Exposures of nuclear track emulsion to light radioactive nuclei, neutrons and heavy ions

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XXII Baldin ISHEPP, 19.09.2014
BECQUEREL at the JINR Nuclotron is devoted systematic exploration of clustering features of light stable and radioactive nuclei.
Nuclotron 21/12/2013
Tune 1.2 A GeV $^{11}$C
x20

x90
The fragmentation of a large variety of light nuclei was investigated using the emulsions exposed to few A GeV nuclear beams at JINR Nuclotron. A nuclear track emulsion is used to explore the fragmentation of the relativistic nuclei.
Proposal on exposures of NTE to beam of $^{11}$C nuclei at 1.2 A GeV

based on:

• results of Becquerel project for carbon isotopes ($^9$C, $^{10}$C, $^{12}$C)


1810 nuclei of $^{11}$C produced from $5 \cdot 10^4$ of $^{12}$C

$<E/A> = 1.18$ GeV
RMS = 0.03 GeV

Polyethylene target (thickness - 1 cm) irradiated by $^{12}$C nuclei with 1.2 A GeV. Used CHIPS physics list, and G4_POLYETHYLENE target (Geant4). All equipment located in air.
$^{11}\text{C}$

$\frac{14.9019}{^9\text{B}+\text{d}}$

$\frac{13.1197}{^\text{10}\text{C}+\text{n}}$

$\frac{9.2225}{^8\text{Be}+^3\text{He}}\xrightarrow{\text{slow n}}\frac{9.4521}{^6\text{Li}+^6\text{Li}-\text{n}}$

$\frac{7.5580}{^9\text{Be}+^3\text{He}-\text{n}}\xrightarrow{\text{slow n}}\frac{6.4648}{^\text{10}\text{B}+\text{d-n}}$

$\frac{3.1959}{^\text{10}\text{B}+^3\text{He}-\text{d}}$

$\frac{1.8560}{^{12}\text{C}+^3\text{He}-\text{a}}$

$\pi = \frac{15.35}{16.7}$

$\pi = 15.59$ (T = 3/2)

$\pi = 14.76$

$13.90 - 14.07$ (T = 3/2)

$13.4 - 13.33$

$13.01 - 12.65 - 12.4 - 12.51 - 12.16 - 12.16 - T = 3/2$

$11.44\xrightarrow{T = 1/2} 10.679 - 11.03 - 9.621 - 9.970 - 7/2^+$


$8.1045 - 7.4997 - 7.4 - 6.9048 - 6.3392 - 6.4782 - 7/2^-$

$4.8042 - 3/2^-$

$4.3188 - 5/2^-$

$\gamma = \frac{7.5436}{^7\text{Be}+\alpha}$

$\gamma = \frac{8.6894}{^{10}\text{B}+\text{p}}$
Charge topology of $^{11}$C fragmentation

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>B + H</td>
<td>5</td>
<td>8%</td>
</tr>
<tr>
<td>$^7$Be + He</td>
<td>11</td>
<td>18%</td>
</tr>
<tr>
<td>3He</td>
<td>10</td>
<td>16%</td>
</tr>
<tr>
<td>2He + 2H</td>
<td>26</td>
<td>42%</td>
</tr>
<tr>
<td>He + 4H</td>
<td>4</td>
<td>7%</td>
</tr>
<tr>
<td>Li + He + H</td>
<td>3</td>
<td>5%</td>
</tr>
<tr>
<td>6H</td>
<td>3</td>
<td>5%</td>
</tr>
</tbody>
</table>

\[ ^{12}\text{C}(\text{n},\text{n}')3\alpha, \ E_n = 14.1 \text{ MeV} \]

DVIN - explosives detector on the basis of fast tagged neutron method for complex program for population safety in transport.

\[ M_{2\alpha} = \left[ 2\left( m_\alpha^2 + E_{\alpha 1}E_{\alpha 2} - p_{\alpha 1}p_{\alpha 2} \cos(\Theta) \right) \right]^{1/2} \]

\[ Q_{2\alpha} = M_{2\alpha} - 2 \cdot m_\alpha \]
EXPOSURE TO $\mu$-MESONS

Deep inelastic scattering of ultrarelativistic $\mu$-mesons is a recognized approach to study the parton structure of nucleons and nuclei. Exposure of NTE to these particles allows one to perform a study of nuclear multifragmentation under a purely electromagnetic probe. Multiphoton exchanges or transitions of virtual photons to vector mesons leading to nuclear interactions may serve as the mechanisms of fragmentation. NTE has been irradiated at CERN by $\mu$-mesons of energy of 160 GeV. Earlier such an exposure hasn’t been carried out. The purpose of this irradiation was a study of experimental downloads near a beam axis and the preliminary assessment of the nature of interactions $\mu$-mesons.
72 stars containing only a triple of $b$-particles stopped in NTE are assigned to the disintegration $\mu + ^{12}\text{C} \rightarrow 3\alpha$ and compared with the case $n(14.1 \text{ MeV}) + ^{12}\text{C} \rightarrow 3\alpha + n$. 
БОР

Расщепление бора тепловыми нейтронами

\[ _6\text{B}^{10} + _0\nu^1 \rightarrow _2\text{He}^4 + _3\text{Li}^7 \]

приводит к испусканию α-частицы и образованию ядра лития в возбужденном состоянии с энергией 478 кэВ [53]. В этом случае, так же как и в предыдущей реакции, ядро отдачи лития поглощает значительную часть кинетической энергии, и ионизирующие способности \(^2\text{He}^4\) и \(^3\text{Li}^7\) отличаются слишком мало, чтобы их можно было распознать путем нормального проявления.
IBR 30m Thermal Neutrons x20
$^{4}\text{He}$  
$^{7}\text{Li}$

$0.73 \pm 0.16 \, \text{мкм}$ 
$0.53 \pm 0.12 \, \text{мкм}$
$L = 3.1 \pm 0.3 \text{ мкм}$

$N_{ev}$

$N_{ev}$

$L \left( ^7 \text{Li} \right)$, мкм

$L \left( ^4 \text{He} \right)$, мкм

$N_{ev}$

$L \left( ^7 \text{Li} + ^4 \text{He} \right)$, мкм

Рис. 15. Реакция $^{10} \text{Be} \left( n, \alpha \right) ^7 \text{Li}$. Плотность пробегов отдельных частиц в сечении пробегов двух частиц.
In the energy range of nuclei several MeV per nucleon, there is a possibility of implantation of radioactive nuclei into detector material. Of course, in this approach daughter nuclei are investigated rather than the nuclei themselves. In this respect it is worth mentioning the known, although somewhat forgotten, possibilities of NTE (Nuclear Track Emulsion) for the detection of slow radioactive nuclei. More than half a century ago, alpha tracks from the decay of $^8\text{Be}$ nuclei through the first excited state $2^+$ of about 2.0 MeV were observed. They occurred in the alpha decays of stopped $^8\text{Li}$.
In March 2012 NTE was exposed at the Flerov Laboratory of Nuclear Reactions (JINR) at the ACCULINNA spectrometer (http://aculina.jinr.ru/). The beam in use was enriched by $\approx 7$ A MeV $^8$He nuclei. A 107 $\mu$m thick NTE pellicle was oriented at a $10^\circ$ angle during irradiation, which provided approximately a five-fold effective thickness increase. For 10 minutes of irradiation, statistics of about 2 thousand of such decays was obtained. It is pleasant to note that the used NTE have been recently reproduced by the enterprises «Slavich» (Pereslavl-Zalessky, Russia).
Data modeling and experiment ($^8$He at $\approx 7$ A MeV)

Radioactive Decay (Geant4)

Experiment

counts

counts
Alpha spectrum from \( ^8\text{He} \rightarrow ^8\text{Li} \rightarrow ^8\text{Be} \rightarrow 2\alpha \) (our experiment)

**Fig. 1.** Alpha spectrum from \( \text{Li}^8(\beta)\text{Be}^{8*}(\alpha)\text{He}^4 \). The vertical intensity scale is arbitrary. The numbers given indicate approximately the actual number of particles counted for the points below 3 Mev. Above 3 Mev the actual count is about twice that indicated by the numbers.

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**Alpha Spectrum in the Decay of Li\(^{8*}\)**

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The alpha-particle spectrum in the successive beta-alpha decay of Li\(^8\) was observed with magnetic analysis from 1 to 6.5 Mev, corresponding to excitation energies in Be\(^8\) from 2 to 13 Mev. The only definite structure in the spectrum corresponds to the well-known broad state at 2.9 Mev.
$^8\text{He} \rightarrow ^8\text{Li} \rightarrow ^8\text{Be} \rightarrow 2\alpha$ at ~7 A MeV

\[ M_{2\alpha} = \left[ 2\left( m_\alpha^2 + E_{\alpha 1} E_{\alpha 2} - p_\alpha p_{\alpha 2} \cos(\Theta_{12}) \right) \right]^{1/2} \]

\[ Q_{2\alpha} = M_{2\alpha} - 2 \cdot m_\alpha \]

2$^+$, $^8\text{Be}$ (2.9 MeV, 1.5 MeV)
NTE is exposed to ions $^{86}$Kr$^{+17}$ and $^{124}$Xe$^{+26}$ accelerated to energy of about 1.2 $\alpha$ MeV at the cyclotron IC-100 of the Flerov Laboratory of Nuclear Reactions, JINR. Since energy of these ions is small the exposure of NTE is performed without a light protective paper. Therefore, fixing of the NTE plates in the irradiation chamber was performed at a light which is ordinary for a photographic laboratory. For 5 seconds of exposure the track density amounted to about $10^5 - 10^6$ cm$^{-2}$. The NTE layers with an inclination angle of $45^\circ$ to the beam axis which provided observation of ion stops.
Summary

• The presented observations serve as an illustration of prospects of the Nuclotron and NTE for nuclear physics researches.

• The possibilities of nuclear track emulsion for study of fragmentation of relativistic $^{11}$C nuclei is shown.

• In the energy range of nuclei several MeV per nucleon, there is a possibility of implantation of radioactive nuclei ($^{8}$He) into detector material.

• The possibilities of NTE for study with neutrons and muons are shown.

• Demonstrated the possibilities of the newly reproduced nuclear emulsion for research with heavy ions at extremely low energies ($^{86}$Kr and $^{132}$Xe).

Thank you for your attention!
http://becquerel.lhe.jinr.ru/