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ALPHA-PARTICLE EMISSION IN THE ^{48}Ca + Ta REACTION AT COULOMB ENERGY

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Испускание альфа-частиц в реакции ^{48}Ca + Ta вблизи кулоновской энергии

Были измерены инклюзивные энергетические спектры легких заряженных частиц, испускаемых при взаимодействии Ta-мишени с пучком ^{48}Ca при энергиях 261 и 471 МэВ. Продукты реакции регистрировались с помощью $\Delta E - E$ телескопа, помещенного в фокальную плоскость магнитного спектрометра, расположенного под прямым углом относительно направления пучка. Во всех реакциях исследованы легкие заряженные частицы с энергией, близкой к соответствующему рассчитанному кинематическому пределу для выходного канала с двумя телами, с относительно большой вероятностью. Полученные результаты позволяют сделать некоторые выводы о механизме реакции, связанной с испусканием легких заряженных частиц.

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Alpha-Particle Emission in the ^{48}Ca + Ta Reaction at Coulomb Energy

Inclusive energy spectra have been measured for light charged particles emitted in the bombardment of Ta target by ^{48}Ca ions at 261 and 471 MeV. The reaction products were analyzed and detected by means of a $\Delta E - E$ telescope placed in the focal plane of a magnetic spectrometer located at forward angles with respect to the beam direction. In all the reactions studied light charged particles with an energy close to the respective calculated kinematic limit for a two-body exit channel are produced with relatively great probability. The results make it possible to draw some conclusions about the reaction mechanism involving the emission of light charged particles.

The investigation has been performed at the Flerov Laboratory of Nuclear Reactions, JINR.

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INTRODUCTION

In heavy ion reactions, light charged particles are emitted with cross sections which constitute a significant part of the geometrical cross section of the reaction [1–3], particularly, in the case of α particles. The measured energy spectra, angular distributions, and cross sections of these particles are not describable within the evaporation model of a compound nucleus decay. The noticeable increase in the yields of energetic light particles, as well as their strongly forward-peaked angular distributions, suggests a fast mechanism of their formation [2, 3]. The experimental investigation of α-particle spectra as a function of momentum transfer, reported in [2, 3], convincingly shows that the emission of fast particles takes place during the early stages of the reaction, when the final fate of the interacting nuclei is not determined yet.

The experiments described below are an extension of our earlier studies [2,3] and were carried out in order to measure the probability of emission of α particles with energies close to the kinematic limit at the forward angles with respect to the beam direction in the reaction induced by ^{48}Ca projectiles.

1. EXPERIMENTAL METHOD

The experiments have been performed using ^{48}Ca ion beams from the U400 heavy ion cyclotron of the Flerov Laboratory of Nuclear Reactions (JINR). The energy of ^{48}Ca ions was 261 and 471 MeV. The tantalum targets were placed in the entrance focus of a high-resolution magnetic separator MSP-144 [4].

The average beam current during the experiment was maintained at value of about 200 nA. The self-supporting Ta target with thickness of 5 μm was prepared from a thin foil of 99% purity. To measure reaction products, a set of two telescopes, each consisting of ΔE and $E_{\rm r}$ detectors with thicknesses of 100 μm and 3 mm, respectively, were used. Particle identification was performed based on the energy-loss measurements ΔE and residual energy $E_{\rm r}$, i.e., by the so-called $\Delta E{-}E$ method. The example of two-dimensional plots (yield versus energy loss ΔE and residual energy $E_{\rm r}$) is shown in Fig. 1, *a*. This method gives absolute identification of detected reaction products in neutron excess $N{-}Z$ (see Fig. 1, *b*). We have found that accuracy $\Delta Z/Z = 0.4$ for oxygen isotope and mass uncertainty is less than 0.5%.

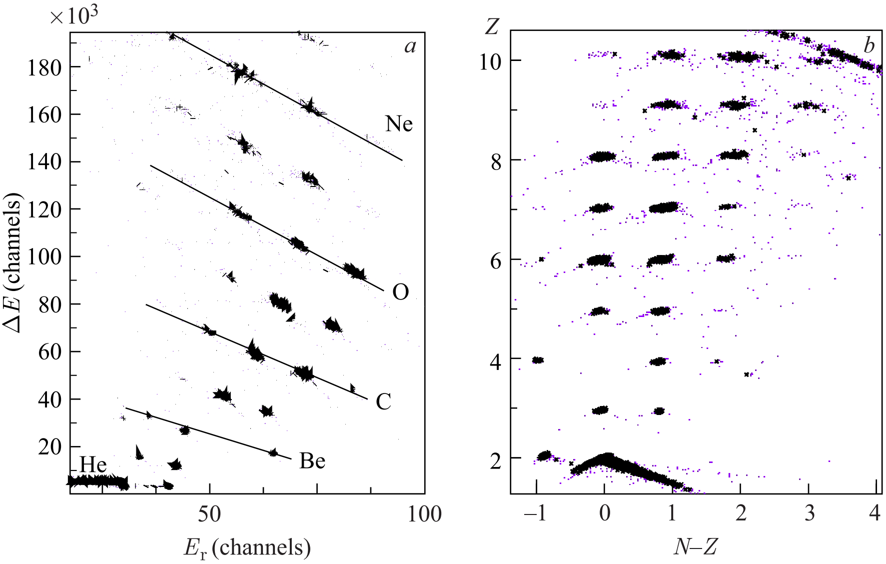

Fig. 1. *a*) Particle identification plot for the products of the ^{48}Ca + Ta reaction from ^{4}He up to Ne-isotopes. ΔE is the energy loss and $E_{\rm r}$ is the residual energy. *b*) Identification matrix (product yield versus atomic number Z and neutron excess $N-Z$ values) obtained by the so-called $\Delta E - E$ method

To obtain cross-section value, we used values of experimental yield and beam flux, measured by the Faraday cup. Overall efficiency of the detection system, including solid angle of the spectrometer and Si-telescope, was determined by a very intensive α-particle source of ^{238}Pu isotope with calibrated intensity. By this we have found that the value of total detection efficiency is about $2 \cdot 10^{-6}$.

This experimental technique allows us to identify the particles from ^{4}He till Ne isotopes. Mainly, we concentrate on study of the production cross sections for ^{4}He and ^{7}Li isotopes in the ^{48}Ca + Ta reaction.

2. RESULTS AND DATA ANALYSIS

Energy spectra for α and ^{7}Li are presented in Fig. 2, *a* and *b*, respectively. In Fig. 2, *a*, the arrow on the $E_{\rm lab}$ axis indicates the limiting values of the particle energies (specified for different particles by their mass numbers), calculated on the basis of the energy and momentum conservation laws under the assumption of two-body kinematics. These energy limits were estimated with an accuracy corresponding to the accuracy of determining both the heavy ion beam energy and the reaction Q-value and amounting to about 2 MeV. As is seen from the figures, in the case of α particle, an experimental energy limit was obtained. This result together with the conclusion given in [3] indicates that in heavy ion reactions α particles with an energy close to the kinematic limit for a two-body exit channel are formed with great probability. It has been shown that in this case a "cold" nucleus is formed whose mass is by 4 units and atomic number by 2 units smaller than those of the compound nucleus.

In the case of ^{48}Ca projectile at energy of 261 MeV, the production cross section is smaller than in the case of ^{22}Ne [3]. During the similar measurement on energy of α particle with higher value of the ^{48}Ca projectile at 471 MeV, we found larger value of the production cross section than at the projectile energy of 261 MeV by a factor of two orders. It seems that the higher energy of the bombarding ions leads to deexcitation intensively.

Contrary to the strong dependence of production cross section of α particle on the sort and value of the projectile energy (which is demonstrated in Fig. 2), ^{7}Li production does not show this dependence, and values of the cross section are very similar both for ^{22}Ne and ^{48}Ca projectiles (see Fig. 2, *b*).

Comparison of angular distributions of α particles from ^{48}Ca at 261 and 471 MeV and ^{22}Ne [3] is shown in Fig. 3. These angular distributions were obtained by integration of the obtained energy distribution of α particles, partic-

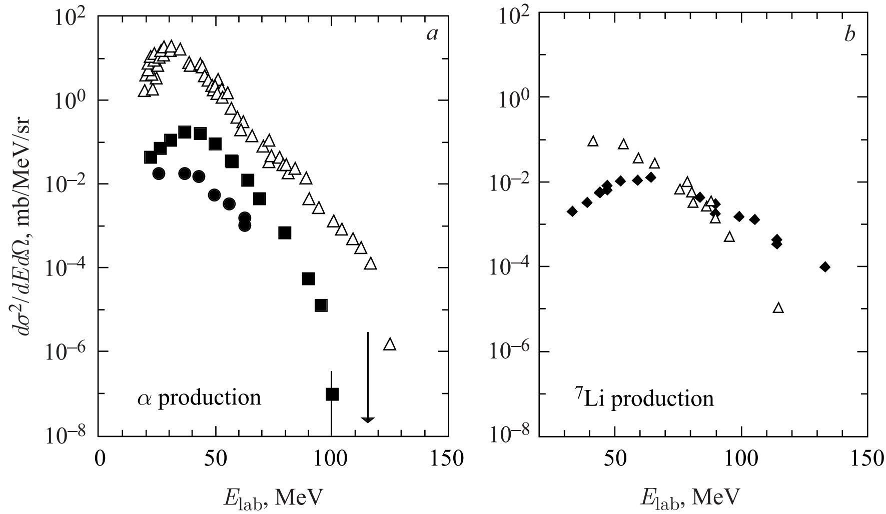

Fig. 2. *a*) Energy spectra of α particle measured in the ^{48}Ca + Ta reaction at 261 MeV at 0° (■) and at 10° (•). For comparison, experimental data for the α particle obtained in the reaction ^{22}Ne + Ta [3] at 178 MeV are shown by △. The arrows indicate the calculated end-point energies for the corresponding isotope in the case of a two-body exit channel. *b*) Energy spectra of ^{7}Li particle measured in the ^{48}Ca + Ta (♦) and for reaction ^{22}Ne (△) measured at 10°

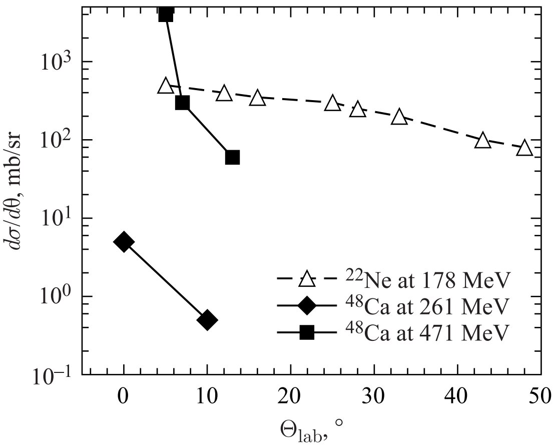

Fig. 3. Comparison of angular distributions of alpha particles from ^{48}Ca at 261 MeV (♦) and 471 MeV (■) and ^{22}Ne (△) [3]. The curves are drawn through the experimental points to guide the eye

ularly, presented in Fig. 2, *a*. The angular distribution in the case of ^{48}Ca projectile is more forward-peaked than in the case of ^{22}Ne projectile due to higher momentum.

To summarize, in our preliminary experiments involving the bombardment of ^{181}Ta with ^{48}Ca (261 and 471 MeV) ions, a number of light charged particles were observed. We have measured reaction products cross section for ^{4}He and ^{7}Li isotopes detected at different emission angles.

We observed that the alpha particles with an energy close to the respective calculated kinematic limit for a two-body exit channel were produced with relatively great probability in the studied reaction. The production cross section for emitted alpha is strongly forward-peaked. The larger value of the production cross section for alpha was observed for the higher value of the projectile energy.

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