector. This system is described in detail elsewhere [2]; basically the two α-particles from ^{8}Be decay are detected in subnanosecond coincidence in the ΔE detectors as shown in fig. 2(a), where the full width at the base of the peak reflects the minimum energy ^{8}Be that could be detected and the central dip is the effect of collimation on the break-up α-particle velocity distribution; it is asymmetric due to off-set position gates. The ^{8}Be is further identified using the summed ΔE detector signals and the E signal feeding a standard particle identifier as shown in fig. 2(b) [it identifies as if it were a ^{7}Li event]; finally, its total energy and position spectrum are also obtained, permitting good detection efficiency and reasonable energy resolution. With this approach, background levels as low as 0.1 μb/sr are readily achieved with summed ΔE counting rates of 50K cps.

An application of this detection technique has been in qualitatively testing theoretical predictions of α-structure amplitudes. An example of this is shown in fig. 3, which presents data from the ^{10}B(α,^{8}Be)^{6}Li reaction. Kurath [3] predicts a dominant transition to the 3^{+} state at 2.18 MeV and a small yield to the ^{6}Li g.s. Good qualitative agreement with this prediction is observed: the cross section to the ^{6}Li g.s. is only 3 μb/sr and the ratio of $d\sigma(3^{+})/d\sigma(1^{+})$ over an angular range from 27 to 70 degrees c.m. is > 4.5/1.

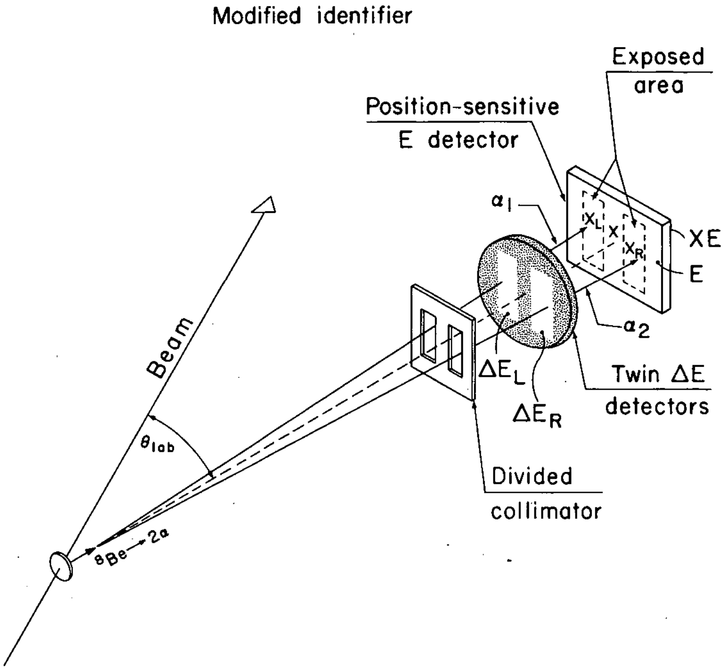

Fig. 1. A schematic diagram of the ^{8}Be identifier.

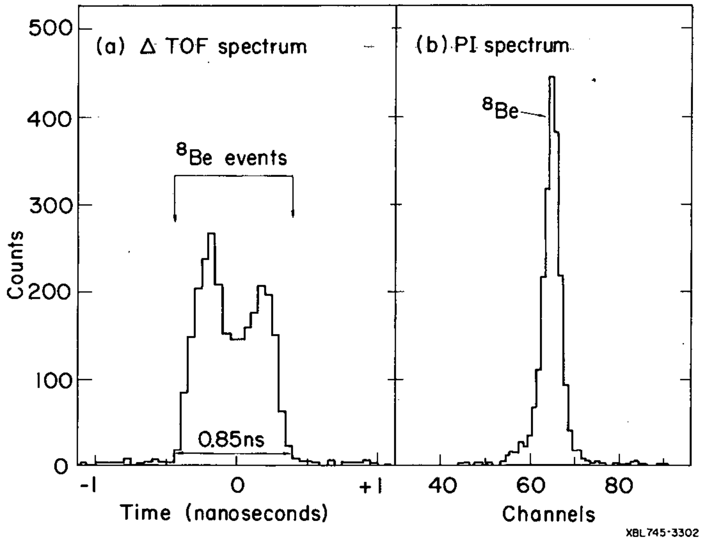

Fig. 2. (a) A time to amplitude converter spectrum showing the difference in time-of-flight between the two α-particles resulting from ^{8}Be g.s. decay. (b) A particle identification spectrum of the ^{8}Be events.

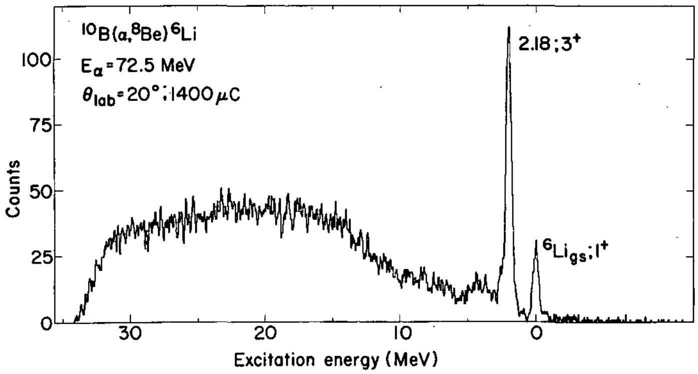

Fig. 3. A ^{8}Be energy spectrum from the ^{10}B(α,^{8}Be)^{6}Li reaction at 72.5 MeV.

Although many possibilities exist [1] for extension of this counter telescope approach to the study of nuclei far from stability, an immediate application might arise in such reactions as ^{14}C(^{7}Li,2p)^{19}N or ^{18}O(^{18}O,2p)^{34}Si. Studies of 70 MeV ^{3}He on polyethylene with the Bol system [4] have seen strong particle identification peaks due to "pseudo diprotons" and one could hope that reactions induced by more complex projectiles might show similar effects, although most probably at much lower yield. Particularly of interest would be a study of the ^{7}Li(^{7}Li,2p)^{12}Be reaction with this approach to compare to the technique of Howard et al. [5] who first established the mass-excess of ^{12}Be as shown in fig. 4. In this very difficult experiment, which has been confirmed by recent results at Chalk River as will be mentioned later, coincident protons were detected at opposite sides of the beam axis. All peaks shown in fig. 4 that are not labelled were shown to arise from reactions on carbon and oxygen target contaminants. Whether the reaction mechanism would favor detecting the strong two-proton final state interaction in such studies of neutron-excess nuclei is an exciting and open experimental question.

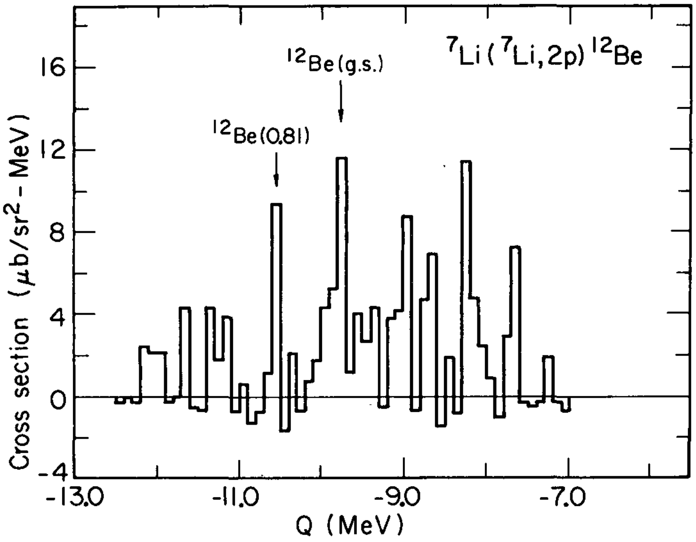

Fig. 4. Cross section data from the ^{7}Li(^{7}Li,2p)^{12}Be reaction induced by 30 MeV ^{7}Li ions. Protons were detected in coincidence at ±30° on opposite sides of the beam axis. See text [from Howard et al., ref. 5].

III. Studies of Multi-Neutron Final States

Heavy ion transfer reactions provide an additional tool in studies of multi-neutron systems. Table I lists a selection of the many reactions that might be employed in which one detects a heavy, neutron-deficient reaction product. I would like to show some results of a preliminary exploration of the ^{7}Li + ^{7}Li system [6] aimed at a first look at the ^{11}C + 3n and ^{10}C + 4n exit channels.

Table I. Examples of Heavy Ion Reactions Producing Multi-Neutron Final States

A. Three, Four Neutron Systems

$$^{7}\mathrm{Li} + {}^{7}\mathrm{Li} \longrightarrow \begin{matrix} ^{11}\mathrm{C} + 3n \\ ^{10}\mathrm{C} + 4n \end{matrix}$$

B. Five Neutron Systems

$$^{7}\mathrm{Li} + {}^{7}\mathrm{Li} \longrightarrow {}^{9}\mathrm{C} + 5n$$

$$\left.\begin{matrix} ^{7}\mathrm{Li} + {}^{11}\mathrm{B} \\ ^{9}\mathrm{Be} + {}^{9}\mathrm{Be} \end{matrix}\right\} \longrightarrow {}^{13}\mathrm{O} + 5n$$

C. Six Neutron Systems

$$^{9}\mathrm{Be} + {}^{10}\mathrm{Be} \longrightarrow {}^{13}\mathrm{O} + 6n$$

$$^{9}\mathrm{Be} + {}^{14}\mathrm{C} \longrightarrow {}^{17}\mathrm{Ne} + 6n$$

Figure 5 presents particle identifier spectra of the boron and carbon isotopes produced in the reaction of 80 MeV ^{7}Li from the Berkeley 88-inch cyclotron on ^{7}Li and ^{16}O targets. The latter spectrum is included to indicate relative isotopic yields from one of the major target contaminants, since reactions on carbon and oxygen were a severe source of background. As can be seen from this figure, both ^{11}B and ^{11}C are relatively strongly produced in the ^{7}Li + ^{7}Li reaction.

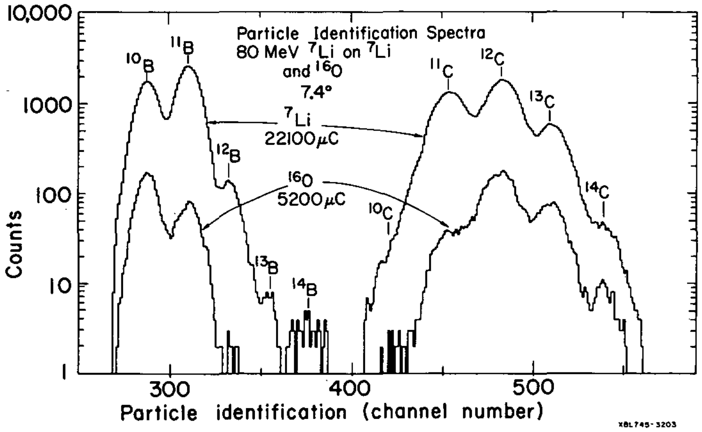

Fig. 5. Particle identification spectra from ~ 80 MeV ^{7}Li on ^{7}Li and ^{16}O (the latter as SiO_2). A counter telescope consisting of two ΔE detectors, 18 and 14μ thick, and a 195μ E detector was employed. Two particle identifications were performed and compared for each accepted event. Note that certain weak groups in the ^{7}Li + ^{7}Li data, such as ^{14}B, must arise from reactions on target contaminants.

Data from the ^{7}Li(^{7}Li,^{11}B)t and ^{7}Li(^{7}Li,^{11}C)3n reactions at 7.4° lab are shown in fig. 6(a) and 6(b-c), respectively. Strong transitions to the ground state [$d\sigma/d\Omega \sim 5$ μb/sr c.m.] and a number of the excited states of ^{11}B are seen in fig. 6(a) and comparable structure was also observed in the ^{7}Li(^{7}Li,^{12}B)d reaction. However, as seen in figs. 6(b) and (c), no structure other than that arising from contaminant reactions is discernible in the ^{7}Li(^{7}Li,^{11}C)3n data. The first several MeV of the ^{11}C energy spectrum that correspond to an unbound three-neutron system is well-fit by four-body phase space, as shown in fig. 6(c). Reactions on contaminants do not interfere in the ^{11}C energy region that would correspond to a bound 3n system, so that an upper limit for a bound ^{3}n of 70 nb/sr c.m. can be set (unfortunately, contaminant reactions completely precluded observation of the two-neutron final state interaction in the ^{7}Li(^{7}Li,^{12}C)2n data).

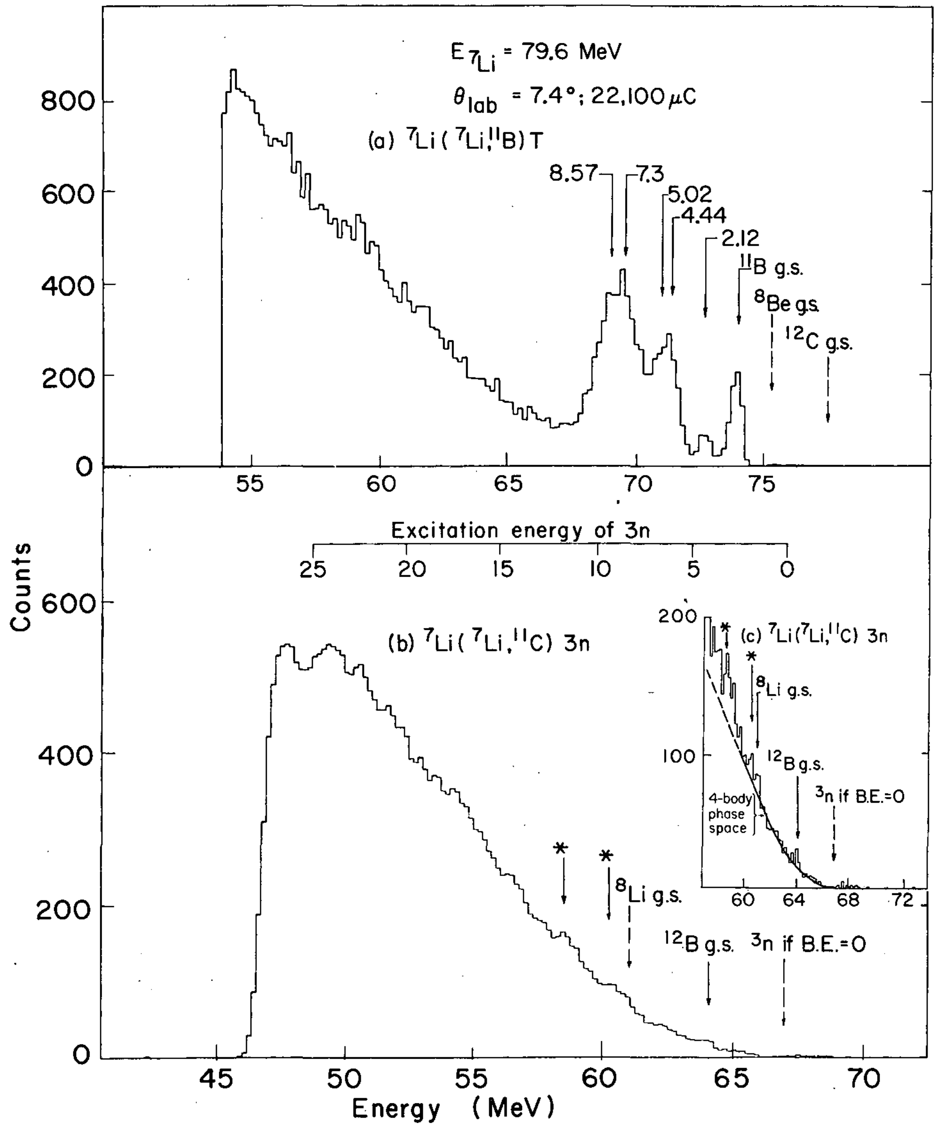

Fig. 6. Spectra from the ^{7}Li + ^{7}Li reaction at 79.6 MeV.
(a) ^{7}Li(^{7}Li,^{11}B)t. Dashed arrows denote the expected location of the indicated transitions.
(b) ^{7}Li(^{7}Li,^{11}C)3n. See (a). An arrow with an asterisk denotes the location of a known contaminant reaction. The ^{11}C energy that would correspond to transitions to a three neutron system with zero binding energy is indicated.
(c) Expansion of the high-energy part of (b).

Figure 7 presents a ^{7}Li(^{7}Li,^{10}C)4n energy spectrum. Groups from the three-proton transfer ^{16}O(^{7}Li,^{10}C)^{13}B and ^{12}C(^{7}Li,^{10}C)^{9}Li reactions [$d\sigma/d\Omega \approx 500$ nb/sr c.m.] account for the observed structure in the 4n continuum region and the underlying background appears well fit by 5-body phase space. Contaminant reactions do not interfere in the region of the ^{10}C energy spectrum corresponding to transitions leading to a bound ^{4}n (an upper limit to the total binding energy of ^{4}n is set by the known ^{8}He mass). The very minor background observed in this region arises from ^{11}C "leak-through" in the particle identification spectrum; however, it is still possible to set an upper limit for the cross section of this reaction leading to a bound four-neutron system of 30 nb/sr c.m. Based on the results of the ^{7}Li(^{7}Li,^{12}B)d and ^{7}Li(^{7}Li,^{11}B)t reactions, it is possible that future studies of heavy ion reactions such as the above may be able to add to our understanding of multi-neutron systems.

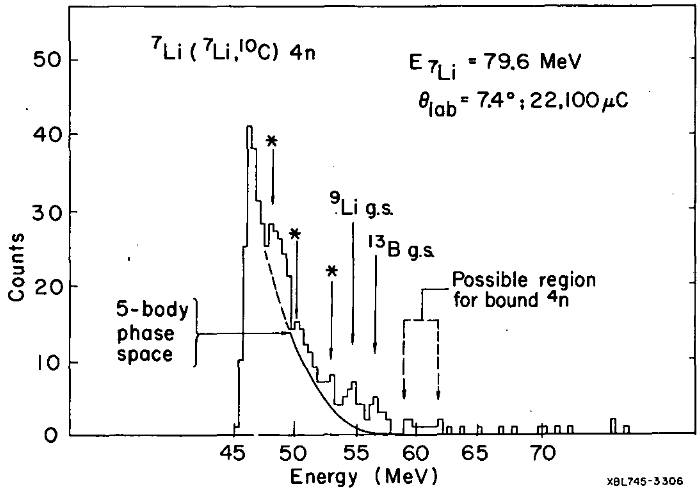

Fig. 7. The ^{7}Li(^{7}Li,^{10}C)4n spectrum at 7.4° and a bombarding energy of 79.6 MeV. Known contaminant reactions are indicated either explicitly or by an arrow with an asterisk.

IV. Mass and Spectroscopic Studies of Light Nuclei far from Stability

Figure 8 presents an overview of the known nuclei through the titanium isotopes; it basically indicates both the limits of our current knowledge of nucleon stability and the extent to which accurate mass measurement has so far been accomplished. This figure explicitly indicates only those nuclei for which an accurate mass is known and which are three or more neutrons removed from the nearest stable isotope (and which were not measured by charge-exchange reactions on stable targets). Current approaches to the utilization of heavy ions for in-beam mass determinations of such nuclei are covered below.

A. Two proton pickup reactions

Due to the difficulties inherent in studying two proton pickup via the (n,^{3}He) reaction, the next simplest such reaction--that of (^{6}Li,^{8}B)--is being investigated in selected cases as a tool for mass and spectroscopic measurements of neutron-rich nuclei difficult or impossible to study with simpler reactions. Counter telescope identification of ^{8}B nuclei is simple since both ^{7}B and ^{9}B are proton-unbound; further, since all ^{8}B excited states undergo particle decay, no "shadow" peak problems arise in the results. Since ^{13}N also possesses no particle-stable excited states, the (^{11}B,^{13}N) reaction might also be useful for two proton-pickup studies. Kurath [7] has noted that this reaction is also of theoretical interest because it possesses a large amplitude for the transfer of the

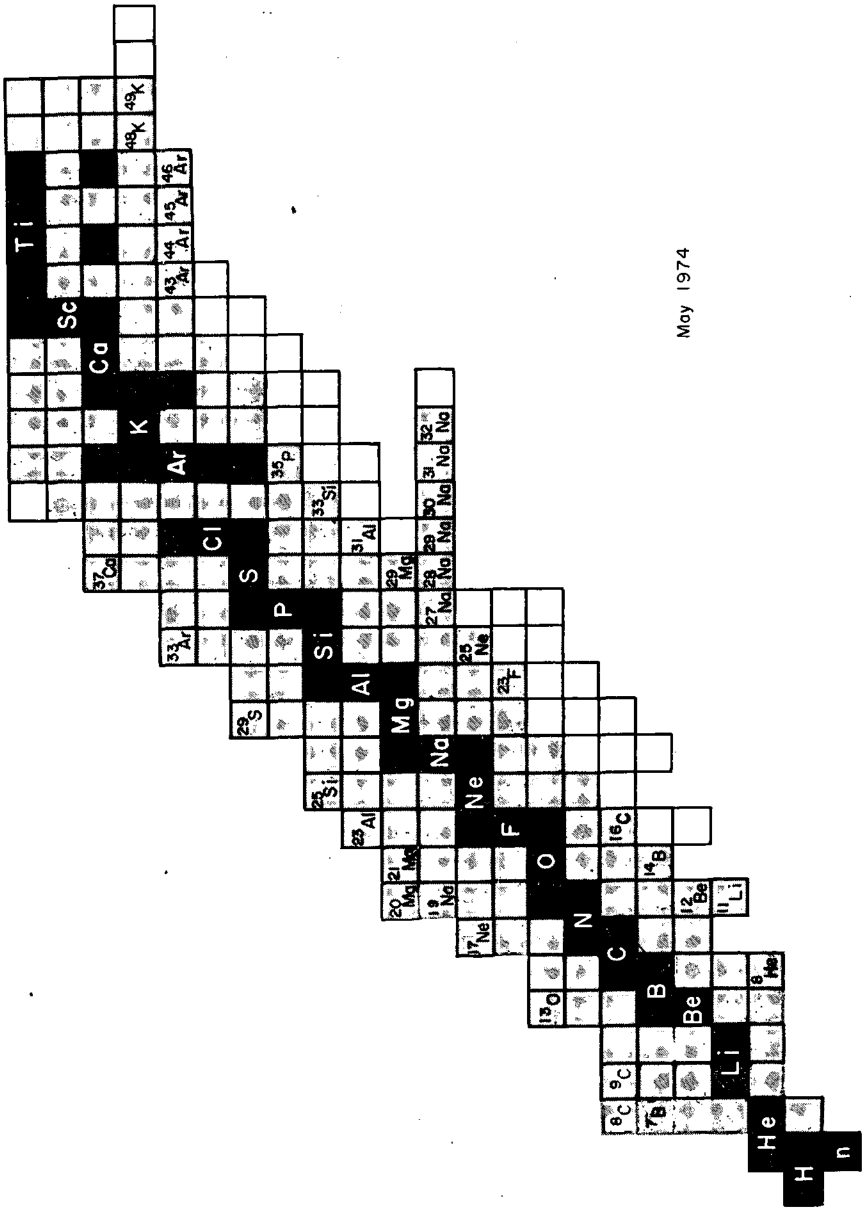

Fig. 8. The light nuclei through the titanium isotopes. Black squares indicate stable nuclei; shaded squares indicate nuclei for which an accurate mass has been determined; and white squares indicate nuclei whose nucleon stability has been established. Nuclei such as ^{8}C and ^{19}Na, which are known to be nucleon unstable, are shaded but are not included in a black box. See text.

two protons in an antisymmetric spatial state. Preliminary data of Harvey *et al.* [8] on the ^{26}Mg(^{11}B,^{13}N)^{24}Ne reaction at 86 MeV find a yield substantially larger than that of the (^{6}Li,^{8}B) reaction on this target, indicating that further exploration of the (^{11}B,^{13}N) reaction would be useful.

Results from a very recent study [9] of the ^{48}Ca(^{6}Li,^{8}B)^{46}Ar reaction induced by 80 MeV ^{6}Li ions from the Berkeley 88-inch cyclotron are given in fig. 9. The ground state transition has an observed cross section of ~ 1 μb/sr c.m. This measurement can be combined with mass-excess determinations of ^{43}Ar and ^{45}Ar from the ^{48}Ca(α,^{9}Be) and ^{48}Ca(α,^{7}Be) reactions, respectively [9], as well as with the preliminary results of the Michigan State measurement of the ^{48}Ca(^{3}He,^{7}Be)^{44}Ar reaction [10] to test the mass-excess predictions of Garvey *et al.* [11] which are based on an independent particle model description of nuclear ground states. This comparison is shown in fig. 10 along with a further comparison to mass predictions based on a shell model description [9] for these nuclei. In this shell model description, the mass-excess of a nucleus with m j-protons beyond a closed shell and with n j'-neutrons filling a different shell (excluding odd-odd nuclei) is related to the mass-excess of the nucleus with no j'-neutrons in terms of the interaction energies of the n neutrons with the closed shells, with one another, and with the m j-protons. As can be seen from the figure, the shell-model predicted mass-excesses agree very well with experiment while significant discrepancies appear for ^{44}Ar and ^{46}Ar in the comparison with the predictions of Garvey *et al*. [11]. Another application of these two approaches to mass prediction of neutron-excess nuclei is made in Section IV D.

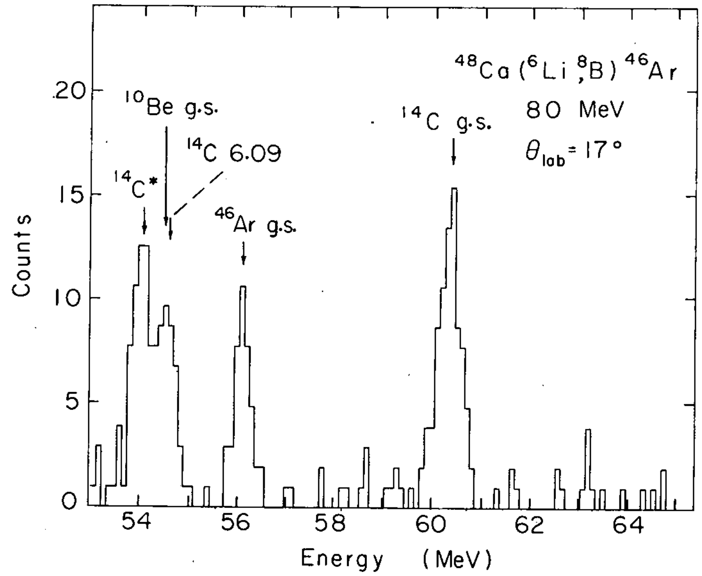

Fig. 9. An energy spectrum from the ^{48}Ca(^{6}Li,^{8}B)^{46}Ar reaction at 80 MeV. A counter telescope consisting of two ΔE detectors and an E detector was employed in these measurements.

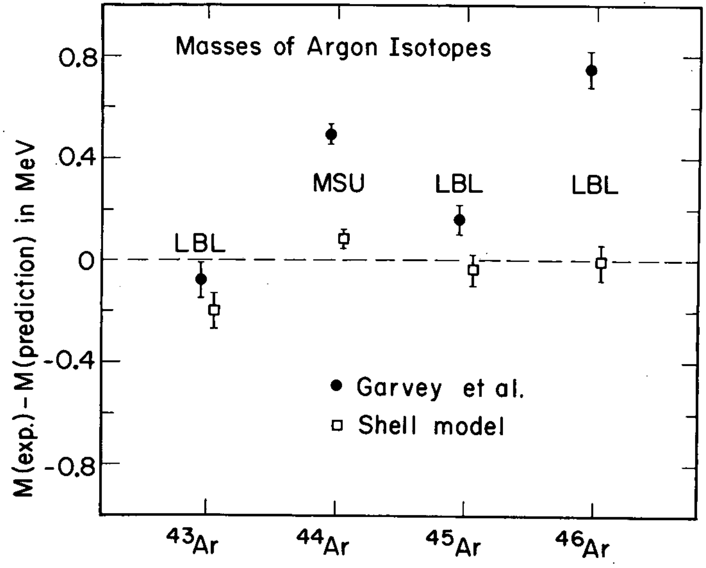

Fig. 10. Comparison of the difference between the measured mass excesses and predictions for the argon isotopes, $^{43-46}$Ar.

An obvious use of the (^{6}Li,^{8}B) reaction lies in searching for new energy levels in light nuclei which are difficult to reach by more conventional nuclear reactions. Studies of ^{7}He are of particular interest since to date only its (unbound) ground state has been observed [12] by (t,^{3}He) and (n,p) reactions, with no excited states established up to 2.4 MeV. Figure 11 presents results [13] from the (^{6}Li,^{8}B) reaction at forward angles on ^{9}Be, ^{11}B and ^{12}C targets. The ^{11}B(^{6}Li,^{8}B)^{9}Li reaction shown in fig. 11(a) was studied to provide an orientation for what might be expected in this reaction on light targets; it clearly populates the ^{9}Li ground state [$d\sigma/d\Omega \sim 2$ μb/sr c.m.] as well as at least two of the four known excited states of ^{9}Li. Noting the data on the ^{9}Be(^{6}Li,^{8}B)^{7}He reaction shown in fig. 11(b), one similarly sees a strong transition to the ^{7}He ground state [$d\sigma/d\Omega \sim 4$ μb/sr c.m.] with evidence for a broad first excited state at 3.2±0.3 MeV with a width of 1.6±0.4 MeV. (This transition also possesses a correct kinematic shift.) Data on the ^{12}C(^{6}Li,^{8}B)^{10}Be reaction shown in fig. 11(c) indicate that reactions on this target contaminant are not a major background problem in this region (nor are reactions on ^{16}O). Studies of two-proton pickup reactions on stable neutron-excess targets make many nuclei (e.g. ^{24}Ne) hitherto only reached by (t,p) reactions and should provide valuable new spectroscopic data to compare with large basis shell model calculations.

B. Three neutron transfer reactions

Although neutron-deficient nuclei have been successfully studied by the (^{3}He,^{6}He) reaction, comparable studies of neutron-excess nuclei require heavy ion reactions, of which (^{11}B,^{8}B) is the first available with a particle-stable reaction product. Studies of this latter reaction are just beginning; data from magnetic spectrometer measurements of the (^{11}B,^{8}B) reaction on ^{26}Mg and ^{28}Si targets by Harvey et al. [8] are shown in fig. 12. The ground state yield in these reactions is quite low- ~ 80 nb/sr lab. for ^{31}Si and only ~ 15 nb/sr lab. for ^{29}Mg-and may account for previous difficulties in observing this reaction with counter telescope techniques due to problems arising from ^{11}B breakup (discussed in detail in Section IV D). By using the previous Brookhaven measurement [14] of the ^{29}Mg mass-excess as a guide, Harvey et al. assign the ground state transition as indicated in fig. 12(a) and are able to obtain a more accurate mass-excess of -10.75±0.05 MeV. (This mass-excess is compared to theoretical predictions in Section IV D.)

At the present time, only in rare cases is anything known about the energy level spectra of light $T_Z = 5/2$ nuclei such as ^{29}Mg, so that further detailed studies of such three-neutron transfer reactions are of extreme interest.

C. Four neutron transfer reactions

Prior to this year, the only four-neutron transfer reaction which had been reported was the ^{26}Mg(α,^{8}He)^{22}Mg reaction [15], which established the mass-excess of ^{8}He. However, this situation is changing rapidly at present, particularly with the advent of large solid angle spectrometers at several cyclotron facilities.

Figures 13 and 14 present spectra from two current investigations of the (α,^{8}He) reaction. The ^{26}Mg(α,^{8}He)^{22}Mg reaction (Q-value ~ -45 MeV) has been reinvestigated at Berkeley [16] to reduce the 120 keV error bar of the original measurement as a first step in other (α,^{8}He) studies. This reaction employed 110 MeV α-particles and utilized a magnetic spectrometer for detection of the ^{8}He events. In fig. 13 transitions are clearly observed to the ^{22}Mg ground and first excited states [$d\sigma/d\Omega$ g.s. ~ 7 nb/sr c.m.] as well as to a new state at 8.6 MeV excitation. The new mass-excess for ^{8}He of 31.57±0.03 MeV [based on a ^{22}Mg mass-excess of -396±2 keV [17]] agrees very well with the previous result.

The exciting application of the (α,^{8}He) reaction to studying $T_Z = -2$ nuclei and obtaining the fourth member of an isospin quintet has been realized by Robertson et al. [18] at Jülich as shown in fig. 14. Both the ^{12}C(α,^{8}He)^{8}C reaction (Q value ~ -65 MeV) and the ^{24}Mg(α,^{8}He)^{20}Mg reaction (Q value ~ -61 MeV) are observed in the three runs shown; ^{8}He events were detected via a DQQ magnetic analyzer plus a ΔE-E silicon detector counter telescope with cross sections of ~ 20 nb/sr lab. to the ^{8}C ground state and ~ 7 nb/sr lab. for the ^{20}Mg ground state.

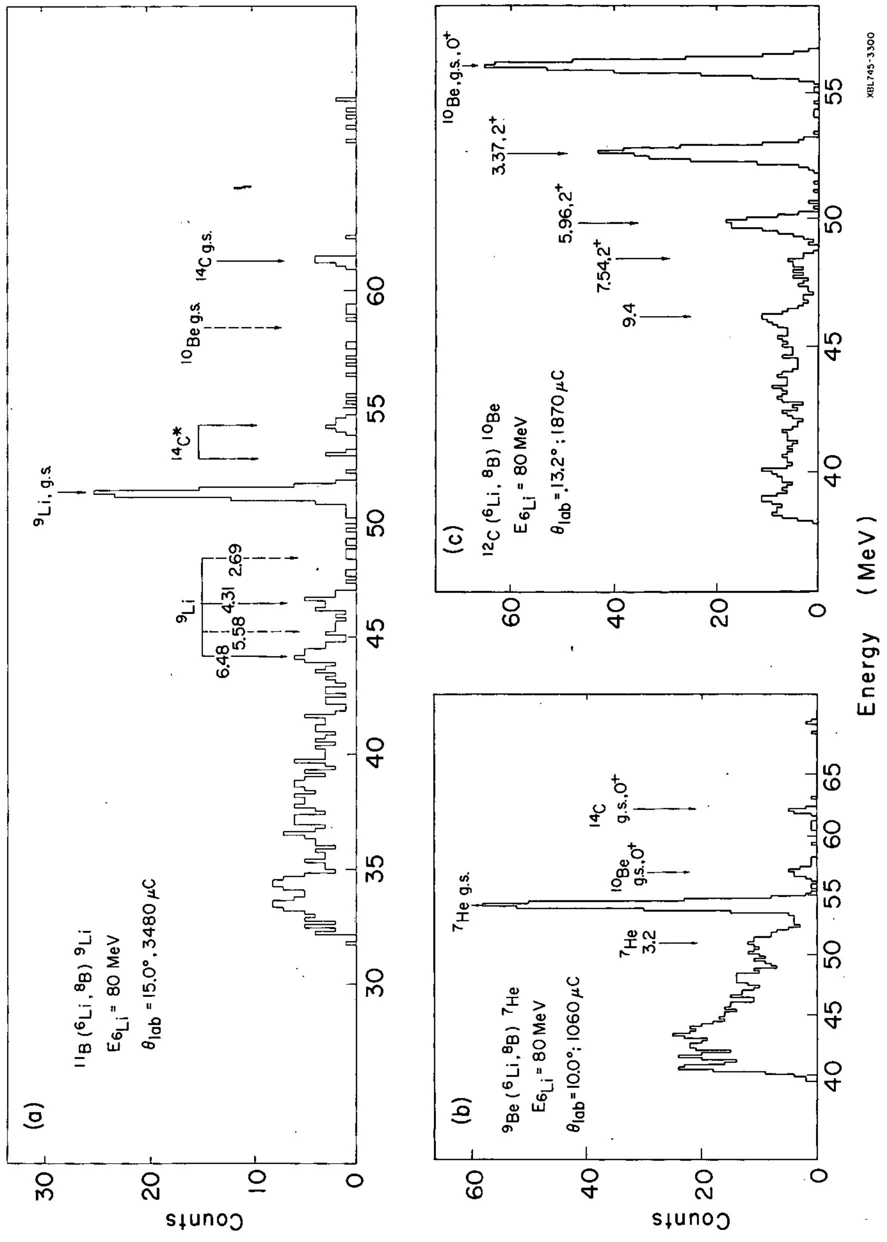

Fig. 11. Spectra from the (^{6}Li,^{8}B) reaction at 80 MeV on (a) ^{11}B; (b) ^{9}Be; and (c) ^{12}C.

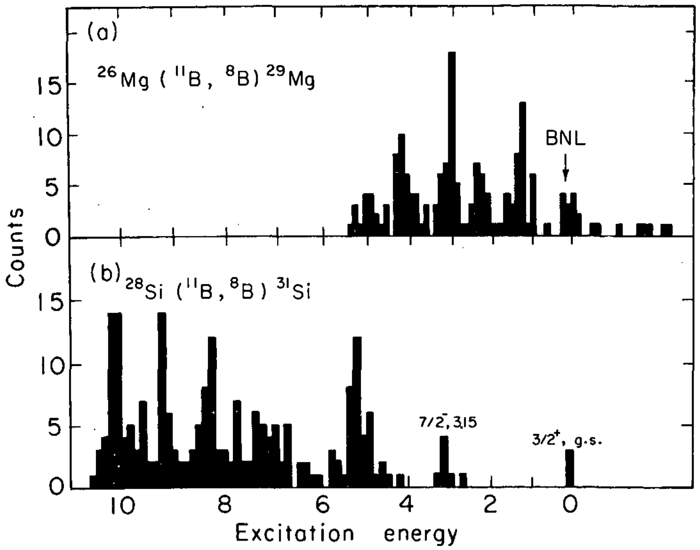

Fig. 12. Spectra from the (^{11}B,^{8}B) reaction at 86 MeV and 11° on (a) ^{26}Mg and (b) ^{28}Si [from Harvey et al., ref. 8 and private communication].

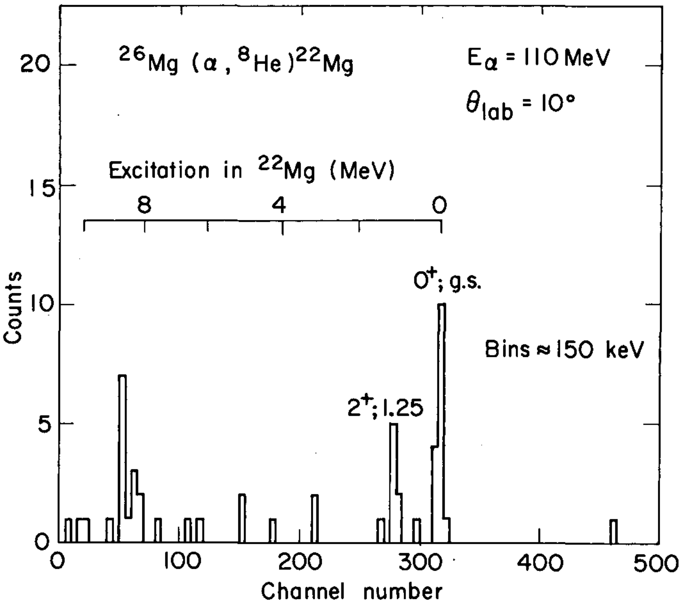

Fig. 13. A spectrum from the ^{26}Mg(α,^{8}He)^{22}Mg reaction at 110 MeV.

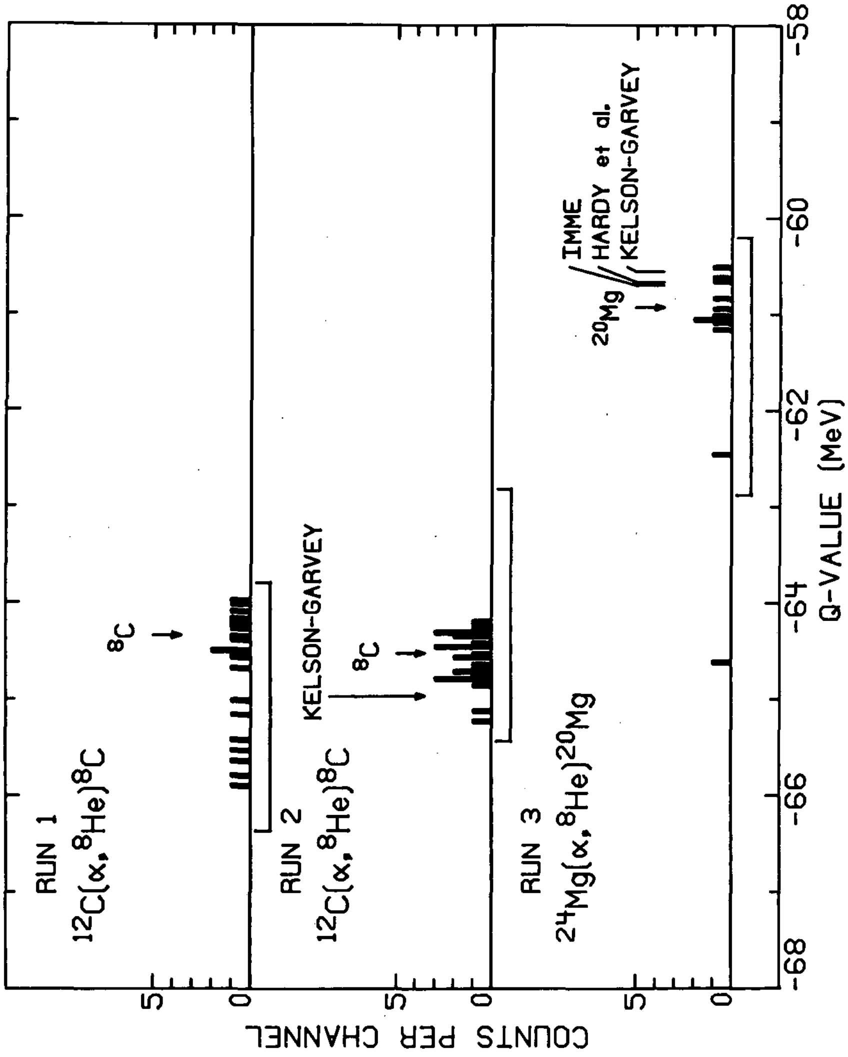

Fig. 14. Spectra from the (α, ^{8}He) reaction on ^{12}C and ^{24}Mg at 156 MeV and θ_{lab} = 2° [from Robertson et al., ref. 18].

Taking into account the new ^{8}He mass, the results of Robertson et al. give mass-excesses of 35.38±0.17 MeV for ^{8}C and 17.82±0.18 MeV for ^{20}Mg so that, as expected, ^{8}C is unbound but with a narrow width (observed $\Gamma_{c.m.} = 220^{+80}_{-140}$ keV) and ^{20}Mg is bound. A very recent prediction of the ^{8}C mass-excess via the Kelson-Garvey approach [19] employing a "systematic" estimate of the ^{5}Li-^{5}He mass difference yields 35.61 MeV, in quite good agreement with observation. Since three other members of the A = 20 quintet are known, Robertson et al. were able in this case to test the isobaric multiplet mass equation prediction for the ^{20}Mg mass-excess of 17.54±0.27 MeV, which also agrees with experiment.

Clearly four neutron transfer reactions populating neutron-excess nuclei are of particular interest and more such studies should be forthcoming in the future. Successful investigation of reactions such as $^{18}O(^{18}O,^{14}O)^{22}O$--for which Brookhaven [20] has set a cross section upper limit of 0.5 μb/sr at 60 MeV bombarding energy--would permit mass and spectroscopic studies of light $T_Z = 3$ nuclei.

D. Exotic Nuclear Rearrangement Reactions

Due largely to experimental reasons, it seems likely that the most successful approach to the study of highly neutron-deficient nuclei in the near future will be through such reactions as (α, ^{8}He), (^{3}He, ^{8}He) etc. However, since the very few in-beam studies of highly neutron-excess light nuclei by "simple" transfer of three or four neutrons show very small cross sections (or limits), it is of interest to establish whether more unusual heavy-ion rearrangement reactions may not proceed with comparable or greater ease of measurement. Most of these studies are quite recent and are noted below.

Ball et al. [21] at Chalk River have used the $^{14}C(^{18}O,^{12}Be)^{20}Ne$ reaction at 88.7 MeV to determine the mass of ^{12}Be. Figure 15 presents energy spectra from this reaction determined with counter telescope techniques. Although the ground state cross section was only ~ 200 nb/sr, by also using data from transitions to excited states of ^{20}Ne, they were able to determine a mass-excess for ^{12}Be of 25.05±0.05 MeV which agrees with the results of the $^{7}Li(^{7}Li,2p)^{12}Be$ reaction noted in Section II. By employing this result and other data in the transverse mass relation of Garvey et al. [11], Ball et al. predict that the known neutron-unstable ^{10}Li nuclide is only unbound by 160±120 keV. An experiment observing ^{10}Li is discussed below; the mass of ^{10}Li has been of considerable interest due to the known nuclear stability of ^{9}Li and ^{11}Li, particularly since Klapisch et al. [22] have recently determined the mass-excess of ^{11}Li by on-line mass spectrometer techniques.

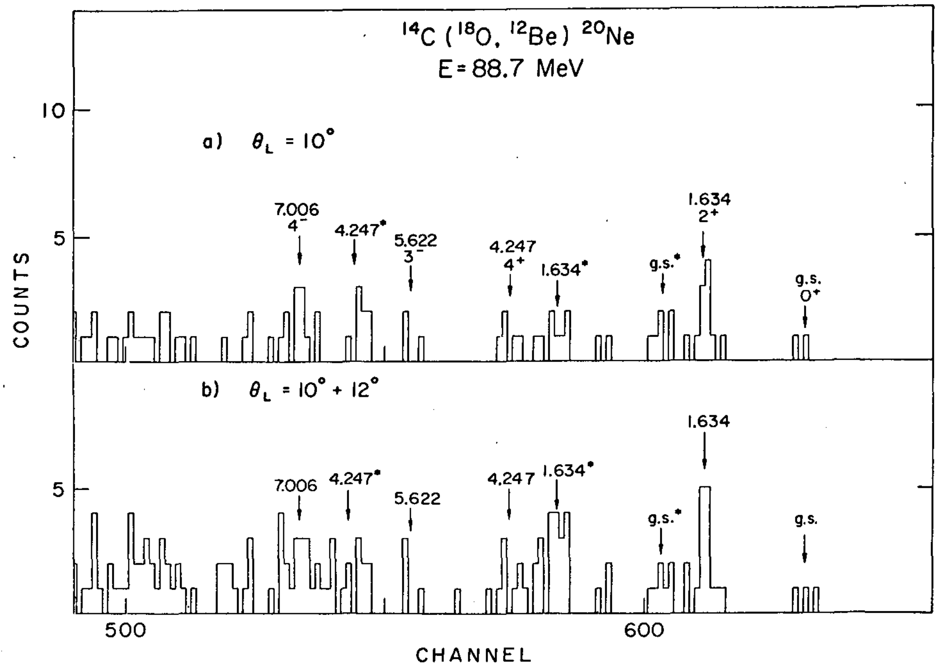

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Fig. 15. Energy spectra from the $^{14}C(^{18}O,^{12}Be)^{20}Ne$ reaction at 88.7 MeV. The asterisks denote a new ^{12}Be excited state at 2.09 MeV. Two independent counter telescopes consisting of two ΔE detectors and an E detector were employed in these measurements [from Ball et al., ref. 21].

Rearrangement reactions measuring ^{8}B nuclei as reaction products via counter telescope techniques have been studied at Berkeley to investigate masses and energy levels of T_Z = 2 and 5/2 nuclei. Figure 16 presents energy spectra from the $^{26}Mg(^{7}Li,^{8}B)^{25}Ne$ reaction induced by a 78.9 MeV ^{7}Li beam [23]. The ground state cross-section is ~ 350 nb/sr c.m. Both the mass-excess of ^{25}Ne (which agreed with, but was more accurate than, earlier results from beta end-point measurements) and a first look at its low-lying excited states were obtained. The mass is compared to theory below; large basis shell-model calculations of the expected level scheme of ^{25}Ne and other T_Z = 5/2 (and greater) nuclei would be particularly useful at this time as guides to similar experimental studies.

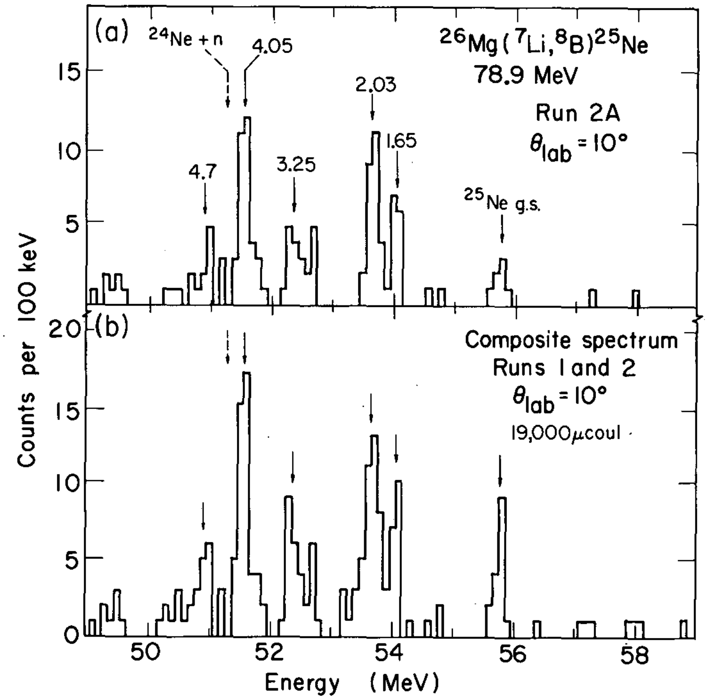

Fig. 16. The ^{26}Mg(^{7}Li,^{8}B)^{25}Ne reaction at 78.9 MeV.
(a) A ^{8}B energy spectrum at 10°.
(b) A composite ^{8}B energy spectrum including data taken at 15° which have been kinematically corrected to 10°.

Figure 17 presents a preliminary investigation of the structure of ^{10}Li via the ^{9}Be(^{9}Be,^{8}B)^{10}Li reaction induced by a 120 MeV ^{9}Be^{+3} beam from the Berkeley 88-inch cyclotron [24]. Contributions from the large background seen in fig. 17(a) have been subtracted in the data shown in fig. 17(b). Noting fig. 18, which compares a typical identifier spectrum with the one from this reaction, one sees in fig. 18 (bottom) both a very low relative ^{8}B yield as well as poor ^{8}B-^{10}B separation; this presumably arises from strong ^{11}B production (deuteron pickup) in this reaction in states subsequently breaking up into ^{7}Li + α, which when simultaneously detected can very nearly simulate ^{8}B events.

Possible evidence can be seen in fig. 17 for ^{8}B transitions with energies corresponding to population of a broad state (or states) in ^{10}Li which, as expected, are unbound to ^{9}Li + n decay. The centroid of the broad peak (c.m. width ~ 3 MeV) would correspond to ^{10}Li unbound by ~ 2 MeV; its cross section is ~ 600 nb/sr-c.m. A very simple analogy based on particle-particle, hole-hole theorems might lead one to expect ^{10}Li to have its two lowest states of similar structure to those of ^{12}B, in which they are separated by 0.95 MeV. Roughly equivalent population of a ground and first excited state of ^{10}Li might be one method of accounting for this very broad peak, which lies at considerably higher excitation above threshold than the current prediction for the ground state noted earlier.

Finally, fig. 19 presents a comparison of the masses of all the $T_Z = 5/2$ nuclei in the 2s-1d shell with the predictions of Garvey et al. [11] as recalculated by Thibault and Klapisch [25], and with the shell model approach indicated earlier [26]. Apart from the ^{25}Ne and ^{29}Mg results discussed here, the ^{21}O measurement is from Volkov's group [27], the ^{27}Na from Klapisch et al. [28] and the remainder from the extensive measurements of Goosman and Alburger at Brookhaven [14,29]. One of the motivations for developing this shell model approach was the large discrepancies found on several occasions between experiment and the predictions of Garvey et al. in the light nuclei and the hope that some simple alternate predictive scheme might also be useful in estimating masses just on the fringes of current knowledge. Since the rms error of the shell model approach of 260 keV (excluding ^{21}O due to its large uncertainty) is substantially lower than that of the approach of Garvey et al. of 620 keV for this series of nuclides, it may be useful in other regions. However, further general theoretical work on predictions of masses and level schemes of nuclei far from stability, particularly on the neutron-excess side, would unquestionably be of great value to the many experimental studies of these nuclei which are in progress.

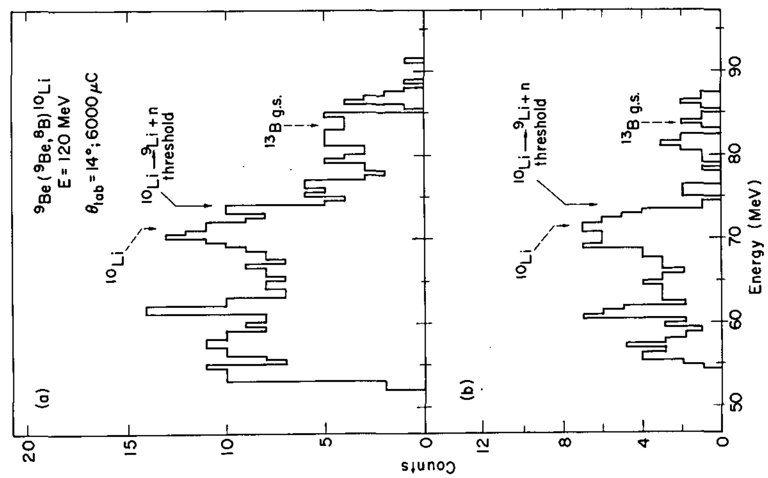

Fig. 17. (a) A spectrum from the $^9Be(^9Be,^8B)^{10}Li$ reaction at 120 MeV. (b) The (a) spectrum after background subtraction. See text.

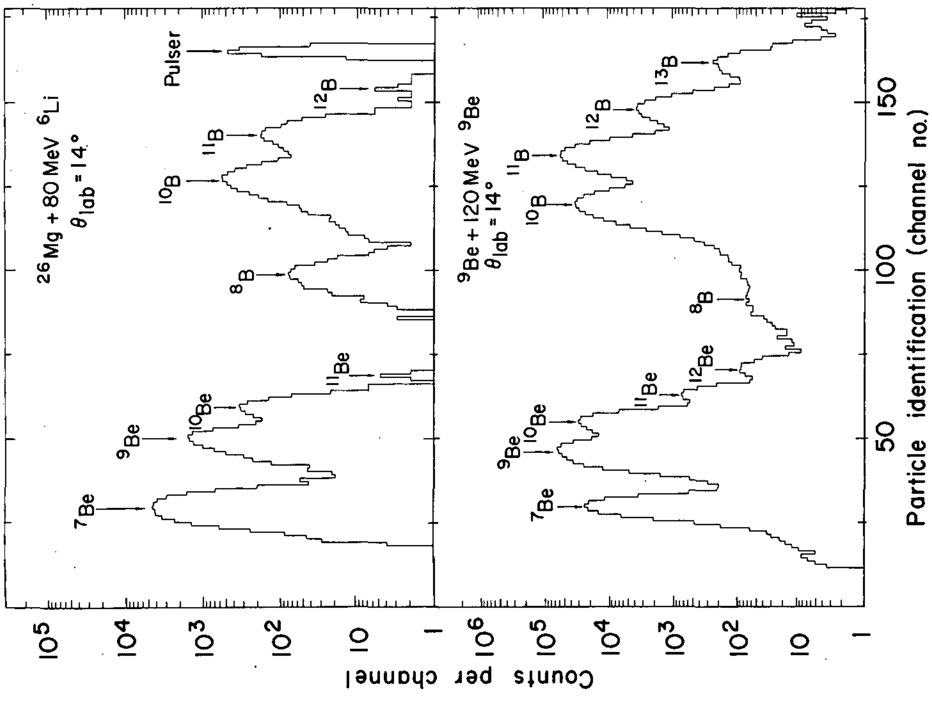

Fig. 18. Particle identification spectra from (top) the ^{26}Mg + 80 MeV ^6Li reaction; (bottom) the ^9Be + 120 MeV ^9Be reaction.

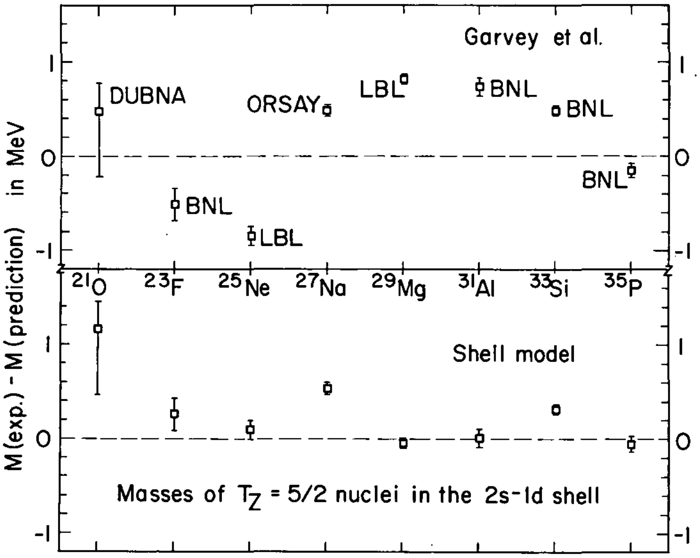

Fig. 19. Comparison of the difference between the measured mass excesses and predictions for the $T_Z = 5/2$ nuclei in the 2s-1d shell. The initials of the laboratory determining the most accurate mass for a given nuclide are indicated.

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