OG 7.2-21

INTERACTIONS OF HEAVY NUCLEI, Kr, Xe AND Ho, IN LIGHT TARGETS

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1. Introduction. Over the past few years, we have been analyzing the HEAO-3 measurements of the abundances of ultra-heavy cosmic ray nuclei (Z>26) at earth.[1] In order to interpret these abundances in terms of a source composition, allowance must be made for the propagation of the nuclei in the interstellar medium. Vital to any calculation of the propagation is a knowledge of the total and partial interaction cross sections for these heavy nuclei on hydrogen. Until recently, data on such reactions have been scarce, and we have relied on the semi-empirical formalism of Silberberg and Tsao[2] to predict the partial cross sections. However, now that relativistic heavy ion beams are available at the LBL Bevalac, some of the cross sections of interest can be measured at energies close to those of the cosmic ray nuclei being observed.

During a recent calibration at the Bevalac of an array similar to the HEAO-C3 UH-nuclei detector, we exposed targets of graphite (C), polyethylene (CH_2), and aluminum to five heavy ion beams ranging in charge (Z) from 36 to 92. Total and partial charge changing cross sections for the various beam nuclei on hydrogen can be determined from the measured cross sections on C and CH_2, and will be applied to the propagation problem. The cross sections on Al can be used to correct the abundances of UH cosmic rays observed in the HEAO C-3 detector for interactions in the detector itself. Table 1 shows the combinations of beams and targets, as well as the number of events incident on the target for each run. The energies of each beam are also shown. Our preliminary results show that we achieved a charge resolution on the fragments that ranged from 0.21 charge units for Kr on Al to 0.28 c.u. for Au on C, permitting unambiguous resolution of individual fragments. In this paper we report on the total cross sections for Kr on Al, and total and partial cross sections for Xe and Ho on C, CH_2 and H.

Table 1. Number of Events (x 10^3)

Energy (GeV/n):	Kr 1.5	Xe 1.2	Ho 1.1	Au 1.0	U 0.9
Target					
C	--	210	130	260	60
CH_2	--	330	200	400	90
Al	90	160	190	200	--
"Blank"	35	110	120	260	40

2. Experimental Setup. The detector consisted of an array of two front ion chambers, a target space, two rear ion chambers, followed by a Pilot 425 Cherenkov counter. From signals in the front ion chambers, we find that approximately 10% of the nuclei incident on the detector do not have the nominal charge of the beam, and we eliminate these events from further analysis. Fragments produced in the target as well as beam nuclei surviving through the target are measured in the rear ion chambers and the Cherenkov counter. Scatter plots of the signals in these detectors show well resolved peaks for individual fragments.

3. Total Cross Sections. The interaction mean free path can be found by counting the number of beam nuclei which survive through the target and our detector, and correcting for interactions in the detector itself. This correction is found from a "blank" or no target run. The total interaction cross section per nucleus is related to the mean free path by the following expression:

$$\sigma\ (\mathrm{mb}) = \bar{A}_T/(6.02 \times 10^{-4})\ \lambda\ (\mathrm{g/cm^2})$$

where $\bar{A}_T$ is the mean mass number of the target. Our results for the total cross sections are given in Table 2, along with values calculated using the formula from Westfall et al.[3] for charge changing cross sections, σ_W. Although this formula was derived from data for nuclei with $Z \leq 26$, it gives values which only slowly deviate from those measured as Z increases, with σ/σ_W = 0.85 for Ho on H.

Table 2. Total Cross-Sections

Beam	Target	λ(g/cm^2)	σ(mb)	σ_W	σ/σ_W
Kr	Al	19.3	2300±100	2460	.95
Xe	C	8.9	2240±80	2460	.91
Xe	CH_2	5.1	1510±50	1670	.91
Xe	H	1.4	1150±90	1270	.90
Ho	C	7.8	2560±70	2760	.93
Ho	CH_2	4.6	1690±40	1910	.89
Ho	H	1.3	1260±75	1490	.85

4. Partial Cross Sections. The numbers of fragments produced in the target are measured in the rear ion chambers and the Cherenkov counter. A histogram of the Cherenkov signal for events consistent with their being fragments is shown in Fig. 1. The charge resolution for this particular run is 0.23 charge units.

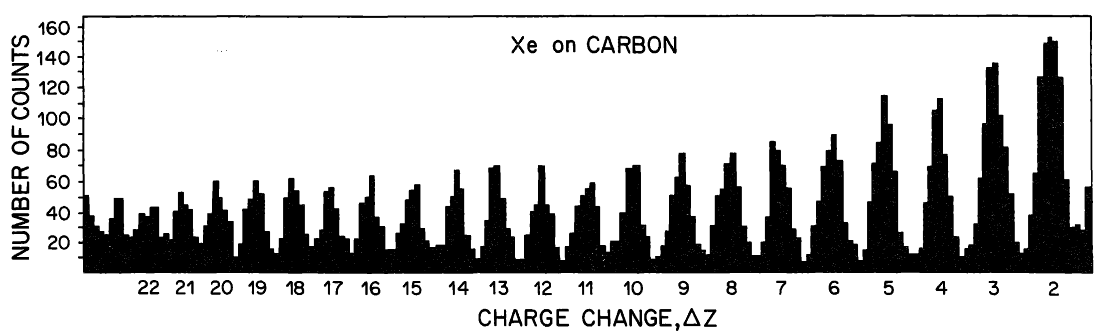

Fig. 1. Cherenkov histogram for Xe nuclei on Carbon.

Several corrections must be applied to the yields obtained from these histograms. First, there is a correction for events observed in the blank run which are also consistent with their being fragments.

These events are due to interactions of the beam in the matter between the Cherenkov counter and the ion chambers. Also, for a given Z, there is a background due to the fragments of charge Z + 1 making a $\Delta Z = 1$ interaction in the Cherenkov counter. Both of these corrections are small, being less than 2%. In addition, there must be a correction for absorption in the detector. We have done this by applying an exponential absorption law, using the Westfall et al.[3] charge changing cross section, scaled to our measurements, to calculate the necessary mean free paths. The numbers resulting from this correction are the numbers of each fragment exiting the target. To obtain the partial cross sections from these numbers we need to correct for multiple interactions in the target. The targets used were approximately 0.25 of a mean free path, and were chosen as a compromise between being thick enough to produce a reasonable number of interactions, yet thin enough so as not to degrade the charge resolution of the Cherenkov due to the energy spread of the fragments. We have used a slab propagation program to do this thick target correction.

Table 3 lists the partial cross sections of Xenon and Holmium on C, CH_2, and H. The hydrogen cross sections are derived from the C and CH_2 cross sections per nucleus by a subtraction procedure:

$$\sigma_H = 1/2\ (3\ \sigma_{CH_2} - \sigma_C)$$

Also given in Table 3 are the values predicted[4] for Xe and Ho on H. Fig. 2 shows the ratios of our values and those predicted, as a function of ΔZ for Xe and Ho. The errors shown are the statistical errors on the target and blank runs, combined with the errors due to the top of detector correction. Also shown is a fit to previously measured ratios reported for Au nuclei,[5] showing distinctively different behavior.

Table 3

ΔZ	Xe on C	Xe on CH_2	Xe on H	S & T	Ho on C	Ho on CH_2	Ho on H	S & T
1	249±21	230±9	220±17	257	343±35	270±26	234±42	267
2	128±5	137±4	141±6	169	138±5	133±4	131±6	257
3	105±4	104±3	104±5	106	103±4	117±3	124±5	166
4	72±4	94±3	105±5	106	81±4	97±3	105±5	114
5	73±4	79±3	82±5	61	73±3	89±3	97±4	95
6	63±3	73±2	77±4	64	67±3	78±2	84±4	81
7	53±3	65±2	71±4	50	60±3	67±2	71±4	66
8	53±3	53±2	53±1	47	53±3	57±2	59±3	71
9	45±3	47±2	48±3	33	45±3	51±2	54±3	53
10	43±3	43±2	43±3	31	46±3	49±2	51±3	51
11	40±2	37±2	35±3	21	43±3	40±2	38±3	34
12	35±2	33±2	32±3	18	34±2	32±2	31±3	32
13	37±2	31±2	28±3	14	38±2	29±2	24±2	18
14	37±2	27±2	23±3	14	33±2	25±1	20±2	14
15	33±2	20±1	14±2	9	33±2	22±1	17±2	12
16	33±2	19±1	12±2	8	32±2	19±1	13±2	8
17	30±2	17±1	10±2	6	34±2	18±1	10±2	7
18	32±2	16±1	7±2	6	32±2	15±1	7±2	5
19	31±2	15±1	6±2	5	27±2	13±1	6±2	5
20	30±2	13±1	5±2	6	25±2	15±1	10±2	5
21	27±2	13±1	6±2	5	--	--	--	--

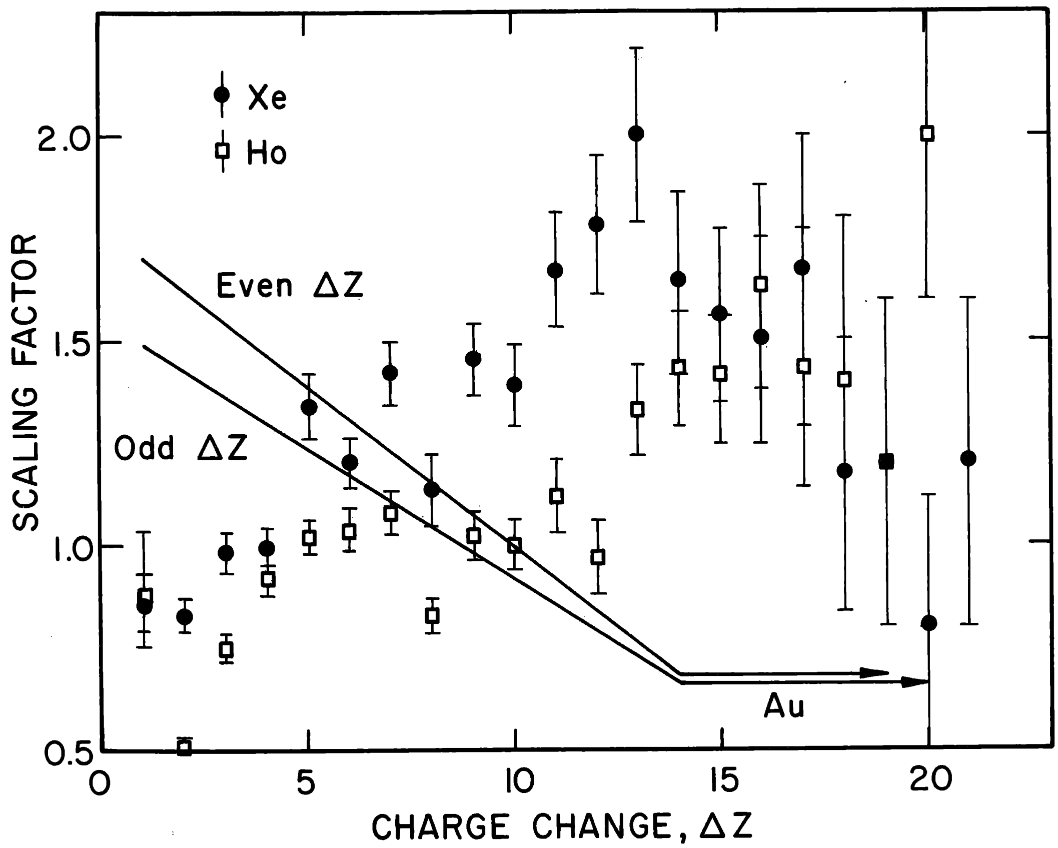

Fig. 2. Ratio of observed to predicted cross-sections as a function of ΔZ.

Examination of these data and of the earlier Au-data from Brewster et al. (1983) shows that they can be well represented by universal curves if expressed as $d\sigma/\sigma_T$ versus ΔZ. We find that for heavy targets, carbon and aluminum, $d\sigma/\sigma_T = a\ (\Delta Z)$ where a and m are closely similar constants for all non-hydrogenous targets and projectiles. Similarly for a hydrogen target, $d\sigma/\sigma_T = b \exp(-n\Delta Z)$, where b and n are closely similar constants for all studied projectiles. The polyethylene targets also show a similar exponential dependence.

4. Acknowledgements. We are grateful to the staff of the LBL Bevalac. This work was supported in part by NASA under grants NAG 8-498, 500, 502, and NGR 05-002-160, 24-005-050, and 26-008-001.

References

[1]Binns, W. R. et al. (1984), Ap. J. 247, L115; (1983) Ap. J. 267, L93.

[2]Silberberg, R. and Tsao, C. H. (1973), Ap. J. Suppl. 25, 335.

[3]Westfall, G. D. et al. (1979), Phys. Rev. C 19, 1309.

[4]Tsao, C. H. and Silberberg, R., (1979), Proc. 16th ICRC (Kyoto), 2, 202.

[5]Brewster, N. R. et al. (1983), Proc. 18th ICRC, 9, 259; (1984) Ph.D. Thesis, Univ. of Minn.