PROPAGATION OF THE HEAVIEST UH - COSMIC RAY NUCLEI

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ABSTRACT

Our previous studies showed that the fragmentation cross sections of gold nuclei interacting in hydrogen have large variations between the values measured at 0.9 and 10.6 GeV/n, which has very significant implications on calculations of the propagation of the heaviest UH cosmic ray nuclei, such as Pb and Pt We have now completed a series of runs at the Brookhaven AGS using beams of gold nuclei of intermediate energy. The data from these runs will allow us to establish the excitation functions for these cross sections in a wide range of targets and hence model propagation more accurately than hitherto. In addition we will be able to study the energy dependence of nuclear charge pickup, electromagnetic dissociation and fission. Beams of gold nuclei with seven energies between 4.0 and 0.9 GeV/n were studied interacting in targets ranging in mass from hydrogen to lead. We will present data on the cross sections derived from several of these beams and discuss some of the implications.

INTRODUCTION

With the possibility that new and more precise observations of the abundances of the UH nuclei will become available in the near future, Westphal et al. (1997), O'Sullivan et al. (1995), it is important to examine the validity of current programs used to deduce the souce abundances from those observed. In earlier exposures to gold nuclei accelerated at the LBL Bevalac and the Brookhaven AGS we measured the fragmentation cross sections, σ, in various targets at energies of 0.56, 0.92 and 10.6 GeV/n, Cummings et al. (1990), Geer et al. (1995). These results showed that the σ's in hydrogen varied rapidly with energy and suggested that calculations of the source abundances of the heaviest UH cosmic ray nuclei, those with $Z \geq 70$, had to take account of these variations when considering propagation through the interstellar medium, Waddington (1996). The large variations in σ between 0.92 and 10.6 GeV/n, the energy range in which most of the observed UH nuclei lie, meant that any propagation calculations were subject to serious uncertainties. In the treatment by Waddington (1996) it was assumed that limiting fragmentation, E_{limit}, was reached at 5.0 GeV/n and that the σ's could be linearly interpolated between 0.92 and 5.0 GeV/n. The first assumption, which was based on an analysis by Silberberg and Tsao (1990), appears to have been essentially correct, the second was far too simplistic.

In January 1996 we made a series of runs at the AGS to a beam of gold nuclei with an initial energy of 4.0 GeV/n. By using internal and external energy degraders, cross sections were measured at seven different energies between 4.0 and 0.92 GeV/n in targets that ranged between hydrogen and lead. These results will allow us to establish the excitation functions for the σ's of fragments with charge changes from the gold nuclei of between +1 and ≈ -25. In this paper we will report the results from three of these runs.

MEASUREMENTS.

The detector array was very similar to that used during the earlier AGS run, Geer et al. (1995). and is shown schematically in Fig. 1. Incident nuclei pass through a series of parallel plate ion chambers, I -0 to -4 and Cherenkov detectors, C-0 to -1, which measure the charge before and after passage through one of six different targets (CH_2, C, Al, Cu, Sn and Pb). The hydrogen σ's are then calculated from the CH_2 and C results. An example of the charge resolution obtained is shown in Fig. 2. Energies were reduced between 4.0 and 2.0 GeV/n with a local lead degrader placed directly in front of the array, and between 2.0 and 0.92 GeV/n by adding a external copper degrader placed upstream so that the majority of the fragments produced in it were removed by the intervening bending magnets. This upstream degrader reduced the energies of the surviving gold nuclei to 2.0 GeV/n, which could then be further reduced in energy by the local degrader. Surviving gold nuclei were then identified by the two front ion chambers before reaching the targets. The analysis of the measurements in order to obtain the absolute values of the σ's was essentially similar to that used previously by Cummings et al. (1990) and Geer et al. (1995). As of early May 1997, we have determined the σ's for three energies, 4.0 GeV/n, with no degrader, 2.4 GeV/n with a local degrader, and 2.0 GeV/n with an external, but no local, degrader. We still have to analyze results taken at 3.3 and 2.0 GeV/n with local degraders, and 1.6, 1.2 and 0.9 GeV/n with both external and local degraders.

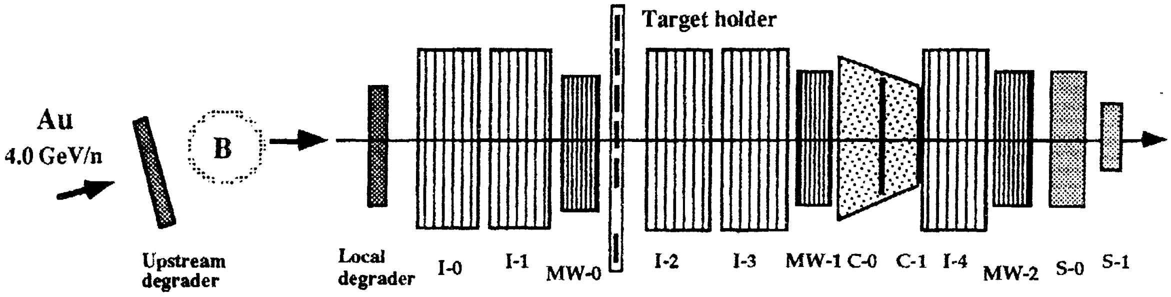

Fig. 1 Schematic of detector array exposed to 4.0 GeV/n gold nuclei (BNL Exp. 869)

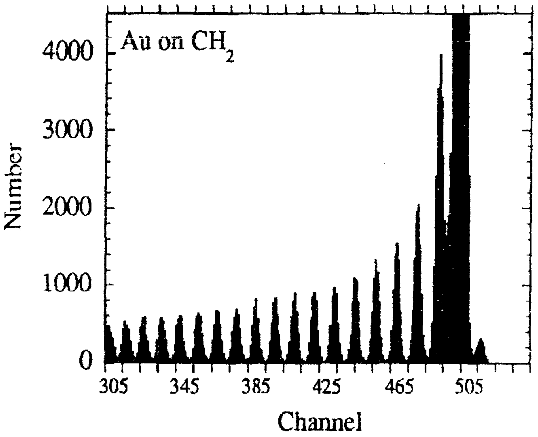

Fig. 2 Experimental charge resolution for 4.0 GeV/n Au on a CH_2 target.

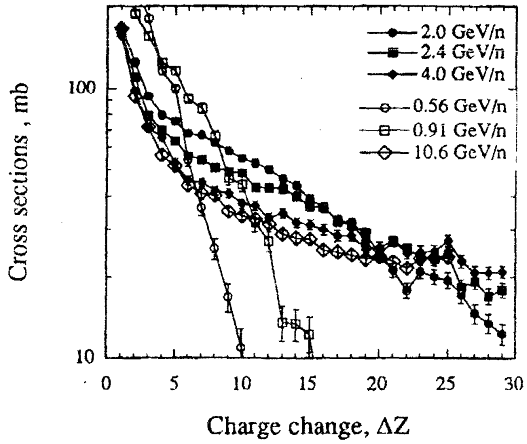

Fig. 3 Cross sections in hydrogen as a function of charge change at various energies

RESULTS.

The cross sections in hydrogen obtained at the three energies analyzed thus far are shown in Fig. 3 and compared with the earlier results. This figure shows variations in the σ's of the sort expected between 4.0 and 2.0 GeV/n, and that still larger variations can be expected between 2.0 and 0.91 GeV/n. The variations measured thus far are illustrated in Fig. 4, which shows some of the differences in the σ's between those at the highest energy of 10.6 GeV/n and those measured at the lower energies. It can be seen that although there is a finite difference between the σ's at 10.6 and 4.0 GeV/n, these differences are quite small, and it is reasonable to assume that E_{limit} is reached at ≈ 5.0 GeV/n, as previously assumed. It can also be seen that as the energy decreases the cross sections rapidly change from those at the highest energy, but that even at 2.0 GeV/n they are still very different from those at 0.92 GeV/n, which go off scale for extreme ΔZ's. The variations in σ as a function of energy are plotted in Fig.5 for several values of ΔZ and show a well defined trend. The excitation function is certainly not linear between 0.92 GeV/n and E_{limit}, but must vary most rapidly below 2.0 GeV/n. The differences between the σ's measured at 2.0 GeV/n and those predicted from a linear interpolation between 0.92 and E_{limit} = 5.0 GeV/n are considerable and will required modification of the propagation calculations made earlier, Waddington (1996).

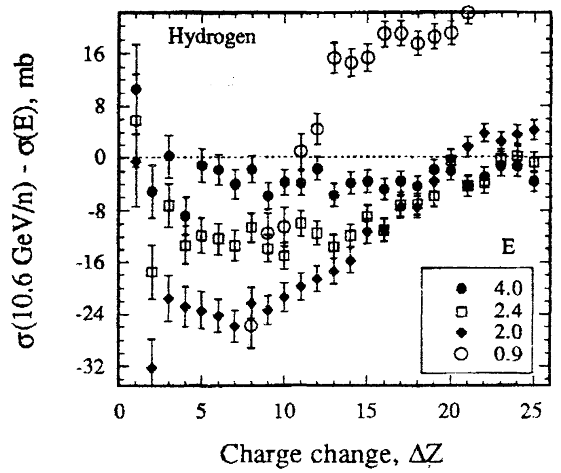

Fig. 4 Cross section differences in hydrogen

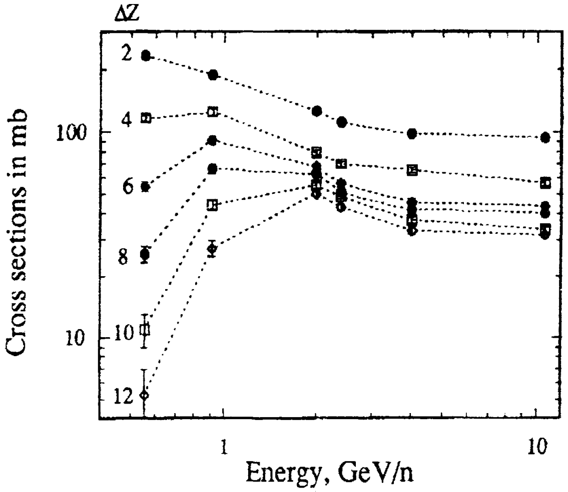

Fig. 5 Cross sections vs. energy for various ΔZ

The cross sections in heavier targets also show variations with energy, although not as strongly as those in hydrogen. It appears that E_{limit} is probably reached in these targets at a lower energy than in hydrogen. The cross sections for charge pickup, Nilsen et al. (1994), where the incident nucleus gains a charge, which are of interest from a nuclear physics point of view, since the phenomena is not well understood, are also energy dependent, at all energies and all charges, as shown in Fig. 6. However, it is unlikely that these σ's have much significance in cosmic ray propagation considerations, except, if these charge pickup nuclei are stable, possibly for determining the source abundances of some rare odd charge elements.

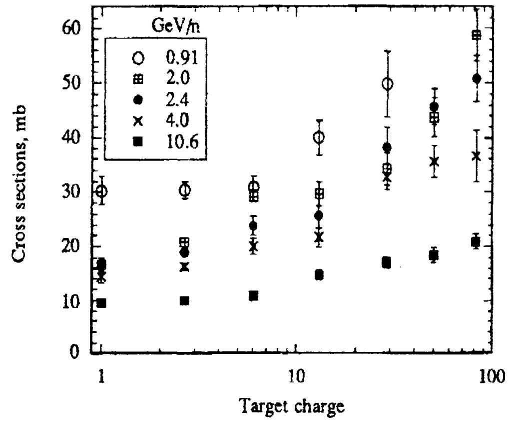

Fig. 6 Cross sections for charge pickup.

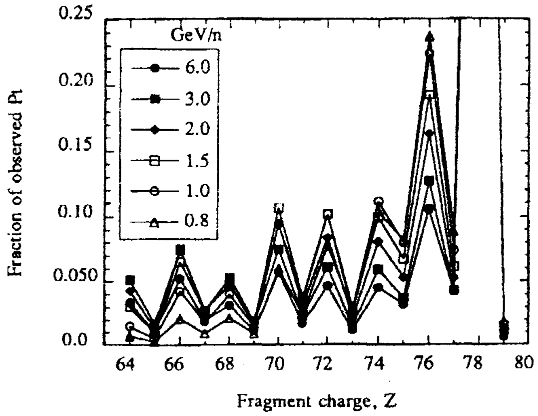

Fig. 7 Pt propagated using 5 σ sets at 6 initial energies

EFFECTS ON PROPAGATION

In order to properly calculate the effects on the source composition of propagation in the ISM, values are required for all the $\sigma(E,Z)$ used. Since most of these have not yet been measured it is necessary to predict those not measured from a model. Such models have been proposed by Silberberg and Tsao (1990) and by Cummings et al.(1990), modified by Nielsen et al.(1995). Still simpler is to just scale the values by the total cross sections from those measured. Such scaling can only be justified over a limited range of charges but does provide a first approximation that can be used to estimate the effects of propagation. As an example of the influence of the energy dependence of the gold nuclei σ's, consider the propagation of Platinum nuclei, $_{78}$Pt, originating from a source with various initial energies. Using a weighted slab leaky box model, Waddington (1996), and five separate sets of gold cross sections, with linear interpolation between each, we can examine the production of secondary nuclei. Fig. 6 shows the results of such an analysis for six different initial energies. It can be seen that the production of $_{76}$Os, for example, decreases by more than a factor of two as the initial energy increases. Since Os is an element that is generally treated as part of the "platinum group", such a large variation cannot be neglected. Clearly, any such analysis is extremely model dependent and the results must be treated with caution, Waddington (1997).

CONCLUSIONS.

Measurements of the cross sections for the production of fragments from incident gold nuclei show that below $\approx$ 5.0 GeV/n they change rapidly with energy. In order to deduce source abundances from the observed abundances of cosmic ray UH nuclei these variations must be taken into account, unless the observations are made at appreciably higher energies than is usual. These gold cross sections can be used to improve current models that attempt to predict those cross sections that have not been measured, but such predictive models have never yet succeeded in matching the results from new experimental measurements with the degree of accuracy that will be needed when more precise abundance determinations become available. There still is a requirement to make more measurements of cross sections using different heavy projectiles such as lead or platinium.over a wide range of energies.

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