Conference Paper

Charged particles evaporation in the stopped pion absorption reactions

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Abstract

In the present work we have analyzed evaporation spectra and yields of p,d,t formed in the reaction of stopped pion absorption. It is shown that the values of equilibrium temperature obtained through the usage of proposed model are in agreement with the values obtained in various other experiments. We also discuss the A-dependences of the evaporation yields and consider possible contributions of the "indirect" evaporation processes.

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1. Introduction

The main stages of stopped negative pion absorption by atomic nuclei are well known [1, 2]. A slow pion loses its kinetic energy due to ionization processes and then is captured by the Coulomb field of a target nucleus. The pion is set to an orbital with high principal quantum number n>20 [3]. Then the pion undergoes electromagnetic cascade and moves to lower orbitals. The cascade ends when the pion is absorbed by strong interaction from a low-lying orbital of the mesoatom. The absorption occurs at the nuclear surface.

Due to the laws of energy and momentum conservation, the stopped pion absorption is a multinucleon process. The dominant mechanism is the absorption by a intranuclear pn-pair with the deuteron quantum numbers ($J^P = 1^+$, $I = 0$, $l_{np} = 0$) leading to formation of a pair of "primary" neutrons: $\pi^- + pn \rightarrow nn$. The processes that lead to formation of primary charged particles are less probable. They include pion absorption on a pp-pair ($\pi^- + pp \rightarrow pn$), as well as absorption on some more heavy clusters like ^{3,4}He [1].

Mechanisms of charged particle formation still are not understanded clearly. The main obstacle here is experimental restrictions: thin targets are required due to the interactions of newly formed charged particles with target matter, but very few pions stop in thin targets which leads to serious normalization issues. Many experimental works were dedicated to measuring charged particle spectra [4 - 12] and there were significant differences in the measured spectra

This is the main reason we developed our own method of selection of events with stopped pions [13], applied it to significant number of targets from a large range of mass numbers (light nuclei ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, ^{11}B, ^{12}C, medium nuclei ^{28}Si,^{40}Ca, ^{59}Co, ^{93}Nb, tin isotopes ^{114}Sn, ^{117}Sn, ^{120}Sn, ^{124}Sn and heavy nuclei ^{169}Tm, ^{181}Ta, ^{209}Bi). There is a number of models which were applied to particle formation in stopped pion absorption reactions based on simulations of the absorption process in the successive intranuclear cascades [14]. These models are sophisticated and still provide rather limited precision, so we developed new model [15]. We made it simple and phenomenological, which is now possible when we have a systematical set of data on charged particle spectra and yields, but we tried to design it to grasp main kinematic features of the reaction. The model already showed satisfactorily agreement with experimental results and allowed us to analyze charged particle formation during the stage of pion absorption by a cluster as well as the mechanisms of particle formation during intranuclear cascades. In the present work we investigate the formation of low-energy particles (p, d, t) at the terminal stage of the reaction - deexcitation of residual nuclei through the evaporation of particles from its surface.

2. Materials and methods

The experiment was carried out on the synchrocyclotron at PNPI using the semiconductor spectrometer for charged particles. The pionic beam with the momentum of 100 MeV/c was slowed down by the graphite moderator, passed through the monitor system consisting of two thin semiconductor detectors and then stopped in the target. The target was placed at the angle of 45° with respect to the beam. Its thickness was equivalent to the reference silicium target 440 μm thick.

As it was shown in [13], the monitor system allowed reaching the absolute normalization precision of 7%, and the relative error of measurements on different targets was not greater than 3.5%. Charged particles were detected by two multilayer semiconductor telescopes. The energy threshold of proton identification was 5 MeV. The measurements were performed up to the kinematic thresholds of the reactions. The energy resolution (*FWHM*) of the spectrometers in the proton detection was 0.6 MeV.

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3. Results and discussion.

The primary results of the experiment were energy spectra of charged particles formed in the reaction of stopped pion absorption on the wide variety of target nuclei. Applying the model to all obtained spectra we derive A-dependances of model parameters and partial yields. The spectra of evaporation particles were fitted with simple exponential approximation due to rather high lower energy thresholds:

$$\frac{dY}{dE} = C \exp\left(-\frac{E}{T}\right)$$

Here C - normalizing constant, T - equilibrium temperature. A-dependances of T are shown in fig. 1.

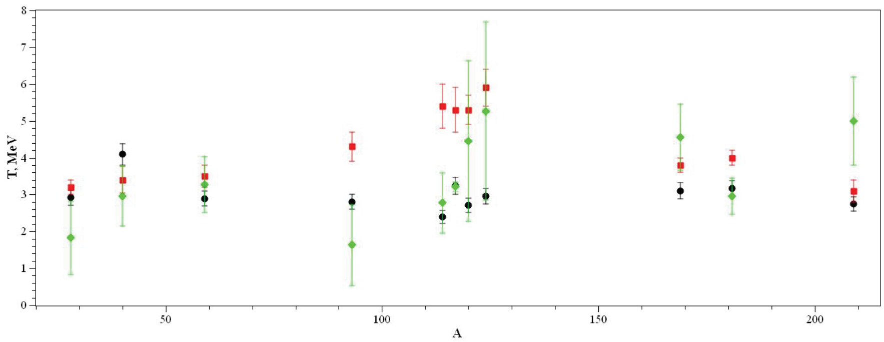

Figure 1: The equilibrium temperatures based on spectra of p (□), d (•), t (♦) from pion absorption by various nuclei.

Here only results for the medium-high mass number region since for the light nuclei there is no equilibrium at the terminate stage of the reaction are shown. The equilibrium temperature mostly lies in the range of 1,5 - 6 MeV with the median value being 3,5 MeV. This result is in agreement with measurements conducted in various ways [16]. This gives us one more evidence that our model separates different reaction stages well.

Using the model we also calculated partial yields and contributions of different stages into the full yields of p, d t. The A-dependence of evaporation yields of protons is presented in the fig. 2 for medium and heavy nuclei as an example. For the medium nuclei evaporative protons contribute nearly 50% into the total yields. For the protons from heavy nuclei and for d and t across all the range the contribution is 10-15%. The dependencies for d and t have similar, but generally more smooth behaviour.

The yields demonstrate maximum values in the region around ^{40}Ca and then they drop quickly as the mass number increases. The most dramatic decrement can be observed for protons from Sn isotopes: several additional neutrons heavily influence

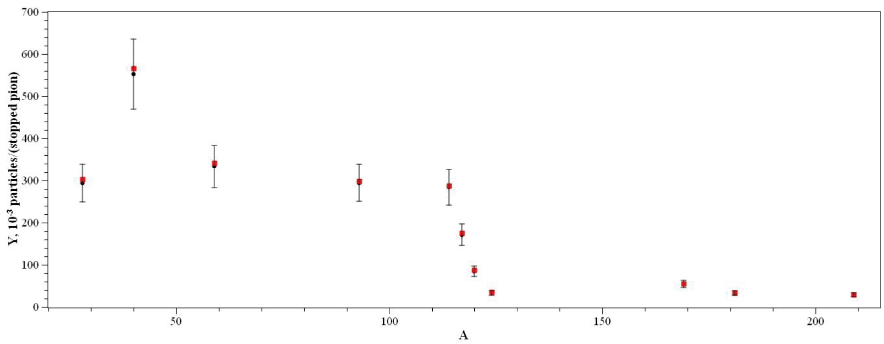

Figure 2: Proton evaporative yields from our model (black) vs modified yields estimated with the consideration of the indirect evaporation (red).

the proton multiplicities. This may probably be due to the non-equal distribution of protons and neutrons in a nucleus and the effect of the so-called neutron-skin.

It should also be noted that for the complex particles (d, t) a possibility exists that they are formed in the process of so-called indirect evaporation, in which nucleons are first evaporated separately and then form a more complex after they left a nucleus [17]. It was mentioned that the contribution of the process may reach as high as 50% of evaporative yield. In order to get more accurate results we modify our proton evaporation yields accordingly. With such estimation we approximately evaluated the number of protons that originally evaporated but then was drawn into d and t formation and therefore were not registered as protons. But due to the low yield values of evaporative d and t the modified proton yields mostly lie within its error, and thus the picture doesn't change significantly.

4. Conclusions

In the present work it is shown that our model allows the reproduction of spectra of protons formed in the reaction of the stopped pion absorption on nuclei from the wide range of masses ($6 < A < 209$) and evaluate values of equilibrium temperatures. It is shown that the contribution of the evaporation reaches ~50% of the full yields for protons from medium nuclei, while for the p from heavier nuclei and for d and t from all the mass number range is at the level of 10-15%. steady drop of proton yields at the tin isotopes originates probably from the thickening of their neutron skin.

The shapes of A-dependences of evaporative yields doesn't allow to fit them with straightforward analytical solutions and thus to bound yield values to target nuclei parameters. Nevertheless, we demonstrated the main tendencies in the A-dependencies and showed that taking into account effects of indirect evaporation doesn't affect the final results significantly.

Acknowledgments

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