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Production and Interaction of some Exotic Nuclei at High Energy

O.W. Ibrahim, M.M. Sherif, Y.Assran and M. El –Nagdy
Physics department – Faculty of science – Cairo University – Giza 12613, Egypt
Presenter: M.M.Sherif (hepl2cu@mailer.eun.eg), egy-sherif-MM-abs2-he21-poster

The isotopic composition of the emitted relativistic fragments in the interactions of ^{6}Li, ^{7}Li and ^{12}C projectile nuclei with target nuclear emulsion nuclei at 4.5 AGeV/c is investigated.
The relativistic isotopes (fragments) were separated (identified) by their charges and pβc measurements in the emulsion.
Yields of [^{1}H (^{3}He)], [^{2}H or ^{1}H (^{4}He)] and [^{2}H and /or ^{1}H (2 ^{4}He)] appear to have the highest probability among all other yields due to the fragmentation of ^{6}Li, ^{7}Li, and ^{12}C projectiles respectively.
A special concern was devoted to the production of ^{6}He exotic nuclei, the production ratios of ^{6}He nuclei was found to be 0.7% for ^{6}Li, 3% for ^{7}Li and 0.7% for ^{12}C projectiles nuclei.
The preliminary results of the interaction mean free path of ^{6}He fragments were found to be ~14.6±2.3cm, while for ^{4}He = 19.96±0.60cm.

1. Introduction

Great progress [1-4] has been made toward studying the structure of nuclei with excess and maximum number of neutrons while research on the structure of proton-rich (or neutron deficient) nuclei is merely being planned. The major goal of the appropriate experiment is to define the structure features of nuclei near the boundary of proton stability. Such nuclei are stable in absence of electron shell. The structure of such nuclei can turn out to be another key to understanding the process of nucleosynthesis. For instance, the presence of the proton halo (proton far removed from nucleus core) may serve as a "stringboard" for the isotope generation when advancing along the boundary of proton stability with a subsequent decay into stable isotopes.

In a previous analysis [2,6] a systematic comparison using shower particle distributions of ^{6}Li and ^{7}Li nuclei interactions with emulsion nuclei when they participate in the interaction with one (Z=1) or two (Z=2) charged particles, respectively, lead to the assumption that ^{6}Li can be consider as a cluster of $(\alpha+d)$, while ^{7}Li may not be $(\alpha+t)$. Here, we report on result from separating hydrogen and helium isotopes by using their momentum measurements of ^{7}Li fragments at 3.8 AGeV/c in emulsion interactions. The corresponding data for ^{6}Li fragments [2] at 4.5 AGeV/c were used for comparison. Branching ratio of fragmentation channels as will as structure estimation has been obtained from analyzing the data. Finally, there were few events including ^{6}He (exotic nuclei) where the (^{6}He+p) was one of the dissociation channels of ^{7}Li nuclei.

2. Experimental methods:

Photo-emulsion chambers, each chamber consists of 40 pellicles 600 μm x10cmx 20cm of BR-2 emulsion was irradiated by beams of ^{6}Li, ^{7}Li and ^{12}C at momentum 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, ^{7}Li [1-2] and ^{12}C [6] we scanned (353.867) meters, (248.63) meters and (286) meters respectively and found (2454) events, (1647) events and (2019) of ^{6}Li, ^{7}Li and ^{12}C respectively. The experimental mean

free paths were (14.42 ± 0.29 cm), (15.096 ± 0.37 cm) and (14.16±0.32cm) 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.

For ^{12}C: a random sample of (504) out of (2019) events of inelastic interactions was selected, within this sample 193 He projectile fragments were found.

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

We measured the quantity (pßc) for all the projectile fragments of (264) events of ^{7}Li and (150) He projectile fragments of ^{12}C with an error (Δp ßc), where ß = v/c.

The determination of (pβc) 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 [5] using KSM1 Zeiss Jena microscope, and the calculations of (pβ c) was made by the ρ-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 [5].

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 µm 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 and ^{12}C interactions and also the charge identification of ^{6}Li projectile fragments were made.

3. Results

All fragmentation channels of the ^{6}Li [2] and ^{7}Li [1] are shown in table 1 and we can see clearly that: For the channels of Q=1, 2 and 3 and $Z_{max.}$ =1, 2 and 3(i.e. channels of p, d and t), where Z_{max} is the maximum possible charge on a given projectile fragment.

In table 2 containing the percentage probability of the composition of H and He isotopes of ^{6}Li, ^{7}Li and ^{12}C projectile nuclei.

The results reported at 14th ICRC[7] discussed the presence of some anomalous component interacting with a very short mean free path(a few centimeters was indicated by Judek[7,8] ,as she studied double charged secondary projectile fragments emitted from the interaction of cosmic ray nuclei with nuclear

emulsion) . Also she found a mean free path of He projectile fragments emitted by ^{16}O –Emulsion interaction at 2.1 AGeV/c shorter than the average mean free path of the accelerated He nuclei [7].
This phenomena were attracted the attention of the scientists [8, 9] between 1980 and 1986 to study this phenomena from the experimental and /or theoretical points of view. Some authors [9] considered the He nuclei as alpha-neutron rings or as a specific model of ring of N alpha particles plus 2N neutrons, so that with the neutrons uniformly distributed around the ring there are two neutrons associated with every pairs of alpha particles as ^{10}Be and ^{6}He. Some scientists now called these types of nuclei halo or exotic nuclei. We devoted our experimental work to find the correct comments on such type of theoretical suggestions [9]. By measuring of momentum and charge of the each emitted projectile fragment in the interactions of ^{6} Li, ^{7} Li and ^{12}C with Emulsion nuclei , we succeeded to know all the fragmentation probabilities for these interactions (as given in table 1) ,also the ratio of emission of ^{6}He nuclei among the He isotopes (as given in table 2),the ratios of ^{3}He : ^{4}He : ^{6}He for ^{6}Li ,^{7}Li and ^{12}C interactions as follows 30.6 : 68 : 1.4 , 51: 46: 3 and 23: 67: 10 respectively.
We have found 5, 8, and 15 ^{6}He projectile fragments among He fragments produced by the interactions of ^{6}Li, ^{7}Li, ^{12}C with emulsion nuclei respectively. We followed each track of these ^{6}He fragments from plate to plate till left the stack or make an interaction. We have found the interaction mean free path of with nuclear emulsion of these limited numbers of ^{6}He approximately equal 14.12+2.3.
In spite of the ^{6}He mean free path in nuclear emulsion is shorter than He fragments and its rate of production is limited to in comparison with the rate of He fragments (as shown in Table 2), we can say the halo or exotic nuclei can not play any effective role to reduce the interaction mean free path of the normal fragments.

4. Conclusion:

1. The production rate of ^{6}He nuclei in the inelastic interaction of ^{6}Li ,^{7}Li and ^{12}C with emulsion nuclei at high energies are as follows 0.7%, 3% and 0.7% respectively.
2. The mean free path of ^{6}He nuclei is shorter than the mean free path of He nuclei.
3. The production of ^{6}He nuclei among He projectile fragments do not play any noticeable role to reduce the interaction mean free path of He fragments

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References:

[1] M.M. Sherif et al., 27th ICRC, Hamburg (2001) 1358.
[2] M.I. Adamovich et al., Physics of Atomic Nuclei, 62, 8(1999)1378.
F.G. Lepekin et al., Eur. Phys. J. A1 (1998)137.
[3] A.H. Wuosamaa et al., Ann. Rev. Nucl. Part. Sci., 45(1995)89.
[4] P.G.Hansen et al., Ann.Rev.Nucl. Part Sci.45 (1995)591.
[5] N. Solntseff, Nuclear Physics, 4(1957) 337.
[6] N. A. Mousa, Ph.D. Thesis submitted to Faculty of Science, Cairo University, Egypt (1986).
[7] B.Judek, Can.J.Phys., 50(1972)2082. and 14th ICRC, Munich,7(1975)2372.
[8] E.M. Friedlander et al., Phys. Rev C 27(1983) 1489.
Y.J. Karant et al., LBL-16281(1983)23.
[9] D.H. Wilkinson, Nucl.Phys.A 434(1985)573.

Table 2 Represents the relative yields of singly and doubly charged fragments of ^{6}Li , ^{7}Li and ^{12}C interaction with emulsion nuclei.

Isotope	Ratio			
	^{6}Li	^{6}Li	^{7}Li	^{12}C
	[2]	[2]	[1]	[6]
p	44%	47%	60.4%	
d	43%	46%	33.3 %	
t	13%	7%	6.3 %	
3He	30.6%	51%	71.7 %	23%
4He	68%	46%	22.8 %	67%
6He	1.4%	3%	5.5 %	10%

Table 1 Fragmentation channels of ^{6}Li and ^{7}Li interaction with emulsion nuclei.

Pfs Cha-nnels	No. of Eve-nts	6Li [2] Percent %(Q>0)	No.of Events	7Li [1] 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	0.52	0	
3He	46	5.99	52	19.69
3He p	18	2.34	34	12.87
3He pp	1	0.13	0	
3He d	29	3.78	14	5.30
3He dp	1	0.13	0	
3Het	8	1.04	4	1.52
4He	97	12.63	24	9.09
4He p	65	8.46	8	3.03
4He pp	4	0.52	0	
4He d	61	7.94	1	0.38
6He	5	0.65	3	1.14
6He p	0		5	1.89
6Li	13	1.69		
7Li			6	2.27