PRODUCTION OF A = 6,7 NUCLIDES IN $\alpha + \alpha$ REACTIONS and COSMIC RAY NUCLEOSYNTHESIS

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The origin of the light elements Li, Be, and B (LiBeB) differs from that of the other nuclides. Most elements are formed in stars, but LiBeB are rapidly consumed by radiative capture reactions in stellar centers, and must therefore be synthesized in cooler or more tenuous environments. It had been generally accepted that ^{6}Li, ^{9}Be, ^{10}B, and some ^{7}Li and ^{11}B were made in the galactic cosmic rays (GCR). They were produced when fast GCR protons and α particles interacted with interstellar targets of carbon, nitrogen, oxygen (CNO) or He (and vice-versa). The big bang made ^{2}H, ^{3,4}He, and the primeval abundance of ^{7}Li.

Recent measurements of abundances in metal-poor stars, formed early in the life of the galaxy, challenge the details of the GCR picture and have stimulated studies aimed at reproducing the LiBeB abundances in the early galaxy. Because there is little interstellar CNO in the early galaxy, the $\alpha + \alpha$ reaction might play a major role in production of ^{6,7}Li. Unfortunately, the $\alpha + \alpha$ cross sections [1] are not known at high enough energies for such purposes – no data are available for ^{6}Li production above 200 MeV, although the cosmic ray α-particle flux remains strong beyond this energy. The predicted early-galaxy abundances of ^{6}Li can vary significantly depending on how the available lower energy cross sections are extrapolated to higher energy.

To provide the necessary data, we measured the angular distributions of A = 6, 7 ejectiles from the $\alpha + \alpha$ reaction for alpha energies between 159 and 620 MeV, and integrated these distributions to obtain the total production cross sections for masses 6 and 7. Since all isotopes of mass 6 and mass 7 decay to ^{6}Li and ^{7}Li on astronomically short time scales, this is equivalent to a measurement of the production of ^{6,7}Li by these reactions.

The cross sections at bombarding energies above 160 MeV were expected to be small, As a result we anticipated problems from low event rates and background scattering from gas-cell windows and the collimators used to define the ejectile emission angle if we took the usual gas cell approach. To avoid these problems, we employed two novel techniques: (1) the detectors were placed inside the large (92 inch diameter) NSCL scattering chamber, which was filled with helium, and (2) a telescope system consisting of two position sensitive detectors was used to define the scattering angle. These techniques essentially eliminated background problems and increased the effective solid angle of the detectors.

The resulting cross sections are shown in Figs. 1 and 2.

A comparison of the present cross sections with those of ref. [3] at the 159.3 MeV overlap point, shows that the cross sections for A = 7 agree, while our cross section for A = 6 is lower by about a factor of two. We found an inconsistency in the normalizations for different reactions in ref. [3]; after a detailed reanalysis, revised cross sections were published [8]. These are in excellent agreement with the present A = 6 result at 159.3 MeV. After these corrections, all the higher energy data for A = 6 and A = 7 are consistent with an exponential decrease with incressing energy as in shown in Figs. 1 and 2. Since the recommended cross section of ref. [1] for A = 6 were based on the earlier cross sections, they differ from the present results as shown in Fig. 1

We have calculated the cosmic ray yields of A = 6, 7 using a spectrum taken from Fields, *et al.*, [9]. The result for the predicted production ratio ^{6}Li/ ^{7}Li is a factor of two smaller for the present exponential extrapolations, than for the Read-Viola [1] cross sections. For the more extreme case, comparing our exponential extrapolation to a σ = *constant* extrapolation of the last measured A = 6 cross section at 50 MeV (the last point for which data was available before our measurements), the reduction is a factor of 15.

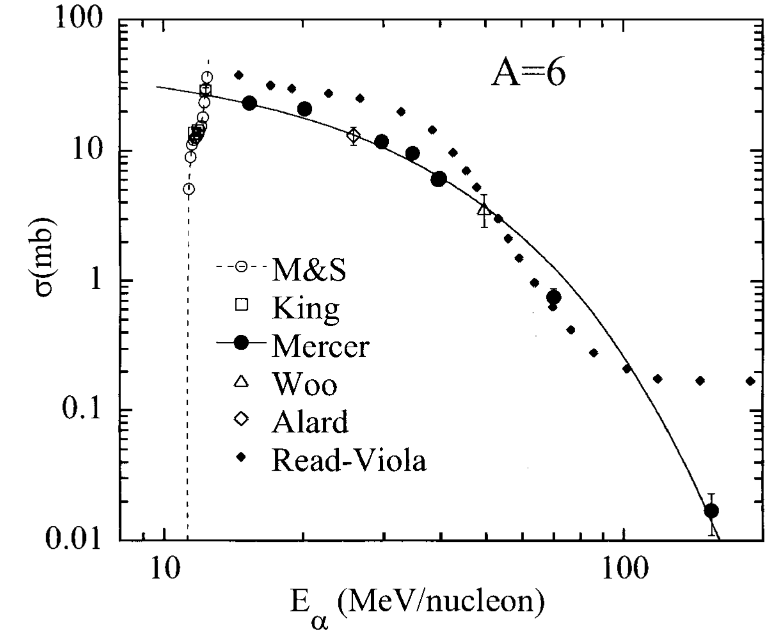

Figure 1. Data for the production of A=6 (contains the production of ^{6}Li and ^{6}He, which decays to ^{6}Li). The small solid diamonds (Read-Viola) are the adopted values from the tabulation of Read and Viola [1], the solid circles (Mercer) are the present result at E_α = 159.3, 279.6, and 619.8 MeV, combined with the results of [8]. The other points are from [2, 4-6]. The solid line is an exponential fit to the data.

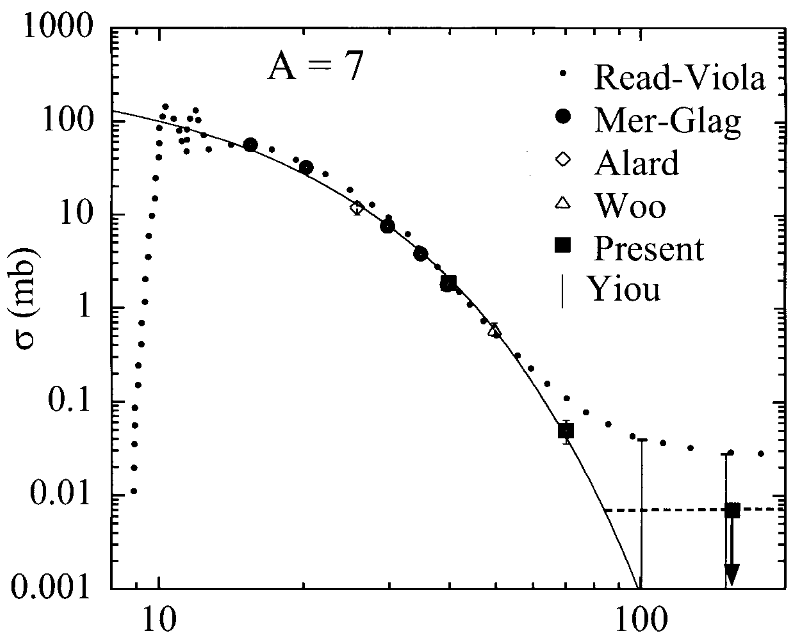

Figure 2. Results for ^{7}Li (contains the contribution of ^{7}Be which decays to ^{7}Li. As expected, the cross sections for ^{7}Li and ^{7}Be are identical). Details are the same as for Figure 1, except that only an upper limit was obtained for the highest energy point.

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