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THE FRAGMENTATION OF ^{28}SI

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Abstract

The fragmentation of ^{28}Si in targets of C, CH_2, Cu and Pb has been investigated at the Lawrence Berkeley Laboratory Bevalac. Total charge changing cross sections, $\sigma_{\Delta Z}$, for these targets and for H (CH_2-C subtraction) were measured at 375, 550 and 1050 MeV/nucleon. The results are compared to previous data, to model calculations and to values used in cosmic ray propagation calculations.

Introduction An understanding of the systematics of heavy ion fragmentation cross sections is critical for the interpretation of cosmic ray data through models for the propagation of energetic particles in the galaxy. In particular, total mass changing cross sections, $\sigma_{\Delta A}$, are needed in order to correct measured cosmic ray spectra for interactions both in the interstellar medium, in the atmosphere above a balloon instrument and in detector materials. The cross sections depend on the beam mass, the target mass and the beam energy.

In the past, $\sigma_{\Delta A}$ has been calculated using an energy-independent overlap model (e.g. Bradt and Peters, 1950) of the form:

$$\sigma = 10\pi r_0^2 (A_t^{1/3} + A_B^{1/3} - b)^2$$

where r_0 is ~1.35 fm, with various forms for the overlap parameter b. Although little data showing the energy dependence of cross sections in nucleus-nucleus collisions has been available, there is a considerable body of information on proton-nucleus total reaction cross sections. An examination of these shows that they have a strong energy dependence below 1 GeV/nucleon, as would be expected from the energy dependence of the individual proton-nucleon cross sections. Since the proton-nucleus total inelastic cross sections are closely related to the $\sigma_{\Delta A}$ of astrophysical interest, energy independent calculations may be reasonable above 1 GeV/nucleon, where the cross sections approach an asymptotic value, but energy dependent forms are needed at lower energies.

A relatively simple instrument capable of measuring $\sigma_{\Delta Z}$ as well as elemental production cross sections, has been used at the Bevalac, and the first results are reported here. Ideally, the energy dependence of $\sigma_{\Delta A}$ for nucleus-nucleus collisions should be investigated by direct measurement at a number of energies. The difference between $\sigma_{\Delta A}$ and $\sigma_{\Delta Z}$, however, is the total neutron stripping cross section and the energy dependence of the charge and mass changing cross sections will be comparable if this cross section is essentially a constant fraction of $\sigma_{\Delta A}$, a reasonable assumption.

Experiment The measurements were performed at the Lawrence Berkeley Laboratory Bevalac using a silicon solid state detector telescope, shown schematically in Figure 1. The telescope consisted of 12 fully depleted

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5 mm thick, 4.6 cm diameter lithium-drifted silicon detectors (D1-D12), and 3 triggering/beam defining scintillators (G1, G2, and H1). The active areas of G1 and G2 were 5.7 cm x 5.7 cm, while H1 was 10 cm x 10 cm with a 1.27 cm diameter central hole. The axis of the telescope was aligned along the axis of the incident beam, which was focussed behind the telescope with a convergence of less than 3 mrad half angle. The basic event trigger was $G1 \cdot G2 \cdot \overline{H1}$ with typically better than 80% of the beam passing through the central hole in H1. The thresholds for G1, G2 and H1 were set at approximately 10% of the ^{28}Si peak and protection was provided in the event logic for beam structure and pile-up. The outgoing detectors (D3-D12) defined an acceptance aperature with a half angle of about 110 mrad for interactions taking place at the front of the target.

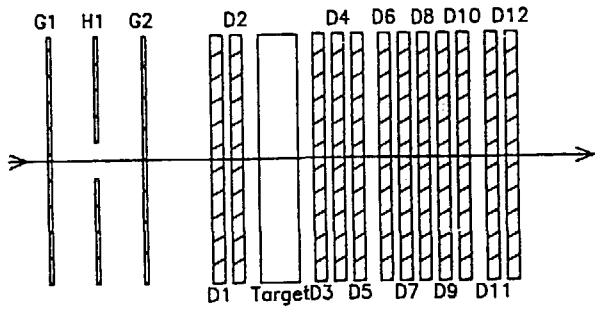

Figure 1: The Telescope

In order to investigate the energy and target dependence of the ^{28}Si charge changing cross sections, runs were made at beam energies of 260, 375, 550 and 1050 MeV/nucleon. At each energy, data were taken with C, CH_2, Cu and Pb targets as well as with no target holder and with an empty target holder for background correction.

To calculate $\sigma_{\Delta Z}$, data for each run were first filtered for interactions in the trigger scintillators and in the beam counting detectors D1 and D2 by requiring that Z=14 in both D1 and D2 using a cut which was tight enough to exclude the tail of the Z=13 peak. Next, the charge in D3-D12 was examined to determine the charge of the outgoing particle and a count, N_S, was made of those which survived as Si. Typically less than 3% of the outgoing particles fell between the Si and Al peaks and were assigned as Si or Al from the overall ratio of Si to Al counts. Target in and target out runs were treated identically. For all runs, the surviving fraction of Si after the target position $f_S = N_S/N_B$ was calculated. The cross section in mb for each target and energy was then found from:

$$\sigma_{\Delta Z}^{t,E} = \langle A_t \rangle \ln(f_S^{TO}/f_S^{T})/(6.02*10^{-4}X_t)$$

where $\langle A_t \rangle$ is the average mass number of the target, X_t is the target thickness in gm/cm^2 and the superscripts T and TO on f_S indicate target in and target out fractions respectively. The $\sigma_{\Delta Z}$ for H, C, Cu and Pb targets at energies of 375, 550, and 1050 MeV/nucleon are shown as closed symbols in Figure 2. The data for 260 MeV/nucleon are currently being analyzed.

Energy Dependence Letaw, Silberberg and Tsao (1983) have derived an empirical fit to the proton-nucleus total reaction cross section data which is directly applicable to mass changing cross sections of nuclei incident on hydrogen. Garcia-Munoz et al. (1987) use the energy dependence of Karol (1975) combined with a fit to a compilation of (p,p) and (p,n) total cross sections. For a hydrogen target the cross section is calculated using the Karol formula and is then scaled to Equation 4 of Kirkby and Link (1966) evaluated at 145 MeV/nucleon. For a He target the Karol calculation is performed for He and the resulting cross section is scaled from the target dependent fit given by Westfall et al. (1979) evaluated at 1 GeV/nucleon.

In the first panel of Figure 2 our measured values of the $\sigma_{\Delta Z}$ for ^{28}Si on H are shown, together with those reported by Webber, Kish and Schrier

(1989), and compared to calculated curves using the Karol formula (solid) and the Letaw formula (dashed), both normalized to the 1050 MeV/nucleon point. Both formulations give an approximate fit to our results although the solid curve shows a stronger energy dependence than the dashed curve.

Shown in the lower three panels of Figure 2 are the measured cross sections for C, Cu and Pb targets along with energy dependent curves calculated for a He target using the Garcia-Munoz et al. (1987) formulation, again normalized to the 1050 MeV/nucleon point. The measurements of Webber et al. (1989) are included for the C target and are in good agreement. The calculated curves are in approximate agreement with the results for all targets although, once again, it appears that the turnover should occur at a lower energy since the 550 MeV/nucleon point is above the curve for all targets. Most interesting, however, is that the overall fit to the measured data is similar for all targets, indicating that the form of the energy dependence is relatively independent of the details of the target. This is important for the development of models for energy dependent cross sections since it suggests that an energy dependence measured or calculated for one target can be scaled to other targets if the target dependence at a particular energy is known.

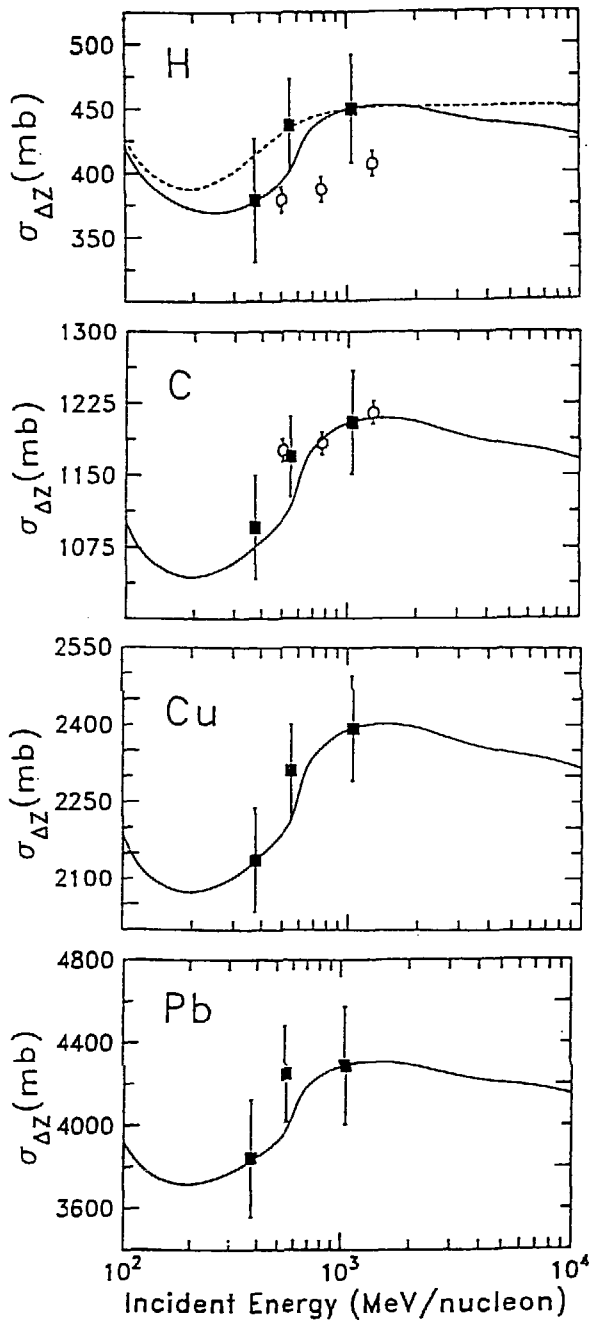

Figure 2: $\sigma_{\Delta Z}$ Results

The lack of agreement between our measured points and those of Webber et al. (1989) for a H target is somewhat surprising since the agreement for a C target is very good. In both cases, the H target points are derived from a CH_2-C subtraction and there may be some systematic difference in the methods used. As a check on our methods, however, we took CH_2 data using both thin (0.79 gm/cm^2) and thick (4.0 gm/cm^2) CH_2 targets. The results were essentially identical, i.e. at 1050 MeV/nucleon we measure 700 ± 28 mb for the thin target and 702 ± 19 mb for the thick target.

Target Dependence No target dependence of $\sigma_{\Delta Z}$ for a ^{28}Si beam has been reported previously. Parameterizations have been reported for energies in the 1-2 GeV/nucleon range, however, for the target dependence of the $\sigma_{\Delta Z}$ of an ^{56}Fe beam in targets from H to U (Westfall et al., 1979; Hoang, Cork and Crawford, 1985) and for beams with Z=36 to 79 in various targets (Binns et al., 1987). These various expressions predict values which are consistently below the measured value at 1050 MeV/nucleon. For example, for the Pb target we measure $\sigma_{\Delta Z}$ = 4290 mb while the parameterizations give 3779, 3856 and 3362 mb respectively. An earlier expression proposed by Hagen (1976) also falls below the data with a value of 3952 mb.

Although the parameters in the various expressions can be adjusted to approximately fit our data, the dependence of our measured $\sigma_{\Delta Z}$ on target mass is more pronounced than the $A_t^{1/3}$ dependence which is a feature of all of the published expressions. If we assume that the exponents should be the same for the target and beam masses, we obtain an expression for our target scaling in a form similar to that given by Hoang et al. (1985):

$$\sigma_{\Delta Z} = C \quad [A_t^p + A_B^p - d/(A_t^p + A_B^p)]^2$$

with a best fit obtained for C=40.72, p=0.368 and d=2.785. Figure 3 shows this fit, which also passes through the calculated cross section for a He target. For the H target, however, the curve in Figure 3 lies well above the measured cross section and must be corrected by replacing the H mass by an effective mass A_H^{eff} = 0.26.

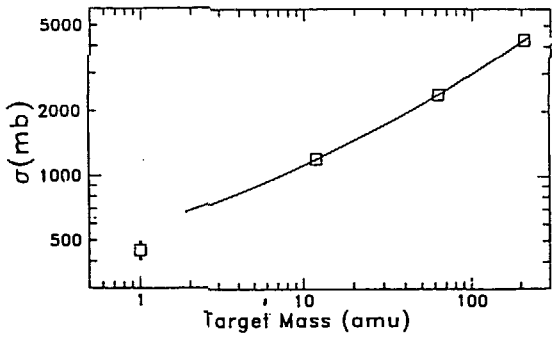

Figure 3: Target Dependence

Conclusions We have shown that the $\sigma_{\Delta Z}$ for ^{28}Si (and, by extrapolation, $\sigma_{\Delta A}$) show a pronounced energy dependence below 1 GeV/nucleon. The form of the energy dependence is in general agreement, for all targets tested, with that calculated using the Karol formulation for a He target. *A scaling formula is given which* will allow this energy dependence to be used for any target.

References

Binns, W. R., et al., 1987, Phys. Rev. C, 36, 1870.
Bradt, H. C. and Peters, B., 1950, Phys. Rev., 77, 54.
Garcia-Munoz, M., et al., 1987, Ap. J. Suppl., 64, 269.
Hagen, F. A., 1976, Ph.D. Thesis, University of Maryland (unpublished).
Hoang, T. F., Cork, B. and Crawford, H. J., 1985, LBL Report LBL-17706.
Karol, P. J., 1975, Phys. Rev. C, 11, 1203.
Kirkby, P. and Link, W. T., 1966, Canadian J. Phys., 44, 1847.
Letaw, J. R., Silberberg, R. and Tsao, C. H., 1983, Ap. J. Suppl., 51, 271.
Webber, W. R., Kish, J. C. and Schrier, D. A., 1989, Phys. Rev. C (in press).
Westfall, G. D. et al., 1979, Phys. Rev. C, 19, 1309.

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