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Measurement of Charge-Changing Cross Sections of 200 *A* GeV S and Fragments with Cu Target

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The charge-changing cross sections of 200*A* GeV S and its fragments P, Si, Al, Mg, Na and Ne in collisions with Cu target are measured. It is shown that the cross sections of secondary fragments are larger than those of primary beams with the same charges. The electromagnetic spallation cross sections deduced show a dependence on the charge of projectile which is consistent with theoretical prediction.

1. INTRODUCTION

As shown in work [1] and [2], in nucleus-nucleus collisions at ultrarelativistic energy, 200*A* GeV at CERN SPS, the dependence of electromagnetic spallation cross section on the charge of target is consistent with that predicted theöretically [3]. It is noticed that the electromagnetic spallation cross section could be even higher than the nuclear cross section, as the energy and mass of collision particles goes very high and quite heavy, respectively. Thus in order to learn the nucleus-nucleus interactions at ultrarelativistic energy, it is important to measure both the total and the electromagnetic spallation cross sections.

It is easier and more efficient to measure the charge-changing cross section in nucleus-nucleus collision by using solid state nuclear track detectors. A preliminary result was reported by Price *et al*. [1,4]. The present work measured the cross sections for S-Cu interactions in more detail and with statistics one order of magnitude higher than that in Refs. [1] and [4]. In addition, we adopted four methods to calculate the values of cross sections in order to compare one another and gave a dependence of electromagnetic spallation cross section on projectile charge.

2. EXPERIMENT

We used track-recording sheets of CR-39 plastic ($H_{18}C_{12}O_7$) to measure the charges of impinging nuclei and their heavier fragments. The detector consist of 8 repeating segments, in which

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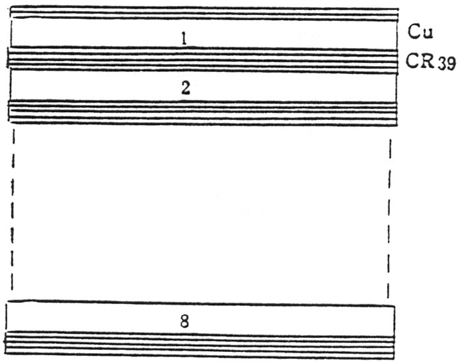

Fig. 1
Schematic diagram of the detector structure.

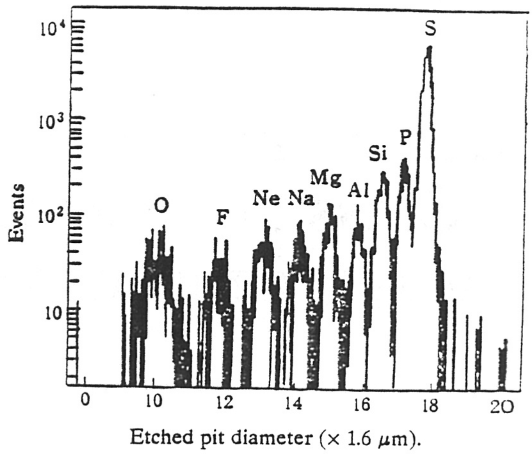

Fig. 2
Distribution of etched pit diameters on a surface of CR-39 sheet.

there was a plate of copper (as target, thickness 0.32 cm, about 10% of the *mfp* for S) and 5 sheets of CR-39 (as charge detector, 740-micron thick) (see Fig. 1). Two sheets of CR-39 placed in front of the detector were used to select tracks of beam particles. The sheets of CR-39 in back of every copper plate were used to measure the charges of particles that pass through that plate.

The detector was exposed to 200A GeV ^{32}S beam perpendicularly at CERN SPS in July of 1987 with ion density of about 1000/cm^2. The total number of impinging particles were approximately 15000.

The CR-39 sheets exposed were etched in 6.25 normal sodium hydroxide solution at 70°C for 40 hours to produce measurable conical etch pits under microscope for nuclei with charges larger than 8.

All pits on both surfaces of the first, third and fifth sheet in the first to the seventh segment and the first sheet in the eighth segment were measured by an automatic microscope imaging system VICOM [5]. A computer recorded diameters of all pits (with accuracy of 0.1 micron) and determined positions of their central points. At 200A GeV, the velocity of each fragment approached that of impinging particle, nearly the light velocity, so the charge of each particle could be determined simply from the pit diameter. Fig. 2 shows a distribution of pit diameters on the top surface of the first sheet of CR-39 behind the fourth copper plate. The peaks correspond to charges of different fragments. The charge resolution reached was found to be 0.23 charge unit.

According to the position of a pit on the surface of a CR-39 sheet, the track of a particle was traced by a computer program to find its position and charge in the subsequent sheet of CR-39 or subsequent segment, until the particle was emitted from of the detector or interacted into fragment with charge less than 8. In this way, nearly 100% reconstruction efficiency was achieved, so that the positions in the detector where impinging particles or fragments changed their charges and the charge of every fragment could be determined. Several reconstructed events showing how the charge of particle changed with depth in the detector are given in Fig. 3.

3. CALCULATION METHOD

The following four methods were adopted to calculated the charge-changing cross section.

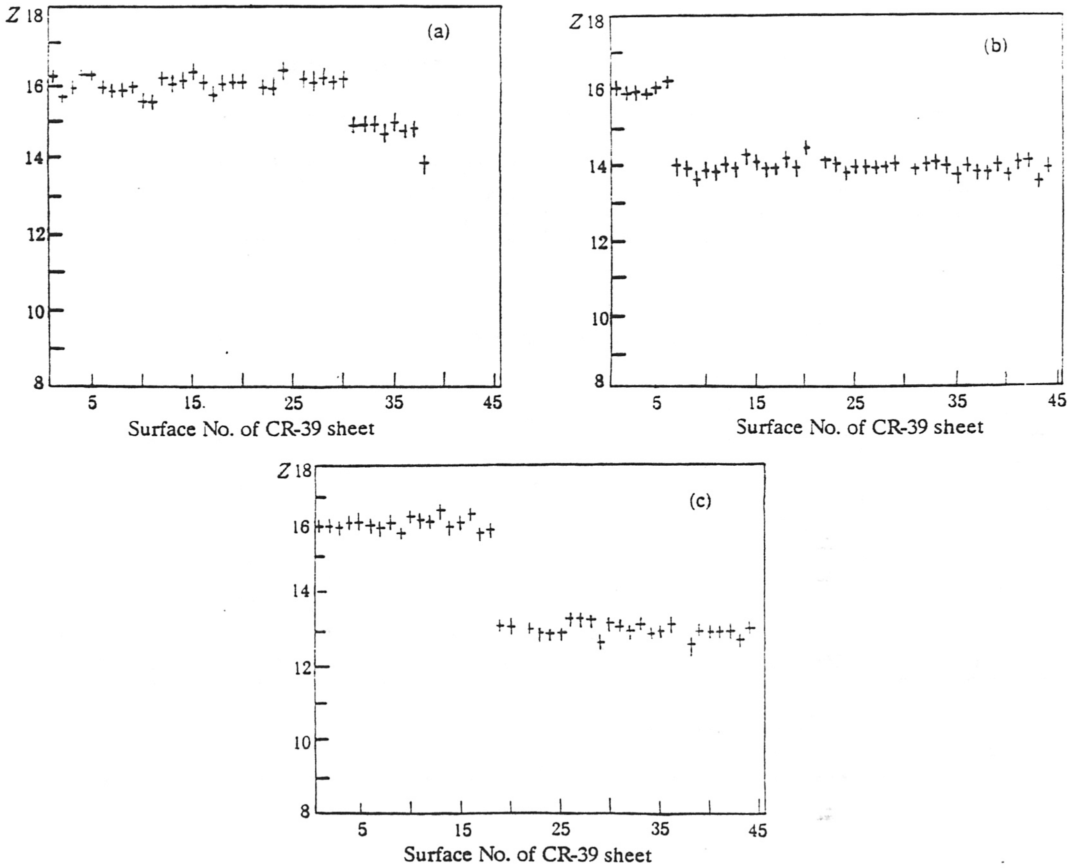

Fig. 3
Example of several events.

1) Treat the detector as a whole. According to the exponential attenuation of particles passing through material, the number of surviving particles at depth L (g/cm^2) is

$$N = N_0 \exp(-N_A \sigma L / A),$$

where N_0 is the number of impinging, σ is cross section (cm^2), N_A is Avogadro's number and A is atomic number of target material. From this equation, σ is evaluated:

$$\sigma = \frac{A}{N_A L} \ln (N_0/N). \tag{1}$$

2) According to the dependence of numbers of surviving N_i ($i = 1, 2, \ldots, 8$) behind every target plate on the depths x_i (g/cm^2) of corresponding targets,

$$N_i = N_0 e^{-Bx_i} \qquad (i = 1, 2, \cdots, 8). \tag{2}$$

Constant B is obtained from least-squares fitting of N_i and x_i and the cross section is evaluated

Table 1
The numbers of surviving S at every target and of interacting S in every target.

No. of targets	1	2	3	4	5	6	7	8
Surviving numbers	11013	9699	8573	7619	6774	6027	5341	4828
Interacting numbers	1388	1314	1126	954	845	747	686	513

Table 2
The experiment data and cross sections for secondary fragments.

Fragment	P	Si	Al	Mg	Na	Ne
Number of fragments	1044	715	280	341	236	215
Number of interaction incidents	407	286	115	120	73	63
Sum of free paths (gcm^{-2})	11631.5	8377.8	3213.9	3904.3	2761.3	2524.2
σ_{tot} (mb)	3660 ± 184	3572 ± 214	3747 ± 353	3214 ± 297	2759 ± 328	2604 ± 334
σ_{NS}	2173	2104	2077	2008	1973	1894
σ_{ES}	1487 ± 184	1468 ± 214	1670 ± 353	1206 ± 297	786 ± 328	710 ± 334

from

$$\sigma = B \cdot A/N_A.$$

3) The maximum likelihood estimate of mfp is expressed by interacted numbers N'_i ($i = 1, 2, \ldots, 8$) in corresponding targets [6]:

$$\hat{\lambda} = H/\ln\left[1 + \sum_1^n N'_i \Big/ \left(nN + \sum_1^n (i-1)N'_i\right)\right]$$

where H is the thickness of a copper plate (in g/cm^2). Then the cross section is obtained:

$$\sigma = A/(N_A\hat{\lambda}). \tag{3}$$

4) The maximum likelihood estimate of mfp is expressed by the free paths l_i ($i = 1, 2, \ldots, N'$) of particles in the detector,

$$\hat{\lambda} = \left(\sum_1^{N'} l_i + NL\right) \Big/ N', \tag{4}$$

where N' is the total number of interacted particles in the detector. Then the cross section is obtained from Eq.(3) also.

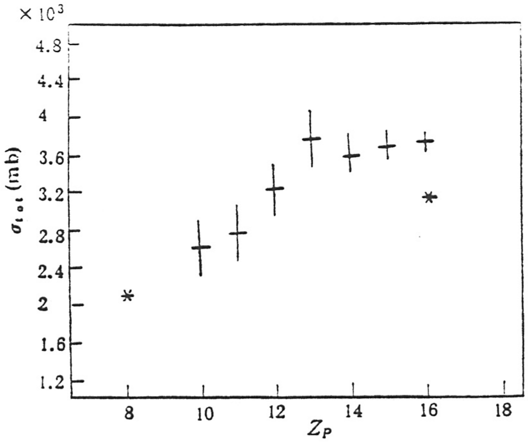

Fig. 4
The change-changing cross sections
of S and its fragments in Cu.

4. RESULTS AND DISCUSSIONS

In the present experiment, N_0 and N, the numbers of impinging S nuclei and of emerged S nuclei from the detector, are 12401 and 4828, respectively, and the total thickness of the detector L = 26.8448 g/cm^2. By using method 1), the charge-changing cross section of S with the detector, composed of Cu and CR-39, is obtained to be 3585 ± 64 mb. Subtracting contribution of CR-39 on the basis of data in Ref. [2], the charge-changing cross section with pure Cu is then obtained as 3675± 66 mb. For convenience we will give the values of cross sections with pure Cu below.

The number N_i of surviving S at depth x_i and N_i' of interacting S in every target are listed in Table 1. The dependence of N_i' on depth follows exponential attenuation relation quite well. The charge-changing cross section is calculated to be 3681 ± 58 mb and 3714 ± 44 mb by using methods 2) and 3), respectively.

The sum of free paths of interacting S (N' = 7573) is 83786.8 ± 72.2 g/cm^2 which gives rise to the charge-changing cross section 3713 ± 44 mb from method 4).

We can see that the values of charge-changing cross sections calculated by all four methods are very close to one another in present statistics. So one needs to pay attention to the calculation method only in small sample cases [6].

The above discussion is for the primary particle case, and the following is for secondary heavy fragments. Because fragments emit in different positions, the charge-changing cross section of fragments cannot be evaluated by the former 3 methods and only method 4) is used. Table 2 lists the numbers of fragments P, Si, Al, Mg, Na and Ne produced, interacted again in the detector, the sum of their free paths as well as the charge-changing cross sections of these fragments.

Fig. 4 shows the charge-changing cross sections for S and its heavier fragments with copper. In Fig. 4 two values without error bar come from Ref.[2] for primary beam ^{32}S and ^{16}O with a thin target. It is seen that the cross sections of S and secondary particles obtained from the present experiment are all higher than those of the primary beams with the same charges. The higher cross section for S in this case may be caused by the S particles traveled through thicker material than that in Ref.[2], hence produced some unstable isotopes which possess higher electromagnetic spallation cross section [7] than the primary beam. Price and He [8] observed

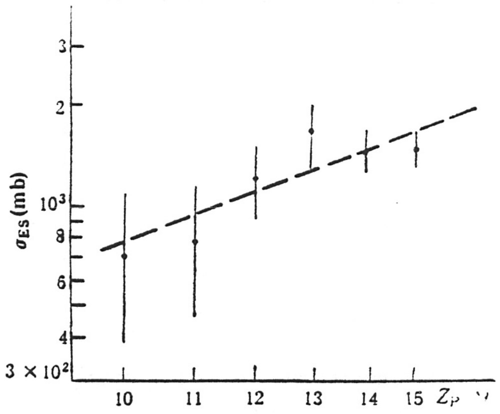

Fig. 5
Cross sections of heavy fragments for electromagnetic spallation σ_{ES} as function of projectile charge Z_p.

similar phenomenon in collisions of 14.5*A* GeV Si with Pb target. The secondary fragments produced in collision at high energy might also contain some unstable isotopes, and result in the enhancement of their cross sections. Of course, the possibility of the existence of some anomalous phenomena for secondary particles cannot be excluded. It needs to be studied further.

It is assumed that the charge-changing interaction observed experimentally can be induced by nuclear interaction or electromagnetic spallation, as the impact parameter is smaller or larger than the range of nuclear force, respectively [1,2,4]. Nuclear interaction cross section can be evaluated according to the semi-empirical expression

$$\sigma_{NS} = \pi r_0^2 (A_P^{1/3} + A_T^{1/3} - b)^2 \tag{5}$$

where A_P and A_T are atomic numbers of projectile and target, respectively, r_0 = 1.32 fm and b = 0.83. The results of the calculation are listed in Table 2.

The electromagnetic spallation cross section σ_{ES} is then obtained by subtracting σ_{NS} from σ and also listed in Table 2. The dependence of σ_{ES} on projectile charge $Z_P^{1.95\pm0.8}$ (see Fig. 5). We should note that work [1], [2] and [4] show a dependence of σ_{ES} on target charge, $Z_T^{1.8-2.0}$. Both are consistent with one predicted by the theory in which, electromagnetic field of a rapidly moving nucleus can be represented by a spectrum of virtual photons whose intensity is proportional to the square of nuclear charge.

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REFERENCES

[1] P. B. Price, Ren Guoxiao and W. T. Williams, *Phys. Rev. Lett.*, **61**(1988)2193.

[2] C. Brechtmann and W. Heinrich, *Z. Phys.*, **A330**(1988)407; **A331**(1988)463.

[3] J. D. Jackson, "Classical Electrodynamics", Wiley, New York, 1975.

[4] P. B. Price, He Yudong, Ren Guoxiao and W. T. Williams, 21th ICRC, OG8.3--11, 1990.

[5] G. Gerbier, Ren Guoxiao and P. B. Price, *Phys. Rev. Lett.*, **60**(1988)2258.

[6] Wu Mei and Ren Guoxiao, *High energy Phys. and Nucl.Phys.* (in Chinese), **11** (1987) 145.

[7] I. Tanihata, *Nucl. Phys.*, **A488** (1988) 113c.

[8] P. B. Price and Y. D. He, *Phys. Rev.*, **C43** (1991) 835.

[9] G. D. Westfall *et al.*, *Phys. Rev.*, **C19** (1979) 1309.