The above results were reproduced and it is concluded that enhancement by a phase-separation technique (which we call the glass-chamber technique) is feasible for the fission fragments.

The glass chamber has the clear potentiality of making the tracks visible inside the solid *without etching*. This can be achieved by causing phase separation such that the separating phase has a considerably different optical index of refraction from the matrix phase, which would cause the tracks to be visible.

*Work supported by the U. S. Atomic Energy Commission under Contract No. At-40-1-2854-AEC and by the Office of Naval Research under Contract No. N00014-68-A-0506-02.

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Experimental Determination of the ^{12}Be Ground-State Mass*

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(Received 25 August 1971)

The ground-state mass of ^{12}Be was measured using the reaction ^{7}Li(^{7}Li, 2p)^{12}Be in a kinematically complete experiment. The mass excess was determined to be 24.95 ± 0.10 MeV. An excited state of ^{12}Be is identified at an excitation energy of 0.81 ± 0.10 MeV.

The limits of particle stability and mass systematics of light nuclei have received much attention in recent years. Many extremely neutron-rich nuclei such as ^{11}Li, ^{12}Be, ^{14}B, ^{15}B, ^{17}C, and ^{18}C are neutron stable.[1-4] However, kinematically complete experiments necessary for the determination of ground-state masses have not been possible because of the lack of suitable targets necessary to reach these nuclei by common nuclear reactions. With the advent of high-quality heavy-ion beams one can bypass the problems of target availability and perform multinucleon transfer reactions on available targets. An example of this situation is the nucleus ^{12}Be for which the most attractive approach is to measure the proton energy spectrum from the reaction ^{10}Be$(t,p)^{12}$Be. However, targets of ^{10}Be suitable for this purpose are not yet available. As an alternative to the (t,p) reaction we have used a Li-ion–induced multinucleon transfer reaction which produces ^{12}Be as a residual nucleus. We report here the first experimental determination of the ^{12}Be ground-state mass through use of the reaction ^{7}Li(^{7}Li, $2p$)^{12}Be in a kinematically complete experiment.

The isotope ^{12}Be was first observed in experiments in which ^{15}N and heavier nuclei were irradiated by protons of GeV energies.[3] A delayed neutron activity with a half-life of 11.4 msec was assigned to ^{12}Be. The observed half-life along with a theoretical calculation of the log*ft* value of the ground-state β transition allows the β end-point energy to be predicted. This in turn leads to an estimated value[3] of 25.1 ± 1.0 MeV for the mass excess of ^{12}Be.

The present experiment used beams of triply ionized ^{7}Li which were prepared at the Los Alamos tandem Van de Graaff with intensities of 25–150 nA and at energies of 25.0, 30.0, and 30.1 MeV. These beams were used to irradiate self-supporting ^{12}C and ^{7}Li foil targets. The ^{12}C target was 210 μg/cm^2 thick. Several ^{7}Li targets ranging in thickness from 216 to 239 μg/cm^2 were used. The ^{7}Li targets were made by evaporating ^{7}Li (99.99% enrichment)[5] onto glass slides in vacuum. The foils were then stripped, weighed, and mounted in an argon atmosphere. The careful handling and storage in vacuum resulted in only small contaminations of ^{12}C and ^{16}O. As reported earlier, no contamination by nitrogen was found with this technique.[6] The ^{1}H contamination of the ^{12}C and ^{7}Li targets presented no problems because the elastic recoil protons were of high enough energy to be rejected by the detection system.

In order to determine the Q value of a (^{7}Li, $2p$) reaction one must measure the momenta of the two coincident protons in the final state. To do this we used two detector telescopes each consisting of a ΔE and E transmission pair of detectors followed by a surface-barrier reject detector. The $\Delta E, E$ pairs completely stopped the protons of interest (2 to 8 MeV) and provided particle identification signals. Time pickoff units connected to the E detectors generated start and stop signals to run a time-to-amplitude converter (TAC). A window of 0–100 nsec was set for the TAC signal, and for coincident events in this range five analog signals (ΔE and $E+\Delta E$ for each telescope together with Δt) were stored on magnetic tape and in the memory of an SDS-930 computer. Both an energy and an angular calibration for each telescope were obtained from fits to the proton energy spectrum for the reaction $^{9}Be(d, p)^{10}Be$ done at a deuteron bombarding energy of 3.5 MeV. The above calibrations gave sufficient information to calculate the momenta of the observed coincident proton events. The on-line computer presented Q spectra for coincident proton events. A similar spectrum was also computed for those proton events not satisfying the time requirement. This last spectrum is a measure of the chance rate, and is used to correct the data for chance coincidence events. The data stored on magnetic tape were analyzed later off line with more stringent particle identification requirements and a time resolution of 4 nsec.

The reaction $^{12}C(^{7}Li, 2p)^{17}N$ yields a nucleus in the final state for which many excited states are known.[7] This reaction was studied at two bombarding energies (25.0 and 30.0 MeV) in order to test the experimental technique. Figure 1 shows the Q-value spectrum as a result of combining the 25.0- and 30.0-MeV data for the equal polar angles ranging from 25° to 50°, with detectors on opposite sides of the beam axis (azimuthal angles of 0° and 180°). Since the Q value is independent of kinematic factors, the Q spectra from a wide range of conditions can be combined to improve the statistical reliability. The locations of all known states in ^{17}N are shown in Fig. 1, and it is clear that indeed a majority of the states with excitation energies up to 7.8 MeV are populated and observed. The technique does not resolve the doublets at 1.85–1.91 and 3.13–3.21 MeV, which is consistent with the ±0.072-MeV resolution of the system. The data taken on the ^{12}C target demonstrate the feasibility of using the $(^{7}Li, 2p)$ reaction to observe states of neutron-rich nuclides.

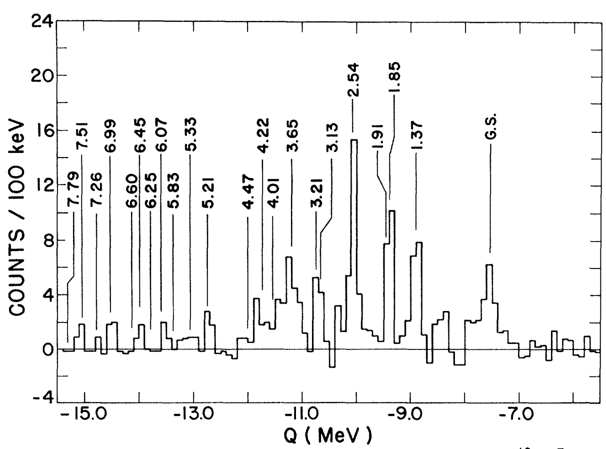

FIG. 1. Q-value spectrum from the reaction $^{12}C(^{7}Li, 2p)^{17}N$ resulting from combining kinematically corrected data taken at beam energies 25.0 and 30.0 MeV with equal telescope polar angles in the range of 25° to 50° (the azimuthal angles were held at 0° and 180°). Positions of known ^{17}N states are shown. The peak at $Q = -8.4$ MeV and the background near the ground-state peak are probably from an oxygen contaminant, although in this energy region the background situation was not intensively studied.

With the ^{7}Li targets data were obtained at ^{7}Li beam energies near 30 MeV, again with azimuthal angles of 0° and 180°. The polar angles were kept equal, but were varied between 20° and 35°. Figure 2 shows a Q spectrum generated from data taken with polar angles of ±30°, and with the mass parameters of the reaction $^{7}Li(^{7}Li, 2p)^{12}Be$. Contaminant peaks were identified by analyzing the same data with mass parameters of the reactions $^{12}C(^{7}Li, 2p)^{17}N$ and $^{16}O(^{7}Li, 2p)^{21}F$, and by comparison with the data taken with the ^{12}C target. The peaks in the Q-value range of −9.45 to −9.05 MeV arise from the carbon contaminant producing ^{17}N states with excitation energies in the range 4.01–4.47 MeV. Similarly, the peaks at Q values of −12.05, −11.25, −8.70, −8.25, and −7.25 MeV are from ^{17}N states at 7.51, 6.45, 3.65, 3.13–3.21, and 1.85–1.91 MeV. The strong $^{17}N(2.54)$ peak of Fig. 1 does not appear in Fig. 2 as a background. This is expected since this peak arises entirely from that part of Fig. 1 data which were taken with a ^{7}Li beam en-

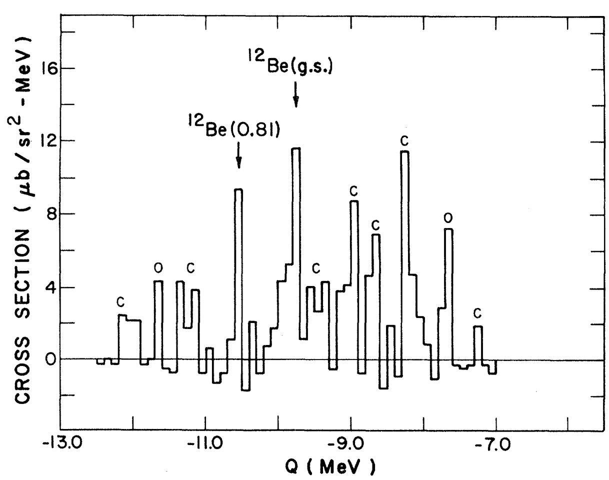

FIG. 2. Cross-section data obtained with a ^{7}Li target bombarded by a 30-MeV beam of ^{7}Li ions. Coincident protons were detected at ±30° on opposite sides of the beam axis. The two peaks labeled ^{12}Be are identified as arising from the reaction $^{7}Li(^{7}Li, 2p)^{12}Be$. Carbon- and oxygen-contaminant peaks which are discussed in the text are labeled by C and O.

ergy of 25 MeV. The peaks at −11.65 and −7.65 are due to the ^{16}O impurity. Further confirmation is obtained from the observation that these impurity peaks had minimum width when Q spectra were generated with the mass parameters of their respective reactions. The remaining two strong peaks are identified as arising from the reaction $^7Li(^7Li, 2p)^{12}Be$. A carbon background spectrum taken with the kinematic conditions of Fig. 2 shows gaps with no intensity at the positions of these two peaks. The gap in the carbon background at the peak identified as the ^{12}Be ground state corresponds to the gap in the ^{17}N spectrum between 4.47 and 5.21 MeV. The gap in the carbon background spectrum near the peak identified as the $^{12}Be(0.81)$ peak is not apparent in the carbon spectrum because the peaks of Fig. 1 in the Q range −13.45 to −13.05 MeV arise entirely from that part of the data taken at angles of ±25°. The two peaks identified as ^{12}Be have minimum width in the Q spectrum generated with the mass parameters appropriate to the ^7Li target, and they have the proper kinematic behavior with changes of polar angles. Data taken at ±35° confirm these identifications. The cross sections obtained from the ±30° data are 2.9 ±1.0 $\mu b/sr^2$ (ground state) and 1.1±0.6 $\mu b/sr^2$

The Q value of the ground state as determined from combining all the data taken on the reaction $^7Li(^7Li, 2p)^{12}Be$ is −9.71±0.10 MeV. The excited state of ^{12}Be has an excitation energy of 0.81± ±0.10 MeV. The above gives a mass excess for ^{12}Be of 24.95±0.10 MeV ($^{12}C \equiv 0$). The major source of error to these determinations was the statistical error which was ±0.08 MeV for the ground state. The systematic uncertainties made up of errors in the knowledge of the beam energy and the angles and energies of the protons amounted to ±0.06 MeV.

The measured mass excess (ME) of ^{12}Be falls within the error bars of the previous estimate based on the measured lifetime for β decay (25.1 ±1.0 MeV). A prediction of the mass of ^{12}Be can be made based on the known[8] lowest $T=2$ states in ^{12}C and ^{12}B. The uniform-charge-density model gives a Coulomb shift of 1.06 MeV between ^{12}B ($T=2$) and ^{12}Be resulting in a predicted mass of 25.02 MeV, which is also consistent with the measured value. For ^{12}Be the Garvey-Kelson method predicts[9] a ME value of 24.95 MeV which is in excellent agreement with our measured value. With the direct determination of the ME of ^{12}Be, three members of the $A=12$, $T=2$ quintet are known, and a determination of the constants of the isobaric multiplet mass equation is possible. This is generally written

$$M(A, T, T_3) = a(A, T) + b(A, T)T_3 + c(A, T)T_3^2. \quad (1)$$

The coefficients for $A=12$, $T=2$ have the values $a(12, 2) = 27.595 \pm 0.020$ MeV, $b(12, 2) = -1.897 \pm 0.062$ MeV, and $c(12, 2) = 0.382 \pm 0.055$ MeV. Using Eq. (1), one predicts that the first $T=2$ state in ^{12}N lies at an excitation energy of 12.54 ±0.09 MeV and that the ground state of ^{12}O has a ME of 32.92±0.25 MeV which makes it unbound to two-proton decay by 2.64 MeV. The measured mass of ^{12}Be together with the relations of Garvey *et al.*[10] allow mass predictions for ^{14}B, ^{15}B, and ^{17}C. The ME of ^{14}B is predicted to be 24.67 ±0.11 MeV. Although ^{14}B has been observed to be neutron stable this estimate shows it to be unbound by 0.04 MeV, but this is within the 0.11-MeV error arising from the errors in the masses used in the calculation. A mass excess of 29.76 MeV is obtained for ^{15}B which correctly shows it to be stable to single- and double-neutron decay. These predicted masses for ^{14}B and ^{15}B in turn give a predicted ME of 20.37 MeV for ^{17}C, correctly showing it to be bound to nucleon decay.

The measured ground-state mass of ^{12}Be shows that it is stable by 3.30 MeV to single-neutron decay and by 3.80 MeV to double-neutron decay. Evidence exists[11] which shows that both ^{13}Be and ^{14}Be are neutron unstable. It thus appears that ^{12}Be is the most neutron-rich isotope of beryllium that is stable to neutron decay.

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

†Doctoral student at Vanderbilt University supported by fellowships from Associated Western Universities and Oak Ridge Associated Universities. This work is contained in a thesis to be submitted for acceptance towards the Ph.D. degree.

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Breaking Nambu-Goldstone Chiral Symmetries*

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We establish that the nonanalytic behavior of some matrix elements in perturbation theory about a chiral symmetry implies that they can be calculated exactly to leading order in chiral breaking. For other matrix elements, analytic to leading order, we establish the hypothesis of threshold dominance in the chiral limit. As an application of this idea we calculate, to leading order in chiral breaking, the seven baryon-octet mass differences in terms of one parameter.

In a previous paper[1] we have pointed out that if a Hamiltonian symmetry is realized by Nambu-Goldstone bosons, then the S matrix and matrix elements of currents are not analytic in the perturbation parameter λ. Some matrix elements, for example, approach the symmetric limit like $\lambda \ln\lambda$. The reason for this nonanalytic behavior is that the Goldstone theorem[2] requires massless mesons in the symmetry limit so that the strong interactions acquire a long-range component.

It is the purpose of this note to point out that for matrix elements that exhibit such nonanalytic behavior in leading order in chiral breaking, it is possible to determine exactly the magnitude of the leading term specified in terms of chiral-breaking parameters. This is to assert that for some matrix elements (particularly those which are derivatives with respect to momentum transfer) *the symmetry itself exactly determines the symmetry breaking to leading order*. It is precisely because we have nonanalytic behavior that we can establish such chiral-limit theorems. We recall that once explicit symmetry-breaking factors have been extracted from a matrix element, this nonanalytic behavior can be viewed as a consequence of dispersion integrals diverging at the thresholds for the production of the Nambu-Goldstone bosons in the chiral limit. However, the production thresholds for the Nambu-Goldstone bosons, the π, K, and η in the case of $SU(3)\otimes SU(3)$, are precisely the points controlled by current-algebra low-energy theorems. It is the two features, that in such matrix elements one may *prove* that the threshold dominates in the chiral limit and that one knows precisely the threshold behavior, that enable one to establish the exact behavior in symmetry breaking as one approaches the symmetry limit.

For other matrix elements, which are analytic to leading order, the characteristic feature is that once explicit symmetry-breaking factors have been extracted, the corresponding dispersion integrals are finite at threshold in the chiral limit. Again the absorptive parts of such matrix elements may be computed exactly in the chiral limit at the production thresholds for the ground-state mesons. Utilizing this exact knowledge of the absorptive part in the threshold region, we may perform the dispersion integration over the threshold region and examine if indeed the threshold region dominates. *In general we expect threshold dominance from the observation that the Nambu-Goldstone bosons, since they are massless in the symmetry limit, provide the longest-range force.* Hence for matrix elements analytic to leading order we advance the hypothesis of threshold dominance (since one cannot prove it as in the nonanalytic case) which may then be established by experimental comparisons.

We propose a theoretical program to examine systematically the symmetry breaking in matrix elements of experimental interest, incorporating these implications of the Goldstone-Nambu realization of chiral symmetry. For nonanalytic matrix elements one may prove exact chiral-limit theorems[3] and for those analytic to leading order one may estimate using threshold dominance.