$CrBr_3$.[12] The origin of the triplet structure for $T < T_C$ including this spin-orbit effect is still the splitting of the final $5d$ conduction-band states by the exchange interaction as we described.

One must also consider the possibility that in EuO the $5d$ levels do not form itinerant bands, but are localized since optical rotation effects in ferromagnetic insulators, such as $CrBr_3$,[12] are due to transitions between localized states. In addition, the red shift of the absorption edge above the Curie point is most easily explained by localized short-range spin-split interactions.[13] However, we feel that if our model for the splitting of the E_1 transition is valid, the change we observe from a doublet structure near T_C to a triplet structure at low temperatures requires the $5d$ state to have delocalized character. Very simply, in a strongly coupled model, the energy state of the d electron will be lowest when aligned with the $4f$ spin on the same ion. Therefore a spin splitting of a localized $5d$ state should exist both above and below T_C. In the delocalized model, the d electron sees an average spin which is zero for $T > T_C$ but is polarized for $T < T_C$. Therefore an exchange splitting will be seen only in the magnetic state, as we observe. Transport measurements[14] and photoconductivity[9] associated with the absorption edge also suggest a conducting d band. However, we have not ruled out the possibility that a broad $6s$ band, degenerate with the $5d$ band at the bottom, may be important for the transport measurements. Extension of this work to other Eu chalcogenides can help elucidate this problem.

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PRODUCTION OF ^{11}B AND ^{10}B BY PROTON SPALLATION OF ^{12}C†

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Measurements of the ^{10}B and ^{11}B spallation production in ^{12}C are presented. These cross sections are related to theories on the origin of the elements lithium, beryllium, and boron.

The nucleosynthesis of the light elements lithium, beryllium, and boron (LiBeB) is a problem of great astrophysical interest.[1-3] Since these elements have very short lifetimes for destruction by stellar thermal protons, they will not survive if produced in the inner regions of stars. It is generally believed that they are produced in a cool stellar environment by the proton-induced spallation of abundant heavier nuclei. The fast protons, with energies of several MeV and higher, are supplied by the acceleration processes associated with flares on the stellar surface. In order to compare the observed abundances of these elements with theoretical predictions, the experimental formation cross sections of LiBeB in the abundant stellar targets ^{12}C, ^{14}N, ^{16}O, ^{20}Ne, and ^{28}Si are required. The proton energies of interest lie in the region just above the LiBeB production thresholds, where the cross sections rise to their peak values and the flux of incident protons is high. In ^{12}C these thresholds range from 15 to 30 MeV. Unfortunately, the only data available in this low-energy region are on the production of the unstable isotopes, and there is a total absence of data for the boron isotopes.

We have measured proton spallation cross sections in ^{12}C for isobars with $6 \leq A \leq 11$, at proton energies between 24.5 and 44 MeV. These cross sections, together with estimated and measured cross sections for other important targets, seem consistent with a recent model[3] locating the spallation site in the stellar atmosphere.

At these proton energies the mass-6 particles are ^6He and ^6Li. The mass-7 particles are ^7Li and ^7Be, while masses 8 and 9 are, respectively, ^8B and ^9Be. Mass 10 consists of ^{10}Be, ^{10}B, and ^{10}C, with ^{11}B and ^{11}C comprising the mass 11 yield. For each mass there is only one stable isobar (except for mass 8, which has none), and the radioactive isobars decay rapidly to it on an astrophysical time scale.[4] Thus for our purposes a mass measurement is sufficient, and mass-6 $\equiv {}^6Li$, mass-7 $\equiv {}^7Li$, mass-9 $\equiv {}^9Be$, mass-10 $\equiv {}^{10}B$, and mass-11 $\equiv {}^{11}B$.

In our experiment, identification was performed by measuring the energy (E) and time of flight (T) of the ions following their production in a thin target. A thin semiconductor detector and the pulsed beam of the Michigan State University sector-focused cyclotron were used. On-line calculation of the quantity ET^2 in a digital computer produced displays such as that shown in Fig. 1, from which total mass yields could be extracted. Integration of the energy and angular distributions permitted the determination of total cross sections for each mass.

A theory describing the origin of LiBeB must explain any deviations from the formation values of the observed isotopic ratios $^{11}B/^{10}B$ and $^7Li/^6Li$. These ratios are observed to be 4.1 and 12.5, respectively, both terrestrially and in meteorites.[5] The original theory of Fowler, Greenstein, and Hoyle[1] (later modified by Burnett, Fowler, and Hoyle[2]) assumed these ratios were

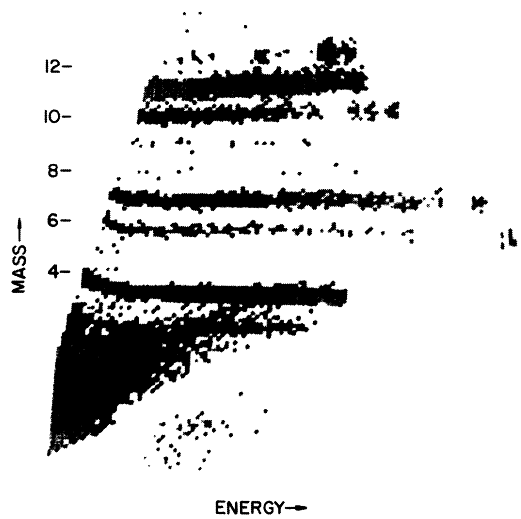

FIG. 1. Computer-oscilloscope display of ET^2 (mass) vs E, showing mass separation.

approximately unity. In order to explain the solar-system ratios, a slow-neutron flux was proposed, which would deplete ^6Li and ^{10}B.

A recent theory due to Bernas et al.[3] takes a slightly different viewpoint. These authors suggest that the observed $^{11}B/^{10}B$ ratio is the unaltered formation ratio. Their estimate of 2.5 for the $^7Li/^6Li$ formation ratio is consistent with our results for ^{12}C. In addition, the large observed $^7Li/^6Li$ ratio is attributed to depletion of ^6Li, but in this case via reactions with low-energy stellar protons. The energy of these protons is assumed to be low enough so that the $^{11}B/^{10}B$ ratio is unaffected. The stellar atmosphere is proposed as the site of the spallation reactions, and hence in the sun the principal targets are the abundant nuclei ^{12}C, ^{14}N, ^{16}O, and possibly ^{20}Ne. No neutrons are required, and in fact their presence would only serve to further increase the $^{11}B/^{10}B$ ratio.

From the above, it is clear that the experimental formation cross sections for ^{10}B and ^{11}B play a key role in determining the origin of LiBeB.

The results of the present experiment on mass-10 and mass-11 production cross sections are shown in Fig. 2. Using these results to calculate the yields of ^{10}B and ^{11}B from ^{12}C requires knowledge of the range of proton energies involved. Recent studies of solar flares[6] show proton energy spectra having an energy dependence of the form $E^{-\gamma}$, where γ varies between 3 and 4. Such a steep energy dependence means that, for the case of ^{12}C, the product of proton flux and pro-

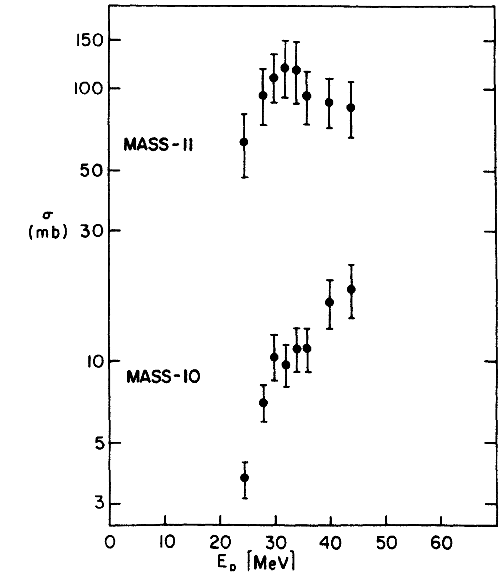

FIG. 2. Cross sections for production of mass-10 and mass-11 isobars by proton-induced reactions in ^{12}C.

duction cross section is significant only for proton energies between 15 and 50 MeV. The cross sections of Fig. 2 show that the production of ^{11}B from ^{12}C considerably exceeds that of ^{10}B under such conditions. The target ^{14}N will also serve as a prolific source of ^{11}B via the low-threshold reaction $^{14}N(p, \alpha)^{11}C$. The low-energy $^{11}B/^{10}B$ ratio for ^{16}O is as yet unknown, but has a value of 2.3 at 135 MeV,[7] in agreement with calculations.[3] These results are consistent with the view of Bernas et al.[3] that the observed $^{11}B/^{10}B$ ratio is the formation ratio, and that the spallation occurs in the stellar atmosphere. Measurements of the ^{10}B and ^{11}B production from ^{14}N and ^{16}O in the threshold region are currently under way in this laboratory.

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OBSERVATIONS OF A_1^-, A_2^- AND HIGHER MASS BOSONS PRODUCED NEAR 180° IN $\pi^- p \to p$ (MISSING MASS)$^-$ AT 16 GeV/c*

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We report observations of A_1^-, A_2^-, and higher mass bosons produced near 180° in $\pi^-p \to pB^-$ at 16 GeV/c, where B^- denotes missing mass with negative charge. Differential cross sections for pA_1^- and pA_2^- final states are given. Data obtained in the mass range $1.40 \le M_{B^-} \le 2.66$ GeV are presented and compared with existing evidence for high mass bosons produced near 0°.

We report here the first detailed search for the production of high-mass bosons ($M_{B^-} > 1.0$ GeV) at small u (i.e., near 180°). This experiment, performed at the Brookhaven National Laboratory alternating-gradient synchrotron (AGS), studied reactions of the type

$$\pi_{(1)}^- + p_{(2)} \to p_{(3)} + B_{(4)}^- \quad (1)$$

at an incident beam momentum of 16 GeV/c. (The subscripts are assigned for the purpose of labeling kinematic variables hereafter and B^- denotes missing mass with negative charge.) The square of the four-momentum transfer, u, equals $(p_1-p_3)^2$, where p_i is the four-momentum of particle i.

The missing-mass method was used to look for

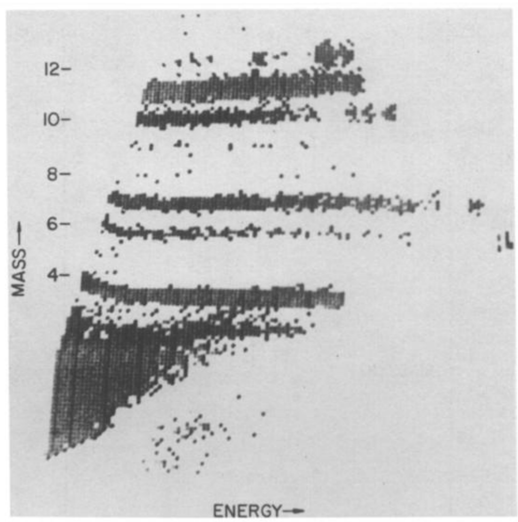

FIG. 1. Computer-oscilloscope display of ET^2 (mass) vs E, showing mass separation.