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Dissociation of ^{6,7}Li nuclei in nuclear photographic emulsion

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Abstract. Diffraction dissociation process of ^{6}Li at incident momentum 4.5 AGeV/c and ^{7}Li at incident momentum 3 AGeV/c, provided by the JINR Synchrophastron, were studied using the photographic emulsion technique. The two stable isotopes of ^{6}Li and ^{7}Li were treated as two weakly-bound systems composed of (^{4}He+d) and (^{4}He+t) cluster configurations, respectively. Along the track double scanning method was carried out in order to search for ^{6,7}Li interactions in emulsion(Em). For ^{6}Li-Em and ^{7}Li-Em about 1050 and 1015 events were recorded with mean free path 14.5±0.5 cm and 15.1±0.6 cm respectively. The measured angular distributions of the outgoing fragments were compared with that calculated theoretically and good agreement between the experimental and theoretical values is obtained. This agreement supported the presence of ^{6,7}Li nuclei in a cluster mode at high energy reactions.

1. Introduction

An extensive amount of experimental data on high energy nucleus-nucleus collisions has already accumulated since the last few decades. These data provide us with tremendous amount of information and motivated a large number of physists to cover a wide range of aspects in nuclear physics. Some of these aspects are concerned with the study of reaction mechanisms and multi-particle production. The study of central collisions usually concerns the occurrence of new phase transitions such as Quark-gluon plasma [see for example 1-4] and searching for new particles.

One of the most important class of projectile fragmentation processes is the fragmentation of loosely-bound cluster-type projectile nuclei, such as ^{6}Li and ^{7}Li. The structure of ^{6}Li and ^{7}Li nuclei at low energies both in theoretical treatments and in many experiments show a pronounced two-cluster configuration [5]. Here ^{6}Li and ^{7}Li projectile nuclei are treated as two weakly-bound systems composed of (^{4}He+d) and (^{4}He+t) cluster configurations, respectively. In these nuclei an easily formed α-cluster core leaves the other nucleons, less tightly connected with the core, free to form the other charged cluster with relatively high probability [6].

The projectile fragmentation processes of these nuclei is Dissociation processes (elastic breakup) [7-10] in which the projectile is elastically dissociates into its constituent clusters in the field of the target nucleus leaving the target in its ground state. In this process two mechanisms usually compete; the nuclear dissociation (diffractive dissociation) and the Coulomb dissociation (electromagnetic dissociation).

2. Experimental Work

Two beams were used to irradiate emulsion stacks ,the first is ^{6}Li nuclei with momentum 4.5 AGeV/c and the second is ^{7}Li nuclei with momentum 3 AGeV/c provided by the JINR Synchrophasotron. The emulsion layer were 550 µm thick and of dimensions 10x20 cm^2. The stacks were exposed in the beam parallel to the emulsion plane, so that the particles traversed the layers along its longer side. Along the track double scanning method was carried out in order to search for ^{6,7}Li interactions in emulsion.

For ^{6}Li- Em, about 1050 events were recorded with mean free path λ_{6Li} = 14.5 ± 0.5 cm while about 1015 events were detected for ^{7}Li-Em with mean free path λ_{7Li} = 15.1 ± 0.6 cm. These results are in good agreement with the results of [11,12].

Out of these 1050 ^{6}Li- Em reactions, 779 elastic and inelastic projectile fragmentation reactions were found. While in ^{7}Li-Em we collected 529 events having projectile fragments. All these events are accompanied by one or two non-interacting projectile fragments emitted with space angle $\theta \leq 3°$ with respect to the direction of incidence. These non-interacting fragments were identified in accordance with emulsion terminology.

As a matter of fact, using emulsion technique, the separation between the different types of projectile fragmentation processes is easily carried. Dissociation reactions: According to dissociation mechanism, we have two fragments in the forward direction (with $\theta \leq 3°$); one singly and one doubly charged clusters without detecting any target fragmentations, i.e., such events are all white stars.

3. Theoretical Analysis

3.1. Dissociation process

In a projectile dissociation process, the projectile dissociates into its constituents by the Coulomb and/or nuclear field of the target nucleus. If the target is left in its ground state, the process will be called elastic break-up. The basic assumption of these kind of reactions is that the nuclei no overlap occurs between the projectile and target during their interaction, i.e., $b > R_p + R_T$. The break up processes of the projectile (^{6}Li or ^{7}Li) in the Coulomb or nuclear fields are a great importance and interest for the study of the nuclear structures of these nuclei ,since they can give precious information about these structures.

3.2. Coulomb dissociation

The passage of a projectile of mass number A_p, charge Z_pe, velocity v and impact parameter b (larger than the nuclear interaction radius) by a target nucleus (mass number A_T and charge Z_Te), initially at rest, will predominantly cause a momentum change for charged constituents of the projectile nucleus. This momentum change Δp is larger in the perpendicular direction to the projectile motion [13].

3.3. Nuclear dissociation

When a loosely bound projectile consisting of two clusters passes near enough to a target nucleus so that it is affected by the nuclear field of this target, there is a large probability that the projectile nucleus will dissociate diffractively into its two clusters. Diffractive phenomena occur if the wavelength associated with the relative motion of colliding particles is small compared to the characteristic dimension of the interaction region. Hence the criteria for the diffraction are readily satisfied at high energies. Interactions between nuclei and composite particles are accompanied by various diffraction processes.

3.4. Angular Distribution Of The Outgoing Fragments

For simplicity but without loss of generality, we shall take the wave functions of the cluster relative motion before and after collision from [10]. we obtain the energy distribution of the second fragment in the solid angle $d\Omega_2$ (because the diffraction dissociation amplitude is calculated in the impulse approximation [10]) as:

$$\frac{d^2\sigma}{d\Omega_2 dE_2} = \frac{(kR)^2\beta_2^2}{2\gamma^2\sqrt{\pi L E_2}}\exp\left(\frac{\left(\sqrt{E_2}-\sqrt{\beta_2 E}\right)}{L} - \frac{x_2^2}{p^2}\right) x\int_0^\infty dx x g^2(x)\sum_{i=1}^{6} H_i(x,x_2) \quad (1)$$

where:

$$g(q) = R\,\frac{J_1(qR)}{q}$$

x = qR, $x_2 = q_2R$, p = $\sqrt{2}\xi$ R, L = $\hbar^2\xi^2/m_2$, E is the incident particle energy, and the functions $H_i(x, x_2)$ are in [10].

4. Results and discussions:

In the following we present the results of measurements for the projectile fragmentation of ^{6}Li and ^{7}Li nuclei in Em. A comparison between the measured and theoretical angular distributions for the fragments produced in dissociation projectile fragmentation reactions are displayed. It also contains a comparison between the experimental and theoretical calculations of dissociation.

Comparing the values of the mean free paths with corresponding values of projectiles with mass number ranging from proton up to silicon shows out that the values obtained here deviate slightly from the well-established parameterizations [14] obeyed by these projectiles. However, they agree well with the results printed in [11,12].

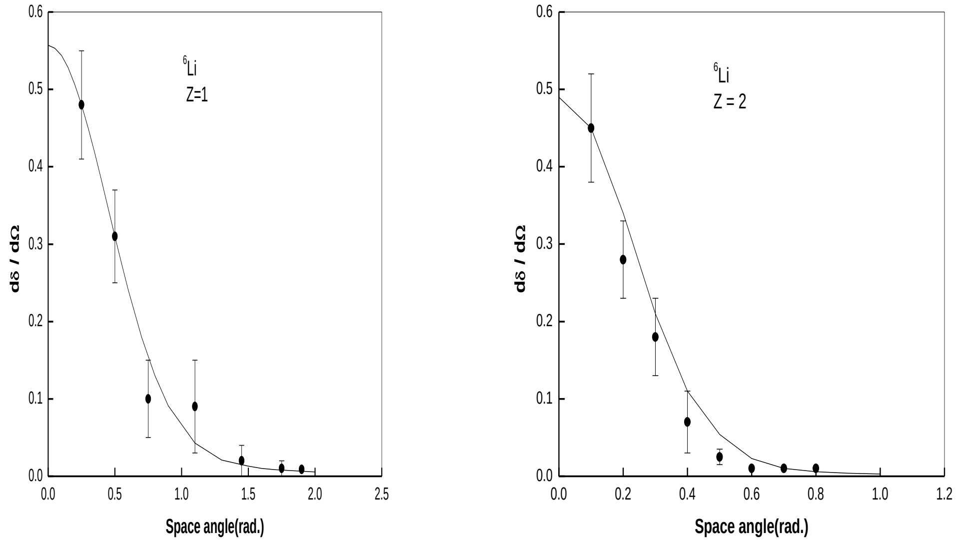

Figure 1. Angular distribution of fragments produced from dissociation reactions of ^{6}Li-Em. Solid lines are the calculations according to eq.(1).

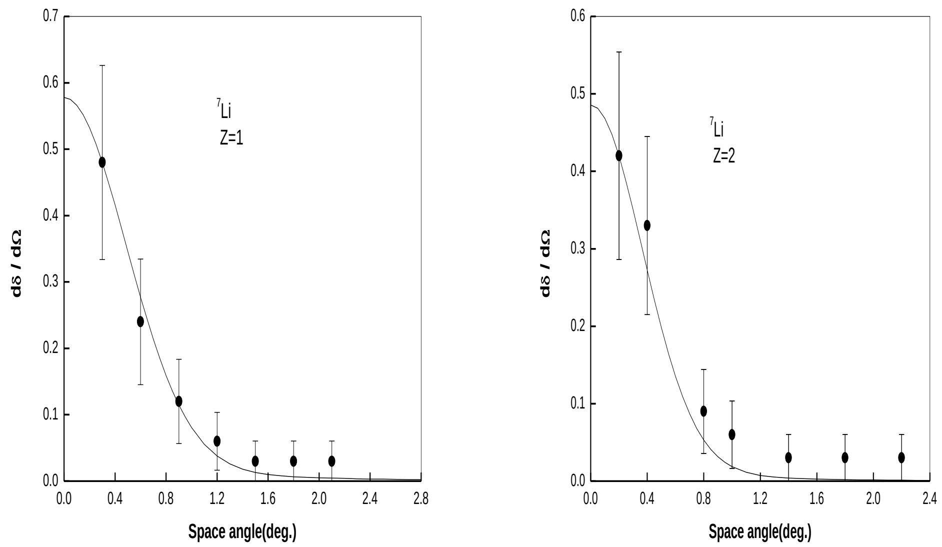

Figure 2. Angular distribution of fragments produced from dissociation reactions of ^{7}Li-Em. Solid lines are the calculations according to eq.(1).

Good agreement is clearly observed between the experimental results and calculations. In conclusion it is shown that the characteristics of the dissociation reactions depend primarily on the fact that ^{6,7}Li nuclei are very loosely bound systems consisting of two clusters with low binding energy, and that the two clusters actually spending most of their time outside the range of their mutual forces.

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