tion.

The production of $Z+2$ Kx rays resulting from ionization before nuclear reaction is a process which is restricted to impact parameters of the order of the nuclear radius; physically, the experiment is equivalent to a collimated beam of a radius of 10^{-12} cm. The ionization could be calculated using relativistic[13] wave functions, and anisotropy in the angular distribution of emitted x rays could be predicted and then measured.

More data on nuclear reactions and ionization cross sections are needed to explore this phenomenon in more detail. However, it has immediate practical consequences in γ-ray spectroscopy, and in sample analysis by fluorescence excited with charged particles, where it is a source of interferences.

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New Spectroscopic Measurements via Exotic Nuclear Rearrangement: The Reaction ^{26}Mg(^{7}Li, ^{8}B)^{25}Ne†

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A 79-MeV ^{7}Li beam and counter-telescope techniques were employed to observe the reaction ^{26}Mg(^{7}Li, ^{8}B)^{25}Ne. 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.

Although all of the $T_z = \frac{1}{2}(N-Z) = \frac{5}{2}$ 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 ($|\Delta T_z| = \frac{3}{2}$) as a prototype for such studies.

By bombarding ^{26}Mg with a 79-MeV ^{7}Li^{2+} beam from the Lawrence Berkeley Laboratory 88-in. cyclotron, we have successfully detected ^{8}B nuclei from the ^{26}Mg(^{7}Li, ^{8}B)^{25}Ne reaction ($Q = \sim -22$ MeV), determining the mass of ^{25}Ne and, for the first time, the level structure of a $T_z = \frac{5}{2}$ 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 undergo particle decay, any possible "shadow" problems are eliminated.

This reaction was studied utilizing a lithium beam produced with a PIG-type internal ion source.[2] Cathode buttons are employed which consisted of a mixture of 20% LiF and 80% W pressed into a Ta 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 h.

The maximum-energy $^7Li^{2+}$ beam (78.9 MeV) was used to bombard a 99.4% isotopically enriched, self-supporting ^{26}Mg target of thickness 150 $\mu g/cm^2$. The energy of the beam was determined using a high-precision analyzing magnet.[3] Outgoing ^8B 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 ΔE_2 and ΔE_1) 15 and 11 μm thick, respectively; a 200-μm E detector; and a 500-μm 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 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 (ΔE_2, ΔE_1, the total E signal, and a particle identification acquired using the summed ΔE pulses) were recorded on magnetic tape for later detailed analysis, and were also sorted on line to give ^8B 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 $^{26}Mg(^7Li, ^{10}C)^{23}F$ reaction were such that no information on ^{23}F could be obtained in these experiments.) To further reduce possible background in the ^8B region, a two-dimensional analysis, ΔE_2 and ΔE_1 versus total energy, was done off line. A small percentage of additional events could be eliminated in this manner.

An energy calibration for the ^8B data was acquired by concurrently observing ^{10}B particles

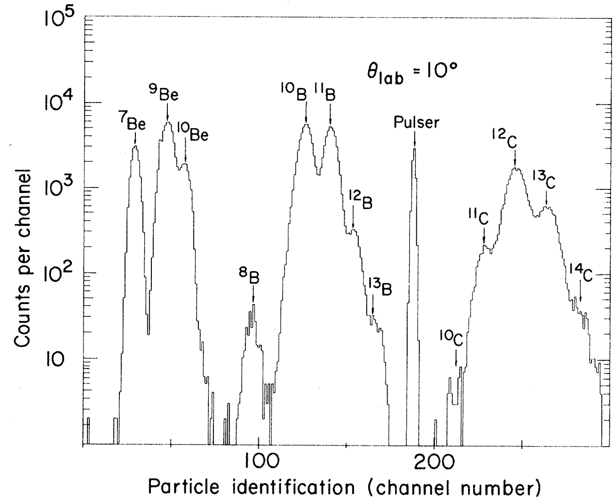

FIG. 1. Particle identification spectrum resulting from bombardment of ^{26}Mg by 78.9-MeV ^7Li.

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

We made two independent investigations of the reaction $^{26}Mg(^7Li, ^8B)^{25}Ne$. The ^8B data collected at θ_{lab}= 10° during run 2 are shown in Fig. 2(a). Figure 2(b) is a composite spectrum of these same data plus θ_{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.) = $\frac{1}{2}^+$],

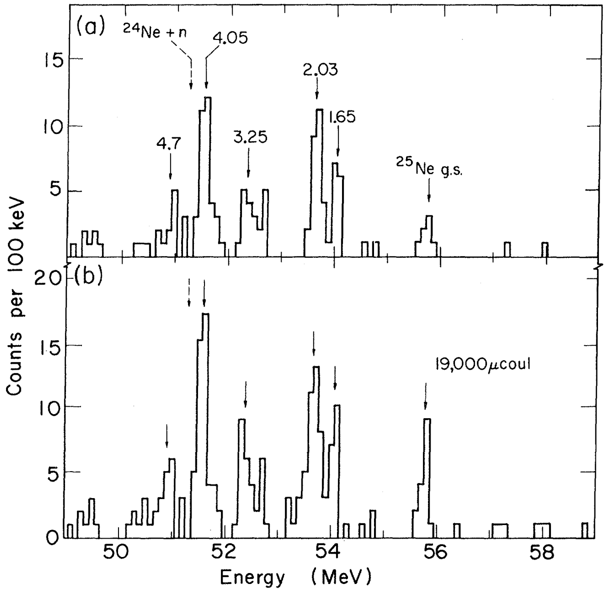

FIG. 2. (a) ^{8}B energy spectrum from run 2 at $\theta_{lab} = 10°$. (b) Composite ^{8}B energy spectrum including data of (a) plus data taken at $\theta_{lab} = 15°$ from runs 1 and 2, kinematically corrected to $\theta_{lab} = 10°$.

whose first two excited states[5] lie at 0.98 MeV ($\frac{3}{2}^+$) and 1.70 MeV ($\frac{5}{2}^+$). 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] one expects a $\frac{1}{2}^+$ ground state, a 1.3-MeV, $\frac{5}{2}^+$ level, and a 2.1-MeV, $\frac{3}{2}^+$ level. The calculated ground-state spin of $\frac{1}{2}^+$ agrees with that preferred by Goosman, Alburger, and Hardy[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 reaction ^{26}Mg(^{7}Li, ^{8}B)^{25}Ne 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, Alburger, and Hardy,[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 Eq. (1) of Ref. 11 specifically, one obtains[12]

$$^{25}\mathrm{Ne} = {}^{24}\mathrm{Ne} + ({}^{26}\mathrm{Na} - {}^{24}\mathrm{Na}) - ({}^{26}\mathrm{Mg} - {}^{25}\mathrm{Mg}) = -1.36\ \mathrm{MeV}.$$

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 cancelation 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:

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

while experimentally ^{24}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]:

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

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

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.

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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.

Bose Condensation of Fermion Composites*

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A simple theory of fermion pair composites is described and applied to the situation where, at low density, Bose condensation into the lowest self-consistent composite state takes place.

We describe in this note some preliminary results emerging from an investigation of a theory of composite particles, and concentrate here on a problem whose solution at low density is intuitively obvious, but which has proven very difficult to obtain from standard many-body methodology.

A theoretical framework for the treatment of composite particles, formed from elementary Fermi or Bose constituents, has been described by Girardeau[1] and extended by Stolt and Brittin,[2] Sakakura,[3] and Girardeau.[4] A characteristic feature of this framework and its subsequent extensions is the use of an "atomic," or composite, basis,[5] together with some projection technique needed to preserve the overall symmetry under interchange of constituents belonging to different composites. It is then possible to construct a second-quantized version of the Hamiltonian, with operators satisfying *elementary* commutation rules, in the form of an infinite series, the first term of which corresponds to free atoms. Subsequent terms contain the effects of symmetry, ionization-recombination, and other interaction processes involving the bound composites and constituent particles. The physically correct "low density" situation of "free atoms" is manifest from the beginning. Corrections, arising from both symmetry and additional interaction effects, are treated by truncation of the new Hamiltonian, together with subsequent dynamical analysis of that truncation.