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Coulomb dissociation of incident heavy nuclei in nuclear emulsion at 4.5 A GeV/c

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Abstract. This work presents a special type of interactions produced in emulsion targets exposed to different incident beams of light ions at a few GeV per nucleon. The events characterized by multi-fragment break-up of the projectile nucleus, which are produced via peripheral collisions or due to the effect of Coulomb field of the target nucleus, have been selected. The size of the impact parameter must be considered for determining the type of interaction. The results are compared with other collected at energies up to 200 GeV/nucleon. The dependence of electromagnetic dissociation cross-section on the incident projectile energy is investigated.

1 Introduction

Recent successive experiments (Baroni. et al., 1990; Bertulani and Baur, 1988; Heckman et al., 1976; Hill et al., 1988; Olson et al., 1981; Yasin and. et al., 1997) in nuclear collision for different projectiles and energies with several types of targets led to the study of important effects according to the value of the impact parameter b which determine the type of the interaction. The collision between two nuclei is peripheral when $| R_p \ \ R_t | < b \leq R_p + R_t$, while the interactions are essentially electromagnetic for b larger than the sum of projectile and target radii , where R_b and R_t are the radii of projectile and target nucleus, respectively.

Due to the up-to-date interest, which is focused on the fragmentation of the projectile nucleus either by peripheral collision or by dissociation through the coulomb field of a target nucleus, we concentrate this study on these specific reaction channels, which are produced from the interactions of ^{6}Li, ^{7}Li, ^{12}C, ^{16}O *and* ^{28}Si at energies *(4.5, 3.7 A* GeV*)* with emulsion and their comparison with the corresponding channels at different energies.

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2 Experiment and results

2.1 Irradiation of the stack, scanning and selection of the events:

The present work has been carried out using standard emulsion stacks of BR-2 type; they are exposed to *4.5A* GeV ^{6}Li ions, *3.7A* GeV ^{7}Li ions, *4.5A* GeV ^{12}C ions, *and 4.5A* GeV ^{16}O ions and *4.5A* GeV ^{28}Si ions at Dubna synchrophasatron, Russia. The dimensions of the pellicles are 20 cm $\times$ 10cm $\times$ 600 .

Scanning was carried out by the along-the-track method. A total number of 2484, 970, 1000, 708 and 930 inelastic interactions were found along the total scanned length of 358.175 m, 144.0 m, 150.0 m, 86.32 m and 101.1 m for ^{6}Li,^{7}Li, ^{12}C, ^{16}O and ^{28}Si-*Em*, respectively. In each interaction, the multiplicities of shower tracks (n_s), the heavy tracks n_h (grey track n_g + black tracks n_b) is identified. The projectile fragments (pf_s) of charge $Z \geq 2$ were recorded. These (Pf_s) are identified by measuring the grain density and d-ray counting as given in (Barkas,1963). For this, a correct judgment is made by measuring a sample of priory identified fragments with $Z=2$ from $(^{6}Li \rightarrow a + H)$, $(^{12}C \rightarrow 3a)$, $(^{7}Li \rightarrow a + H)$, $(^{16}O \rightarrow 4a)$ and $(^{28}Si \rightarrow {}^{12}C + a)$. A systematic charge determination was only performed for fragments with $Z>2$ using a stack calibration curve which exhibits the proportionality between the number of d -rays (Nd) and the square of atomic number (Z^2) of the fragment (Yasin, 1995).

Since our main object is to study the projectile multi-fragments either by more peripheral collision or by Coulomb dissociation, it is important to differentiate between their characteristics and try to distinguish each of them separately from the experimental observations. The expected spectral characteristics of ED event are generally classified as in (Baroni . et al ,1990) .

Table 1 Topologies of ^{6}Li, ^{7}Li, ^{12}C, ^{16}O and ^{28}Si-Em at Dubna energies compared with ^{16}O, ^{28}Si and ^{32}S-Em at higher energies .
a (Douglas Giancoli ,1991), b (Fuller ,1985) .

Projectile and energy (A GeV)	^{6}Li (4.5)	^{7}Li (3.0)	^{12}C (4.5)	^{16}O (4.5)	^{28}Si (4.5)	^{16}O (60)	^{16}O (200)	^{28}Si (14.6)	^{32}S (200)
Total inelastic interactions	2484	970	1000	708	930	528	920	1510	1354
N_h=0 events Fraction %	431 17.35	136 14.02 ± 1.2	98 9.8 ± 1.0	98 13.98 ± 1.4	95 10.22 ± 0.1	_	112 12 ± 1.13	_	_
ED events Fraction %	406 16.34	45 4.64 ± 0.7	60 6 ± 0.77	81 11.43 ± 1.27	85 9.13 ± 0.11	31 5.87 ± 1.0	92 10 ± 1.0	136 9.0 ± 0.77	197 14.55 ± 1
Pure ED events Fraction %	152 6.1	_	21 2.1 ± 0.45	45 6.35 ± 0.94	48 5.16 ± 0.14	_	_	_	_
DD events Fraction %	254 10.2	_	39 3.9 ± 0.6	36 5.08 ± 0.85	37 3.97 ± 0.16	_	_	_	_
Nuc.rad[a](fm) B.E[b].(MeV) B.E./N	2.55 32.09 5.35	2.42 39.25 5.61	2.46 92 7.7	2.73 128 8	4.25 235.3 8.4	2.73 128 8	2.73 128 8	4.25 235.3 8.4	4.44 273.5 8.53
Duration time through Ag target (sec)	$0.66 * 10^{-18}$	$0.93 * 10^{-18}$	$0.66 * 10^{-18}$	$0.68 * 10^{-18}$	$1.1 * 10^{-23}$	$0.5 * 10^{-19}$	$0.14 * 10^{-21}$	_	_
References	Present work	Present work	Present work	Present work	Present work	Singupta 1988	Broni 1990	Sing 1991	Singupta 1990

Table1 gives the number of all the analyzed inelastic collisions for each beam. The $N_h=0$ events include diffraction dissociation events occurring on the nuclear target surface as will as Coulomb dissociation events. An event-by-event analysis was carried out to select ED events from all $(n_h=0)$ events. The ED events can further be divided into two groups, one of them due to the Coulomb field effect and the other due to the diffraction on target surface. These could be separated experimentally by dividing the restricted angle of the emitted fragment $(q_{p.f.} \leq 3^{\circ})$ into two ranges.

This description has been born out by the observations. Counting the number of ED events, which are not associated with pions, has performed this. The fragments emitted in the narrower angular range $q_{p.f.}$ $(0 - 1.0^{\circ})$ are classified as due to the effect of Coulomb field whereas those in the relative wider angles (up to 3.0°) result from the effect of diffraction on the outer surface of the target nucleus. It is clear that these ED events increase with the energy and charge of the incident beam, except for incident ^{7}Li. This exception may arise because the binding energy of the ^{7}Li nucleus is smaller than that of the other nuclei. The different in the ED event ratios for ^{6}Li and ^{7}Li at nearly the same total energy is due to the difference in the binding energy per nucleon. The ^{7}Li nucleus, which contains seven nucleons, is smaller and has higher binding energy per nucleon than the ^{6}Li nucleus. Therefore, ^{6}Li dissociates more readily than ^{7}Li in the case of interaction with the same target and at the same energy per nucleon. For this reason, the larger value of the ED events ratio for ^{6}Li than that for the ^{16}O nucleus at the same energy per nucleon could be anticipated. This is clear from the data given in Table1.

2.2 Inelastic and ED mean free paths (l_{in} , l_{ED}) and their corresponding cross-sections (s_{in} , s_{ED}):

The values for the mean free path and cross-section for the total inelastic and ED interactions of the present work are listed in Table2. The results extracted from (Sengupta. et al., 1988; Sing and Jain, 1991; EL-Nadi. et al., 1993; Sengupta. et al., 1990; Buhk. et al., 1991) are also incorporated. From this table, we can say that ED events as a percentage of the total inelastic events increase with the projectile energy. Meanwhile, the measured value of l_{ED} decrease as the incident projectile energy and charge increase. The total inelastic cross-sections s_{in} are estimated from the relation $s_{in} = (n_{eff}\ l_{in})^{1}$, where n_{eff}

in our type of emulsion, is the effective concentration of the emulsion nuclei = 3.78 * 10^{22} atoms/cm^2, whereas l_{in} is taken as the mean free path for each beam. In order to obtain an absolute value of the electromagnetic dissociation cross-sections, the measured value of l_{in} in the emulsion must be converted into an absolute cross-section on the *Ag* target component, which is the heaviest and most abundant element in the emulsion. The estimated s_{ED} for ED events on the *Ag* target is then calculated from the relation $s = f/\partial\ l$, where ∂ is the concentration of *Ag* nuclei in the emulsion = 1.028*10^{22} atoms/cm^2 and f is the weight factor = 0.67 for this target component reaching unity for the emulsion as a whole.

On the other hand, the value of Lorentz factor g and the maximum photon energy $E^{max}\ g\ (hcg\ /b_{min})$ for the *Ag* target nucleus at Dubna energies and at higher energies are calculated as indicated in Table1, considering $b_{min} = R_p + R_t$. This is briefly discussed in Sect1. it is found that at lower energies(3,0 and 4.5 *A* GeV), the g value are(3.3 and 4.8) and the corresponding $E^{max}g$ values range from 72 to 100 MeV for Lithium, Carbon, Oxygen and Silicon projectiles, whereas these values increase at ultra relativistic energies approaching (g =215) and $E^{max}g$ = *4.64* and 3.91 GeV for Oxygen and Sulfur beams at 200 A GeV, respectively. It could be concluded that at lower incident energies (3.0-4.5 *A* GeV) the maximum photon energy of the *Ag* target is less than the threshold of pionization, while for incident ^{28}Si (14.5A GeV) it will be enough to produce pions having a mass of about 140 MeV, whereas in case of the incident ^{16}O (60 *A* GeV) it is equal to or slightly larger than the threshold of Δ - (1232 MeV). However, at incident 200 *A* GeV ^{16}O and ^{32}S projectiles, it could produce Δ - consequently dissociated into protons and pions. The present results for ^{6}Li, ^{7}Li, ^{12}C, ^{16}O and ^{28}Si at (4.5, 3.7A GeV) ensure that there is no pion associated with the pure ED events.

The topologies of lithium, carbon, oxygen, silicon and interactions of the present work at Dubna energies are tabulated in Table2. For comparison, the corresponding values for oxygen, silicon and sulfur interactions at high energies extracted from (Baroni. *et al., 1990;* Sengupta. *et al.*, 1988; Sing and Jain, 1991; Sengupta et al., 1990) are also included. As shown in Table2, the percentage of ED events increases with both energy and charge of incident beam.

Table2 The nuclear mean free paths and inelastic cross-sections compared with the corresponding ED mean free path and s_{ED} for different projectiles at various energies

Type of projectile and energy	l_{int}(cm)	l_{ED}(cm)	s_{int}(mb)	s_{ED}(mb)	Ref.
^{6}Li (4.5A GeV)	14.42 ± 0.21	88.2 ±	1835	300	Present
^{7}Li(3.0A GeV)	15.2 ± 0.5	351.3 ± 49.6	1740.5 ± 20.0	75.3	Present
^{12}C(4.5A GeV)	14.4 ± 0.33	236.0 ± 28.2	1837.2 ± 20.0	114.3 ± o.5	Present
^{16}O(4.5A GeV)	12.18 ± 0.33	106.45 ± 10.68	2172 ± 140.0	248.52 ± 0.9	*Present*
^{28}Si(4.5A GeV)	10.87 ± 0.033	110.25 ± 0.11	2433.7	240	*Present*
^{16}O(200A GeV)	12 ± 0.2	96.0 ± 5.0	2204 ± 50	275 ± 11.3	*Baroni(1990)*
^{32}S(200A GeV)	9.2 ± 0.20	42 ± 2.0	2875 ± 70	692.76 ± 21.9	*Baroni(1990)*

3 Conclusions

The results confirm the dependence of the electromagnetic dissociation cross section on both incident charge and energy. The measured ED cross section has the same trend as the calculated one based on the Weizsacker-Williams method, and it increase with increasing of the projectile charge and energy.

Calculation by the WW method with data from counter experiments can be used to examine the decay channels for projectile dissociation by the excitation of the projectile nucleus.

Despite the heterogeneity of the emulsion target, it can be used to measure the ED cross section. The larger yield of ^{6}Li projectile dissociation than that for incident ^{7}Li may be due to the smaller binding energy per nucleon of the ^{6}Li nucleus.

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