Experimental search for ^{10}He nuclei in heavy-ion-induced reactions

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An upper limit of 5×10^{-7} mb/sr has been found for the cross section for production of the nucleus ^{10}He in the reaction ^{232}Th + ^{11}B (89 MeV).

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The recent major process in experimental methods and in accelerators themselves has made it possible to move much closer to the nucleon-stability boundaries, especially for light nuclei.[1–4] Reactions induced by heavy ions represent one of the most effective methods for producing nuclei far from the β-stability line.[4] All the theoretical predictions and the extrapolations from experimental data lead to different nuclear masses even in the region of light nuclei and thus give us a rather hazy picture of the nucleon-stability boundary.[5–8] Only experiments can resolve these uncertainties, but attempts to produce nuclei near the nucleon-stability boundary run into major difficulties because the cross sections for the production of these nuclei are small (10^{-34}–10^{-31} cm^2) and their lifetimes are short, reaching $\sim10^{-3}$ s. A further restriction is placed on the production method by the need to produce these nuclei with a low excitation energy because of the weak binding of the nucleons in these nuclei. A fundamental question involved here is the stability of the nuclide ^{10}He; this question has been under study, theoretically and experimentally, for more than 15 years now.

The experimental searches for ^{10}He nuclei in various reactions[1,3,9–13] have yielded only upper limits on the production cross section. Definite progress toward a determination of the stability of ^{10}He was made in experiments carried out to determine the mass of the unstable nucleus ^{9}He (Ref. 14). These experiments yielded the mass defect of ^{10}He (49.40 MeV) and led to the prediction that ^{10}He would be stable with respect to the emission of a single neutron ($B_n = +0.93$ MeV) but unstable with respect to the emission of two neutrons ($B_{2n} = -1.66$ MeV). There is an uncertainty of at least 1 MeV in these estimates, however, so that we cannot rule out the possibility in principle that ^{10}He might also be stable with respect to decay into ^{8}He + $2n$.

In this letter we are reporting an experimental search for ^{10}He nuclei in various heavy-ion-induced reactions by means of a highly sensitive apparatus which detects the production of light particles at cross sections as small as $\sim5\times10^{-35}$ cm^2/sr.

We studied the yield of all known helium isotopes which are produced in nuclear interactions of accelerated ^{10,11}B and ^{22}Ne ions with ^{nat}Ti and ^{232}Th targets in the energy interval from 8 to 10 MeV/nucleon. The experiments were carried out on the U-300 heavy-ion accelerator of the Nuclear Reactions Laboratory of the Joint Institute for Nuclear Research. The energy distributions and production cross sections of

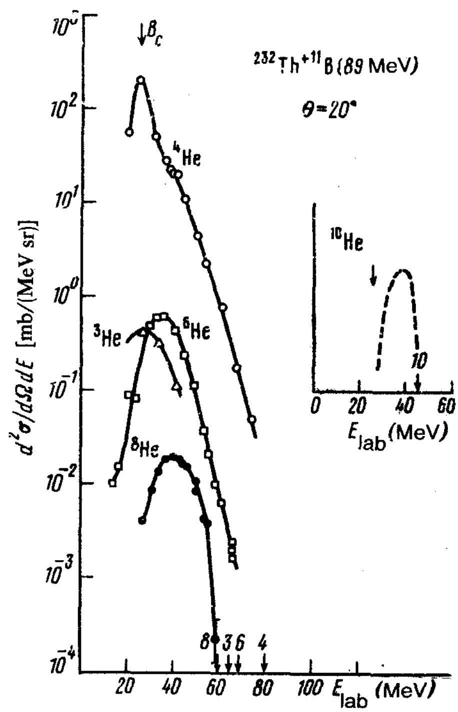

FIG. 1. Energy distributions of helium isotopes measured in the reaction ^{232}Th + ^{11}B (89 MeV). The arrows at the E_{lab} axis show the maximum possible energies for the various isotopes calculated under the assumption of a two-body reaction mechanism. The dashed curve is the expected shape of the ^{10}He distribution.

these nuclei at angles of 0° and 20° were studied with an MSP-144 magnetic spectrometer, in whose focal plane there was a telescope of $\Delta E - E$ semiconductor detectors. The total detection efficiency of the spectrometer with a single telescope consisting of detectors 17 mm in diameter is $\sim 5\times 10^{-4}$ sr. The target thickness was 2.5–7 mg/cm^2 in all the experiments, and the ion beam current at the target was 3–7 μA.

Figure 1 shows energy distributions of the helium isotopes for the reaction ^{232}Th + ^{11}B. The ^{8}He production cross section turned out to be largest in this reaction, so that this reaction was selected for the search for ^{10}He. Extrapolation of the data on the production cross sections of the light helium isotopes (Fig. 2) leads to a prediction of $\sim 5\times 10^{-3}$ mb/sr for the cross section for the production of ^{10}He nuclei in the reaction ^{232}Th + ^{11}B.

A system of eight semiconductor telescopes and a CR-39 dielectric nuclear-particle detector[15] in the focal plane of the magnetic spectrometer were used to detect the ^{10}He nuclei. At the given magnetic field, these detectors spanned the energy range from 26 to 40 MeV for ^{10}He. The measurement procedure and the data analysis procedure are described in more detail in Ref. 16.

This energy range was chosen for detecting ^{10}He nuclei because it was necessary to span the energy interval between the energy corresponding to the Coulomb exit

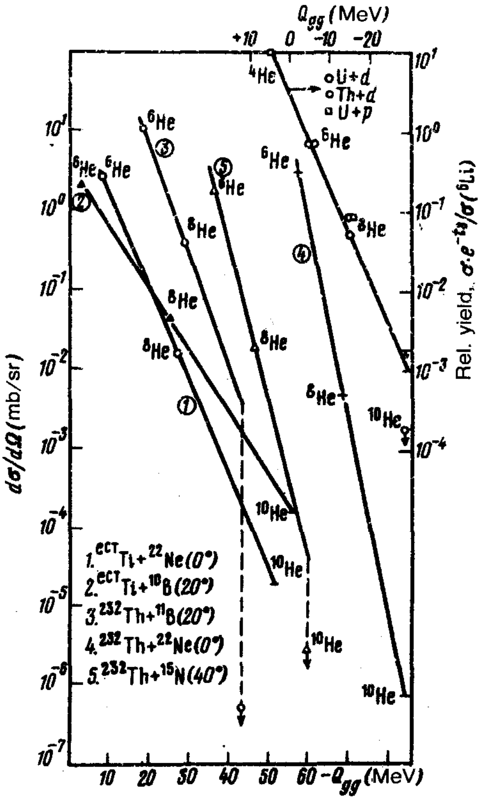

FIG. 2. Yields of the various helium isotopes vs the Q of the reaction $[Q=(M_1+M_2)-(M_3+M_4)]$ for reactions induced by deuterons and protons[3] and by the heavy ions ^{15}N (Ref. 12), ^{22}Ne (Ref. 16), and $^{10,11}B$ (present study).

barrier and the energy corresponding to the kinematic limit calculated under the assumption of a two-body reaction mechanism.[17] The position of the maximum in the ^{10}He energy distribution was determined by extrapolating the most probable energies in the distributions of ^3He, ^4He, ^6He, and ^8He, produced in the same reaction ($^{232}Th + {}^{11}B$). The maximum yield of nuclei was expected at 40 MeV.

The total number of ^8He nuclei detected in our experiment was $\sim 1.5\times 10^6$; the total number of ^{11}B ions in the beam was $\sim 7.5\times 10^{17}$. We did not detect a single event in which a ^{10}He nucleus was produced.

On this basis, an upper limit of 5×10^{-7} mb/sr is placed on the cross section for the production of ^{10}He nuclei in the reaction $^{232}Th + {}^{11}B$ (Fig. 2).

The ^{10}He yield was far less than expected from an extrapolation of the production cross sections for the light helium isotopes (Fig. 2). This result seems to imply that ^{10}He nuclei are unstable. This is not an absolute assertion, however; we cannot completely rule out the possibility that a marginal stability is strongly suppressing the production of ^{10}He nuclei, because part of the energy available in the reaction may go into an internal excitation of reaction products.

We also carried out some model experiments on the production cross sections of the weakly bound nuclei ^{11}Li and ^{14}Be. The cross section for the production of ^{11}Li ($B_{2n} = 0.16$ MeV; Ref. 18), which is formed in the reaction ^{232}Th + ^{11}B at a boron-ion energy of 89 MeV, was 2.8×10^{-3} mb/sr. We also measured the yield of ^{14}Be nuclei ($B_{2n} = 0.21$ MeV; Ref. 18), which are produced in the reaction ^{232}Th + ^{15}N at a nitrogen-ion energy of 145 MeV; the result is 4×10^{-5} mb/sr. The cross sections for the production of the isotopes ^{11}Li and ^{14}Be, found in these experiments are thus several times smaller than the cross sections expected from an extrapolation from the yields of other isotopes of lithium and beryllium.[19,20] It follows that the cross sections predicted for the production of weakly bound nuclei from an extrapolation of data on other isotopes are unreliable.

A final resolution of the question of the stability of ^{10}He nuclei will require producing them in the ground state. We believe that the double charge exchange ^{14}C(^{10}Be,^{10}He)^{14}O may prove the most effective reaction for this purpose. Reactions of this sort have recently begun to be used to excite Gamow-Teller resonances, and their cross sections can run to 10 μb/sr.[21] They provide final products in the ground state. In the case of a nuclear instability of ^{10}He, the mass of this nucleus can be determined quite accurately from the distribution of the ^{14}O kinetic energies measured under specified kinematic conditions, so that a final conclusion about the stability of this nucleus can be drawn. It must be noted, however, that this experiment will involve producing a beam of exotic ions (^{10}Be) and will thus require some special preparations.

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