INTERACTIONS OF 200 GeV GOLD NUCLEI IN LIGHT ELEMENTS

N.R. Brewster, R.K. Fickle, and C.J. Waddington
School of Physics and Astronomy, University of Minnesota
Minneapolis, Minnesota 55455, U.S.A.

W.R. Binns, M.H. Israel, M.D. Jones, and J. Klarmann
Washington University, St. Louis, Missouri 63130, U.S.A.

T.L. Garrard, B.J. Newport, and E.C. Stone
California Institute of Technology
Pasadena, California 91125, U.S.A.

ABSTRACT

Total charge-changing cross sections and partial cross-sections for interactions of 200 GeV $^{197}_{79}$Au nuclei incident on carbon and polyethylene (CH_2) targets have been measured during a calibration of the HEAO-3 Heavy Nuclei Experiment. From these we infer the total and partial cross-sections for $^{197}_{79}$Au incident on hydrogen. The effects of using these cross-sections in one model of cosmic ray propagation are illustrated. Comparisons to predictions using semi-empirical formulae are shown.

1. Introduction

We recently calibrated a prototype of the HEAO-3 Heavy Nuclei Experiment at the LBL Bevalac, using beams of relativistic Au and Mn ions. During this calibration we studied the interactions of primary Au nuclei in targets of polyethylene (CH_2) and carbon. We measured total absorption, σ_T, and partial cross sections, $d\sigma$, in both targets, from which by subtraction we determined the cross-sections appropriate for a hydrogen target. These can be used to examine the validity of the values assumed in models of cosmic ray propagation (e.g., Brewster et al., 1983). In such models, the $d\sigma$ for cosmic ray nuclei heavier than iron, the "ultra-heavy" or UH nuclei, are generally estimated from the semi-empirical equations of Silberberg and Tsao (1973, 1977, and 1979), which are based on sparse data and have errors estimated to be at least 50%. Measurements of $d\sigma$ for Au nuclei are thus interesting both for the nuclear physics involved and for their influence on cosmic ray propagation calculations. In particular, $d\sigma$'s for the production of elements in the range $60 < Z < 80$ are important because any interpretation of the abundances of the secondary elements in this charge range depends on them.

The detector used consisted of: a prototype of the HEAO ion chambers, "D-chambers", (Binns et al., 1981); a dual-radiator Pilot 425 Cherenkov counter, "C-counter", similar to, but half the size, of the HEAO counter; and two thin-walled ion chambers, "B-chambers". During this part of the calibration the beam entered the B-chambers, then traversed a target, the C-counter and finally the D-chambers. Before entering our array, the beam traversed small amounts of material which reduced the energy of the Au beam from 1063.8 to about 990 MeV/amu, and introduced about 0.05 of a mean free path.

Three runs were made, one with a carbon target, one with a polyethylene target, and one with no target. The two targets were 1.321 and 0.927 g/cm^2 thick, respectively. These thicknesses were chosen so that the energy spread introduced by the differing points of interaction should not smear the Cherenkov signal of a fragment of $Z \cong 60$ by more than 0.3 charge units.

2. Data Analysis

The number of gold nuclei incident on each target was determined by selecting only those events that had the signature of gold nuclei in both B-chambers. These were selected from a scatter plot of the signal in one B-chamber versus that in the other. The Cherenkov signals for these selected events were histogrammed separately for both target runs and the blank run. After adjusting for the energy differences between blank and target runs caused by the energy losses in the targets, and normalizing the number of gold nuclei surviving the C-counters, the blank run was subtracted from the target runs. This procedure corrects the numbers of fragments observed in the C-counter for those fragments produced by gold nuclei which survived the target but then interacted in the C-counter. A resulting histogram is shown in Fig. 1 for the CH_2 target. Two corrections were made at this point. The first was to compensate for those secondary nuclei produced in the target but interacting in the C-counter, producing "tertiaries" of lower charge. This correction was made by determining, from the blank run, the fraction of nuclei of each charge produced in the C-counter relative to the number of gold nuclei surviving the C-counter. Then the same fraction was assumed for the production of a fragment of equal charge-change from a parent other than gold.

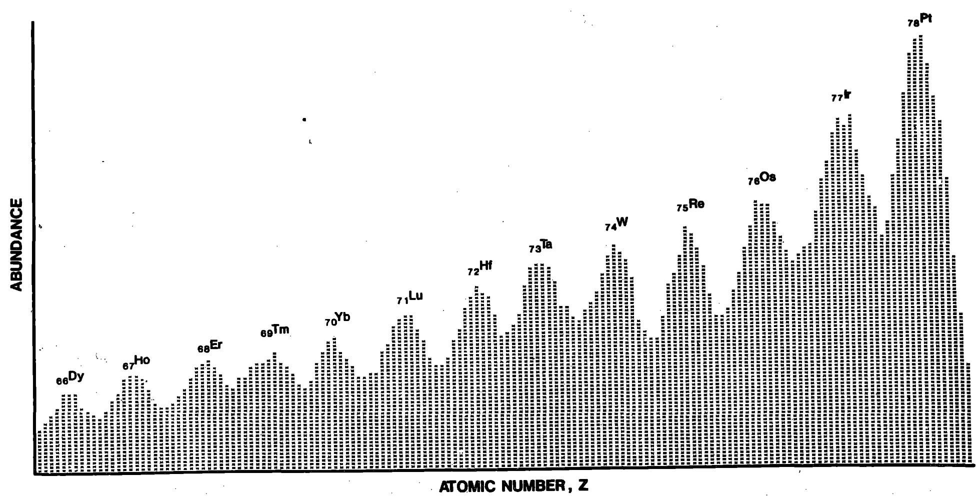

Fig. 1. Signals in the Cherenkov counter from a CH_2 target after subtraction of the background observed in the blank target run.

TABLE

Cross-sections of Au-nuclei measured in CH_2 and Carbon, and deduced in Hydrogen

Z	CH_2† $d\sigma$(mb)	$d\sigma/\sigma_T$(%)	Carbon $d\sigma$(mb)	$d\sigma/\sigma_T$(%)	Hydrogen $d\sigma$(mb)	$d\sigma/\sigma_T$(%)	$d\sigma$(S&T)	$d\sigma_{obs}/d\sigma_{ST}$
78	257±15	14.5	242±23	9.6	265±16	19.0	162	1.64
77	196±10	11.1	190±16	7.5	199±13	14.2	129	1.54
76	134±8	7.6	107±13	4.3	148±10	10.6	95	1.56
75	102±7	5.8	46±10	1.8	130±7	9.3	85	1.53
74	94±6	5.3	57±10	2.3	113±7	8.1	92	1.23
73	90±6	5.1	67±9	2.7	102±7	7.3	73	1.40
72	70±5	4.0	54±9	2.1	78±6	5.6	78	1.00
71	60±5	3.4	49±8	1.9	66±6	4.7	63	1.05
70	44±4	2.5	35±7	1.4	49±5	3.5	67	0.73
69	42±4	2.4	54±8	2.1	36±5	2.6	54	0.67
68	38±4	2.1	42±7	1.7	36±4	2.6	59	0.61
67	27±3	1.5	34±6	1.4	24±4	1.7	47	0.51
66	20±3	1.1	--		--			
65	16±3	0.9	--		--			

	$\sigma_T(CH_2)$ = 1770± 73 mb	σ_T(C) = 2517±143 mb	σ_T(H) = 1397±108 mb
Hagen	2107	2932	1694
Westfall et al.	2138	3033	1691

†per nucleus

The second was an absorption correction, equal to the number of secondary fragments which "should" have been counted in the C-counter but which instead were absorbed by the C-counter or the steel lid between target and C-counter. For this correction we used the mean free paths in lucite and iron calculated from the formula of Hagen (1976), weighted by the ratio 1.19 of our measured mean free path to Hagen's mean free path for Au on CH_2.

To determine the partial cross-sections we assumed a set of initial cross-sections and iterated a slab propagation program (dividing the target into 20 thin slabs) to allow for multiple interaction and modifying the cross-sections until agreement was reached between our measured numbers of fragments and the calculated ones.

3. Results

The table lists the resulting $d\sigma$'s for the CH_2 and carbon targets as well as the ratios of $d\sigma/\sigma_T$. Also given in the table are the cross-sections for Au on hydrogen obtained from $d\sigma_H = (3d\sigma_{CH_2} - d\sigma_C)/2$. These values are for 200 GeV Au-nuclei and can be compared with the energy-asymptotic values of Silberberg and Tsao (S & T) $d\sigma_{ST}$. It can be seen that for small ΔZ the measured values are appreciably greater than those predicted, while for $\Delta Z \geq 10$, the measured values are smaller than predicted. Recently Tsao et al. (1983) have modified the S & T semi-empirical formulae, using the data of Kaufman and Steinberg (1980) for protons on Au targets. At 1 GeV/amu these new values are appreciably greater than the old S & T values.

The table also lists the total charge-changing cross-sections for

Au on CH_2, carbon, and hydrogen, as well as the predicted values from various earlier semi-empirical formulae extrapolated from the $Z < 26$ region (Hagen, 1976; Westfall et al., 1979). Letaw et al. (1983) have recently presented a mass-changing cross-section, so for comparison to our charge-changing measurements the Letaw et al. value for the neutron-stripping cross-section has been subtracted to give $\sigma_T(H) = 1552$ mb. One experimental measurement of the total cross-section for gold on hydrogen is known to us: that of Brick et al. (1982) of $\sigma_T(H) = 1330 \pm 150$, which is in good agreement with our value and significantly below the predictions.

4. Conclusions

The final column in the table lists $d\sigma_{obs}/d\sigma_{ST}(= R)$ as a function of ΔZ. In an attempt to understand the implications of these results to models of propagation, we have represented R by $R = 1.85 - 0.112\Delta Z$ for $\Delta Z \leq 12$ and $R = 0.51$ for $\Delta Z > 12$. This factor has been applied to all the cross-sections for $Z > 60$. The solar system abundances of Anders and Ebihara (1982), corrected for first ionization potential effects, have been propagated with an escape length of 5.5 g/cm^2 of hydrogen (Brewster et al., 1983), first using the $d\sigma_{ST}$ values and then using $R \cdot d\sigma_{ST}$ values. The differences are not major. For example, the abundance ratios $N(80 \leq Z \leq 83)/N(75 \leq Z \leq 79)$ = P80, $N(70 \leq Z \leq 74)/N(75 \leq Z \leq 83)$ = S70, and $N(62 \leq Z \leq 69)/N(75 \leq Z \leq 83)$ = S60, only change from 1.48, 0.26 and 0.67 to 1.34, 0.28 and 0.69 respectively. These differences are much less than those calculated for different assumed source spectra and hence do not affect our interpretation of the observed abundances in this charge region (Fixsen et al., paper OG1-22).

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