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More about structure and fragmentation of ^{6}Li and ^{7}Li nuclei at 3-4.5 A GeV/c

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Abstract The results of investigations of inelastic interactions of ^{6}Li and ^{7}Li nuclei with photo-emulsion at 4.5 and 3.7 A GeV/c respectively are studied. The momenta and yields of hydrogen and helium isotopes and the fragmentation channels of incident projectile nuclei are obtained.

The exotic nuclei ^{6}He produced from pion exchange of ^{6}Li reaction and from fragmentation of ^{7}Li nuclei are estimated. The study showed that ^{6}Li has large fragmentation ratio (81.1%) and its structure as weakly bound system consists mainly of ^{4}He, while ^{7}Li nuclei has fragmentation ratio (28.45%) and it consists mainly of ^{3}He.

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1 Introduction:

Much analysis of the nucleus-nucleus interactions at intermediate and high energies has been carried out quite actively in recent years (Adamovich. et al., 1999, Heckman et al. 1978 and Davis et al 1991).

However comparatively few analysis have been made using projectile isotopes. With the availability of mono-energetic beams of isotopic nuclei at the JINR (Dubna) provides the opportunity to open a new branch of research.

In previous analysis (El-Nadi et al., 1999), a systematic comparison using shower particle distributions of ^{6}Li and ^{7}Li ions lead to the assumption that ^{6}Li can be considered as a cluster of (α + d), but ^{7}Li structure may not be (α + t)

This work is a continuation of the previous one using the two isotopes ^{6}Li and ^{7}Li at 4.5 and 3.7AGeV/c respectively.

We report on results obtained using momentum spectra of relativistic singly and doubly charged fragments resulting from the interactions of both of the two isotopes in nuclear emulsion.

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2 Experimental method :

A photo-emulsion chamber consists of 600 μm and thick (10 x 20) cm^2 pellicles of BR-2 emulsion was irradiated by beams of ^{6}Li and ^{7}Li at momenta of 4.5 A GeV/c and 3.7 A GeV/c respectively at the synchrophasatron of JINR (Dubna).

The events were searched by - along the track- scanning technique using Leitz Laborlux-S microscope.

For ^{6}Li and ^{7}Li we scanned (353.867) meters and (248.63) Meters respectively and found (2454) events and (1647) events of ^{6}Li and ^{7}Li respectively. The experimental mean free paths were (14.42 $\pm$ 0.29 cm) and (15.096 $\pm$ 0.37 cm) respectively.

For ^{7}Li we have chosen a random sample of (1011) inelastic events without any selection rules or discrimination criteria among which there were (347) events with projectile fragmentation (i.e. they have a total charge of - projectile fragments in the forward hemisphere Q>0) and we found (264) events among them measurable and excluded (83) events which were not measurable because of emulsion defects or because overlap of primary or secondary tracks with the marking grid of the emulsion sheet.

For ^{6}Li: a random sample of (1390) events of inelastic interactions was selected, within this sample: (1040) events were found to have projectile fragments. Among these (1040) events, there were (947) measurable events while the remaining (93) events were not measurable were excluded for the same reasons mentioned above.

Singly charged fragments of projectile nucleus (Z=1) were visually separated and identified according to their number of grains per 100 μm (25-30 grains per 100 μm) and the doubly charged fragments (Z=2) were identified from the number of δ-rays normalized to that of the primary track.

We measured the quantity (p β c) for all the projectile fragments of (264) events of ^{7}Li with an error (Δ p β c), where b = v/c.

The determination of (p b c) and its error is made through the measurement of multiple Coulomb scattering of the fragments by the Coulomb fields of the emulsion nuclei along the fragments paths the deviations of their paths were measured by the co-ordinate method (Solntseff 1957) using KSM1 Zeiss Jena microscope, and the calculations of (p b c) was made by the r -method (which takes into account the second and the third differences of the Y-coordinates of the track to exclude the effect of spurious scattering (Solntseff 1957).

We followed the tracks to the maximum possible length and followed some of them from plate to plate to increase the measured length (i.e. increase the number of unit cells)

Also we found that a unit cell length of 500 m m gives the best precision of our measurements.

Increasing the length (number of unit cells) to improve the measurement precision has a limitation because of spurious scattering and emulsion distortions effects.

Events were classified into two main classes:

(1) Central events: which have not projectile fragments (i.e. the total fragments charge Q = 0).

(2) Peripheral and Coulomb dissociation events: which have projectile fragments (i.e. the total charge of projectile fragments Q>0)

We identified all the projectile fragments in the interactions of (Q>0) by using the double ionization-momentum technique for ^{7}Li interactions and also the charge identification of ^{6}Li projectile fragments were made.

The particles emitted from target nuclei are usually classified in emulsion experiments into 3 categories:

(i) Shower particles (s-particles N_S): singly charged particle with velocity (b = v/c) ≥ 0.71.

(ii) Grey particles (g-particles N_g): Singly charged particles with velocity range of $0.23 \leq b < 0.71$ and ionization $(6\ I_o) \geq I > (1.4\ I_o)$ where I_o is the minimum ionization of singly charged particle fragments emitted in the narrow forward cone.

(iii) Black particles (b-particles N_b) : charged particle with $b < 0.23$ and $I > (6\ I_o)$.

Grey and black particles are together classified as heavy particles, (N_h) where: $N_h = N_g + N_b$.

3 Results

The fragmentation channels of the ^{6}Li (Adamovich et al., private communication) and ^{7}Li (present work) are shown in Table (1) and we can see clearly that:

For the channels of Q=1 and $Z_{max.}$ =1 (i.e. channels of p, d and t), where $Z_{max.}$ is the maximum possible charge on a given projectile fragment (i.e. channels of p, d and t). In these channels, the percentages of p, d and t are 53%, 41% and 6% respectively for ^{7}Li, and were 41%, 44% and 15 % respectively for ^{6}Li. In these channels there is only one singly charged particle (p, d or t) emitted as a projectile fragment in the narrow forward cone and the remaining 2 singly charged particles interacted with target nucleus of emulsion.

Table 1: fragmentation channels of ^{6}Liand ^{7}Li projectile nuclei with the frequency of each channel and percentage taken to the total number of events (Q>0).

(a) Private communication with Adamovich M.I. et al.

(b) Present work

Pf_s Channels	No.	^{6}Li [(a)] Percent (Q>0)	No.	^{7}Li [(b)] Percent. (Q>0)
Q=0	179	----	664	----
Q>0				
p	90	11.72%	38	14.4%
pp	23	2.994%	13	4.92%
ppp	5	0.65%	1	0.38%
pppp	1	0.13%	0	-----
d	97	12.63%	30	11.36%
dp	64	0.88%	15	5.68%
dpp	8	1.04%	0	-----
dd	27	3.515%	5	1.89%
ddp	8	1.04%	1	0.38%
ddd	3	0.39%	0	-----
t	32	4.166%	5	1.89%
tp	24	3.125%	2	0.76%
tpp	5	0.65%	0	-----
td	21	2.734%	1	0.38%
tdp	8	1.04%	2	0.76%
t t	4	0.521%	0	-----
^{3}He	46	5.989%	52	19.696%
^{3}Hep	18	2.34%	34	12.878%
^{3}Hepp	1	0.13%	0	-----
^{3}Hed	29	3.776%	14	5.3%
^{3}Hedp	1	0.13%	0	-----
^{3}Het	8	1.04%	4	1.52%
^{4}He	97	12.63%	24	9.09%
^{4}Hep	65	8.46%	8	3.03%
^{4}Hepp	4	0.521%	0	-----
^{4}Hed	61	7.943%	1	0.38
^{6}He	5	0.65%	3	1.14%
^{6}Hep	0	-----	5	1.89%
^{6}Li	13	1.693%	-----	-----
^{7}Li	-----	-----	6	2.27%

(ii) For channels of Q = 2 and Z_{max} = 1 [i.e. channels of (pp), (dp), (dd), (tp), (td), and (tt)] .In these channels: 2 singly charged particles are emitted as projectile fragments leaving the remaining singly charged particle which interacts with the target nucleus.

The percentages of p, d and t in these channels are ~ 60%, 37% and 3% respectively for ^{7}Li and they are 44%, 46% and 10% respectively for ^{6}Li.

(iii) For channels of Q = 2, Z_{max} = 2, i.e. the channels of (^{3}He), (^{4}He) and (^{6}He). The doubly charged ions are emitted as projectile fragments while the remaining singly charged particle interacted with target nucleus .The percentages of

^{3}He: ^{4}He: ^{6}He are ~ 66%, 37% and 3% respectively for ^{7}Li and are 31%, 66% and 3% respectively for ^{6}Li.

(iv) For channels of Q=3 and Z_{max} = 1, [i.e. channels of (ppp), (dpp), (ddp), (ddd), (tpp), (tdp)] the 3 charged particles are emitted as projectile fragments .In these channels, the percentages of p, d and t are ~ 50%, 33% and 17% respectively for ^{7}Li and are ~ 51%, 37% and 12% respectively for ^{6}Li.

(v) For the channels of (Q=3) and Z_{max} = 2 [i.e. channels of (^{3}Hep), (^{3}Hed), (^{3}Het), (^{4}Hep), (^{4}Hed), (^{4}Het) and (^{6}Hep): the projectile nucleus is fragmented into one singly charged particle associated with a doubly ionized helium isotope.

The percentages of p, d and t in these channels are ~ 71.2%, 22.8% and 6% respectively for ^{7}Li and are ~ 46%, 49% and 4% respectively for ^{6}Li. And the percentages of ^{3}He, ^{4}He and ^{6}He in these channels are ~ 78.8%, 13.6%, 7.6% Respectively for 7Li and they are ~ 31%, 66% and 3% respectively for ^{6}Li.

For channels of (Q>3) and ($Z_{max.}$=2) :i.e. (pppp), (^{3}Hepp), (^{3}Hedp) and (^{4}Hepp): the charge conservation is violated in These channels and that appear only among ^{6}Li fragmentation channels and does not appear among ^{7}Li channels .These means there are no cases of pion exchange or nucleon pick-up by projectile nucleus from target nucleus in case of ^{7}Li.Table (2) represents the relative yields of singly and doubly charged fragments of ^{6}Li and ^{7}Li. (Adamovich et al., private communication. and Lepekhin et al., 1998).

For singly charged fragments (z =1): the ratios of p: d are approximately equal in both experiments of ^{6}Li fragmentation (private communication with Adamovich et al) and (Lepekhin et al., 1998) while for ^{7}Li, the relative yields of p and d are 60.36% and 33.33% respectively (present work).

This means that in ^{7}Li, the proton yields increase while deuteron yields decrease compared to the corresponding relative yields of ^{6}Li.

Triton relative yields show an approximate equality between ^{7}Li (present work) triton yields and those of ref. (Lepekhin et al., 1998) (6.31% and 7% respectively), while it is 13% in ref. (Adamovich et al., private communication) For doubly charged fragments (z = 2): relative yields of ^{3}He, ^{4}He and ^{6}He show that in ^{6}Li fragmentation: the relative yields of ^{3}He and ^{4}He are approximately equal in ref. (Lepekhin F.G.et al., 1998) (51% and 46% respectively) while they differ in other experiments (Adamovich et al., private communication) (30% and 68% respectively) i.e. ^{4}He yields exceed ^{3}He by a significant difference. While in ^{7}Li fragmentation, the relative yields of ^{3}He and ^{4}He are ~ (71.72%) and (22.8%) respectively.

From all above, we can deduce clearly that proton yields dominate the singly charged fragments in ^{7}Li-fragmentation process while proton and deuteron yields are approximately equal in ^{6}Li-fragmentation process. Also ^{3}He fragments are dominant on doubly charged fragments in ^{7}Li fragmentation process, while ^{4}He yields are the dominant doubly charged fragments in ^{6}Li fragmentation process.

Table 2: relative yields of emitted fragments from ^{6}Li and ^{7}Li relativistic projectile nuclei.
[a] Private communication with Adamovich M.I. et al.
[c] Lepekhin F.G. et al.1998.

Isotope	Ratio		
	^{6}Li [a]	^{6}Li [c]	^{7}Li Present work
p	44%	47%	60.36 %
d	43%	46%	33.33 %
t	13%	7%	6.31 %
^{3}He	30%	51%	71.72 %
^{4}He	68%	46%	22.80 %
^{6}He	1.4%	3%	5.50 %

This leads us to conclude that the structure of ^{7}Li tends to be (^{3}He+p+3n) while ^{6}Li structure tends to be a weakly bound system of (α +d) and this is confirmed by the fragmentation ratio of ^{6}Li (81.1% of all inelastic events which have projectile fragments [Q>0]), while the fragmentation ratio of ^{7}Li is only (28.45%).

Also it is important to notice from tables (1) and (2) that ^{6}He yields of ^{7}Li is approximately twice as that of ^{6}Li in ref. (Lepekhin et al., 1998) and approximately 4 times as that of ^{6}Li in ref. (Adamovich et al. ,private communication).

This may be explained by the fact that: ^{6}He production occurs in ^{7}Li fragmentation by direct break-up of ^{7}Li nucleus into (^{6}He + p), (in 5 events out of 8 events having ^{6}He fragments, the ^{6}He isotope was accompanied by a singly charged fragment) so that reveals the estimation of the double charge of ^{6}He.While ^{6}He fragments yielded from ^{6}Li fragmentation are produced from pion exchange (nucleon exchange) between the ^{6}Li projectile nucleus and the target nucleus of the emulsion.

Also in ^{7}Li fragemtation there were 5 events of (^{6}He+p) yields, this may be a possible dissociation channel of ^{7}Li through direct break-up of ^{7}Li into ^{6}He and p.

We can see from table (3) that it shows the channels of (Q=3) and the events in these channels are classified into 2 categories according to the number of heavy fragments (N_h=0) and (N_h>0). The 1st category of events is a very sensitive probe for the structure of the projectile nucleus because it contains only the events which have dissociated by Coulomb dissociation in the projectile fragmentation forward cone and are not accompanied with any target fragments (N_h=0). It is clear that the structure of ^{7}Li tends to be mainly of (^{3}He+p+3n) (highest probability), and also there is a less probability for the (^{3}He+d) formula and there are smaller and smaller probabilities for (^{4}He+p), (^{6}He+p) (^{3}He+t) and (^{4}He+d) formulae of internal structure of ^{7}Li nucleus.

Table 3 Channels of dissociation of ^{7}Li of the type (Q=3) classified according to N_h value.

	N_h= 0	N_h >0	Total
ppp	0	1	1
ddp	0	1	1
tdp	2	0	2
^{3}Hep	18	16	34
^{3}Hed	10	4	14
^{3}Het	2	2	4
^{4}Hep	5	3	8
^{4}Hed	1	0	1
^{6}Hep	2	3	5

Also the events which have (N_h>0) show that the above formulae still have the same probability [i.e. (^{3}He+p) is the most probable one, then (^{3}He+d) then the remaining ones].

This also may lead us to conclude that the fragmentation behavior of ^{7}Li keeps the same trend independently from the type of interaction events [i.e. (N_h=0) type or (N_h>0) type].

4.Conclusion:

The results of fragmentation of relativistic ^{7}Li and ^{6}Li relativistic nuclei lead to the following:

(1) In fragmentation of ^{7}Li: the majority of singly charged projectile fragments are protons ,while in fragmentation of ^{6}Li, the proton and deutron yields are approximately equal. Also triton yields of ^{7}Li shows an approximately equal relative yields with those obtained from ^{6}Li .

(2) The majority of doubly charged projectile fragments is ^{3}He isotope in case of ^{7}Li fragmentation, while the majority is ^{4}He isotope in case of ^{6}Li fragmentation.

(3) From the above 2 points we can say that the structure of ^{7}Li nucleus tends to be mainly consisted of (^{3}He+p+3n), while ^{6}Li nucleus tends to be mainly consisted of (^{4}He+d).

(4) Fragmentation ratios of ^{7}Li and ^{6}Li are 28.45% and 81.1% respectively. This reveals that the ^{6}Li nucleus is a weakly bound system while ^{7}Li is not.

(5) Relative yields of ^{6}He from ^{7}Li and ^{6}Li fragmentation are 2.27% and 1.693% respectively. Since ^{6}He production occurs through direct break-up of ^{7}Li into (^{6}He+p), while it is produced from ^{6}Li through a pion-exchange process between the projectile ^{6}Li nucleus and target nucleus of the emulsion.

(6) The fragmentation of ^{7}Li into (^{3}He+p) remains the most probable fragmentation channel independently from the type of interaction [(N_h=0 type) or (N_h>0 type)].

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References:

Adamovich M.I. et al. *EMU-01 Collaboration. Eur. Phys. J. A 5, 429, 1999.*

Adamovich M.I. et al., JINR, Dubna, *High Energy Physics Lab. (Private communication)*

Davis N.J.et al., *J.Phys.G.17, L39, 1991.*

El-Nadi M., El-Nagdy M.S.,Sherif M.,Abdel-Salam A.,Yasin M.N., Ali Mossa N.,Abdel-HalimS.M.,BadawyB.M.,Jilany M.A.,El-Sharkawy S.,El-Tabal A.Y.,and Bakr A., Proc.of *International School of Cosmic Ray Astrophysics 10th Course. Erice, Italy (16-23) June 1996.*

Heckman H.H., Greiner D.E., Lidstrom P.J. and Shwe H.*, Phys.Rev.C17, 1735, 1978.*

Lepekhin F.G.,Sileverstov D.M. and Simonov B.B., *Eur.Phys.A 1, 137,1998.*

Solntseff N. *Nucl.Phys. Vol. 4 p337, 1957.*