Search for He^{10} isotope in the fragmentation reaction of a Th^{232} target nucleus

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A search for an unknown He^{10} isotope is conducted in the fragmentation reaction of a Th^{232} nucleus using a deuteron beam with a momentum of 4.8 GeV/c. The experiment was perfomed using a thin internal target in the JINR LVÉ proton synchrotron. The helium and lithium isotopes were recorded in the energy range of 14–38 MeV by a telescope composed of four semiconducting detectors. An upper limit of $\sim 2\ \mu$b was established for the production cross section of the He^{10} isotope, which is much lower than the value that follows from Q_{gg} systematics of the production cross sections of light fragments.

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Baz' *et al.*[1] calculated the binding energy of the He^{10} nucleus. They showed that the stability of this nucleus relative to the $He^{10} \rightarrow He^{8} + 2n$ decay depends greatly on the shape and magnitude of the central potential $U^{(33)}$ of the interaction of two nucleons with the total and isotopic spin $S = T = 1$. The shape and magnitude of this potential are unknown and are difficult to determine from the NN-scattering data. A small negative value of $U^{(33)}$, which does not contradict the NN-scattering data, gives stability to the He^{10} nucleus and even the He^{22} nucleus in the calculation.

Experimental searches for the He^{10} isotope in the fission products of U^{235} nuclei

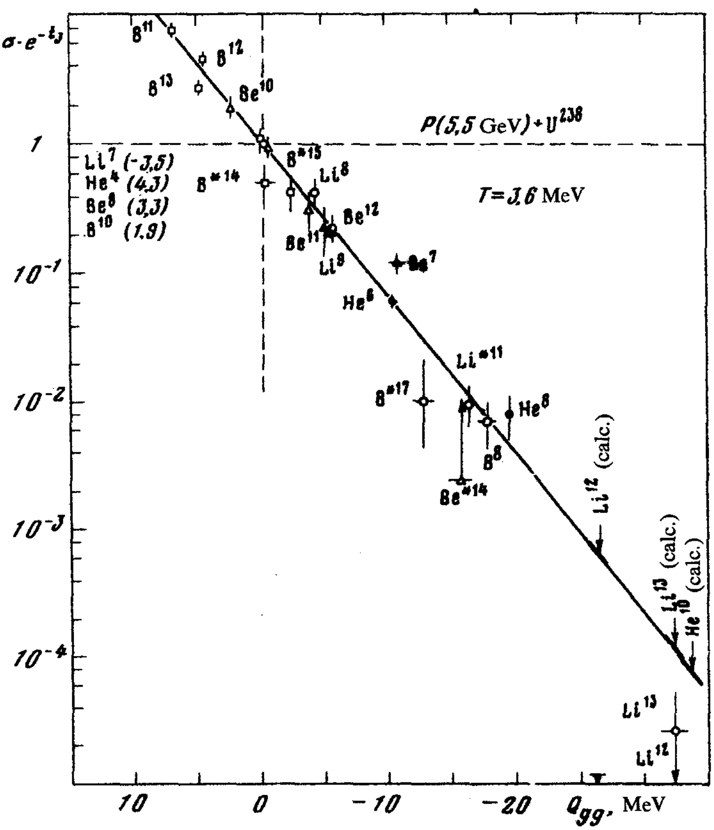

FIG. 1. Relative cross sections for production of fragments in the reaction $p + U^{238} \rightarrow fr + \ldots\ldots$ at 5.5-GeV proton energy[4,8,9] as a function of the energy release of the Q_{gg} reaction. The solid line represents the calculation according to Eq. (1).

bombarded by thermal neutrons,[2] in the many-nucleon transfer reactions in a heavy-ion beam[3] and in reactions via the interaction of 5.5-GeV protons with U^{238} nuclei[4] gave a negative result.

To pass judgment on the nuclear stability of the He^{10} isotope, it is necessary to compare the experimental results with the theoretical cross section for its production. This cross section can be estimated from the Q_{gg} systematics[5] for the fragment yield in nuclear interactions. Avdeĭchikov[6] suggested a new version of this systematic behavior of the cross sections for production of light products (A_1, Z_1, N_1, M_1) as a result of fragmentation of the target nucleus (A, Z, N, M) in the reactions induced by high-energy particles:

$$\sigma(A_1, Z_1) \approx c(Z_1, A)\exp(t_3)\exp(Q_{gg}/T), \qquad (1)$$

where

$$c(Z_1, A) = c(A)\exp(-V^c/T).$$

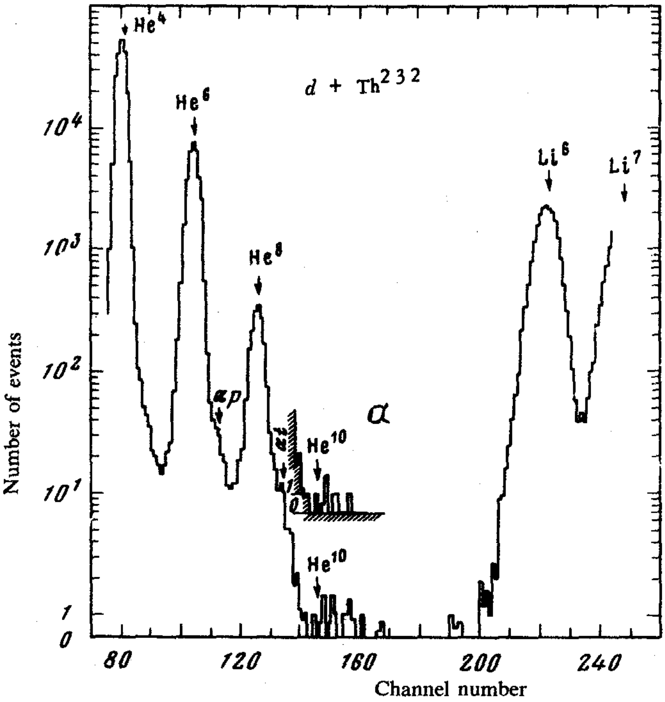

FIG. 2. Spectrogram of helium and lithium isotopes along the diagonal $F_1 \approx F_2$ obtained in this work as a result of irradiation of a Th^{232} target by deuterons with a momentum of 4.8 GeV/c. In inset α) the spectrum is shown in a narrower energy recording interval.

Here $Q_{gg} = M - (M_1 + M_2)$ is the energy release of the reaction, which is calculated for the reaction products in the ground state (M_1 and M_2 are the masses of the fragment and of the residual nucleus), $t_3 = (Z_1 - N_1)/2$ is the third projection of the isotopic spin of the fragment, T is the effective temperature of the target nucleus, $c(A)$ is the normalizing factor, $V^c \approx (0.9 - 1.0)\, V^c_{\text{nom}}$ is the Coulomb barrier of the fragment Z_1 and of the residual nucleus Z_2, V^c_{nom} is calculated for a relative spacing of the particles Z_1 and Z_2 equal to $r_1 + r_2 = 1.25\,(A_1^{1/3} + A_2^{1/3}) + 1.67$ F.[7]

Figure 1 shows the experimental data from Refs. 4, 8, and 9 on the relative yield of the products of interaction of 5.5-GeV protons with the U^{238} nuclei as a function of Q_{gg}. The nuclear masses, including that of He^{10}, were taken from Ref. 11. The newly discovered isotopes are marked by an asterisk.[4,9] By representing the isotopic yield in relative units, we were able to eliminate a certain ambiguity in the calculated values of $V^c(Z_1, Z_2)$. The cross sections for all isotopes of a given element were normalized relative to the isotope whose cross section is known to have a minimal experimental error. These isotopes are shown with their Q_{gg} (MeV) values in Fig. 1. In the given coordinates function (1) is represented by a single line whose slope is proportional to $1/T$. It can be seen that relation (1) describes well the yields of most of the light isotopes from this reaction at $T = 3.6 \pm 0.1$ MeV.

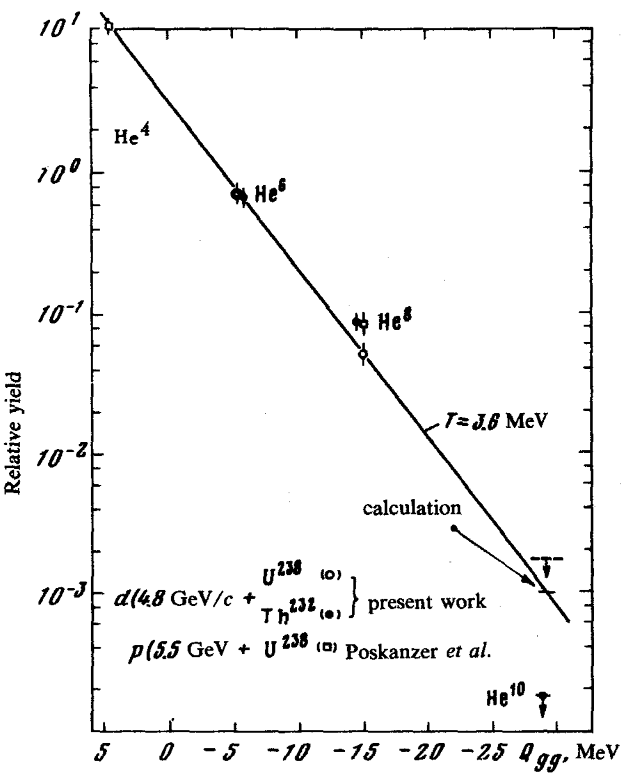

FIG. 3. Relative yield of helium isotopes as a function of the energy release of the Q_{gg} reaction: $\bar{\downarrow}$ represents the upper limit of the production cross section of the He^{10} isotope determined in this work and $\overline{\downarrow}$ denotes the same taken from Ref. 4.

In the experiment of Poskanzer *et al.*[4] they obtained the upper limit for the ratio of yields of the He^{10} and He^8 isotopes $\sigma(He^{10})/\sigma(He^8) \leqslant 1/100$, which is higher than the predicted ratio of 1/160, according to Fig. 1. (This is shown separately in Fig.3.)

The experiment in question was performed on the JINR LVE proton synchrotron by the internal-target method.[10] A 4.8-GeV/c deuteron beam bombarded a thin target made from metallic Th^{232}. The reaction products were recorded by a telescope composed of four semiconducting silicon detectors, which was placed at a 90° angle to the beam and which consisted of two ΔE detectors (with a thickness ΔE_1 of 61.6 μm and ΔE_2 of 45.6 μm), a total E-absorption detector (186.0 μm), and an anticoincidence detector EA (160 μm). By using two ΔE detectors in one telescope, we were able to identify each recorded particle twice. This was accomplished by two analog to digital processors, each of which calculated a function of the form:

$$F(\Delta E, E) = \Delta E(E + k\Delta E)^{m}$$

with optimum parameters $k = 0.75$ and $m = 0.72$.

The average value of this function for any isotope is proportional to the characteristic product $M^{0.7}Z^{2}$ and its dispersion is adequate for reliable separation of the light isotopes. Moreover, the result of two quasi independent identifications are compared in each recording event $F_1 = F(\Delta E_1, E + \Delta E_2)$ and $F_2 = F(\Delta E_2, E)$. In the (F_1, F_2)

plane the true events lie along the diagonal line $F_1 \approx F_2$. This criterion allows a significant reduction of the background associated with nonideal operation of the detectors (channeling effect, incomplete charge collection, etc.) and a partial reduction of the background from a random superposition of several particles.

In the experiment the secondary products were recorded in eight energy intervals each 3-MeV in width and having independent calibration. Figure 2 shows a spectrogram of helium and lithium isotopes, which was obtained as a result of a 50-h irradiation, for the full range of the recorded energies 14–38 MeV. The arrows indicate the calculated positions of the isotopes and the centers of mass of the peaks of the random superpositions of $\alpha - p$ and $\alpha - t$ (the $\alpha - d$ peak coincides with the position of He^8). The main background of the events near the calculated position of He^{10} is due to simultaneous (within the limits of ~ 100 nsec) random transmission of the particle pairs $He^6 - p$ and $He^6 - d$ through the telescope. The maximum yield of such superpositions corresponds to the energy range of 28–32 MeV, and the He^{10} isotope can be recorded in the interval of 18.2–31.4 MeV. Therefore, a section of the spectrogram near the position of He^{10} is shown in inset (a) of Fig. 2, which corresponds to a narrower energy recording interval equal to 18.2–28.1 MeV.

There were altogether 2000 He^8 nuclei recorded in the experiment. If we assume that the two events recorded in the region of He^{10} is the background level, we can give an upper limit for the ratio of the yields of the He^{10} and He^8 isotopes in the form $\sigma(He^{10})/\sigma(He^8) \leqslant 1/1000$.

Figure 3 shows the yield of the helium isotopes normalized to the production cross section of Li^6, which were obtained in three different reactions. There was no evidence of the presence of He^{10} nucleus at the ~ 2-μb cross-section level in the investigated $d + Th^{232}$ reaction. The upper limit of the production cross section of He^{10} obtained in this experiment is six times lower than that predicted by the Q_{gg} systematics according to Eq. (1).

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