Production of ultraheavy hydrogen isotopes in absorption of π^- mesons by ^{6,7}Li nuclei

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In an effort to detect ultraheavy isotopes of hydrogen, $^{4-6}$H, in two-particle reaction channels, an analysis has been made of the spectra of the p's, d's, and t's produced during the absorption of stopped π^- mesons by the isotopes ^{6,7}Li. The results indicate that resonance levels may exist in both the ^{4}H system and the ^{5}H system.

The question of the existence of ultraheavy isotopes of hydrogen and their properties has yet to be finally resolved. All that has been solidly established is that a quasistationary ^{4}H state exists. There has been essentially no study of the structure and characteristics of the excitation spectrum of this isotope. In the case of ^{5,6}H, the experimental information available is clearly insufficient for drawing any reliable conclusions about the presence of or (especially) the characteristics of such states.[1,2]

Theoretically, on the other hand, one can see significant progress, associated with the development of a method of hyperspherical functions for describing few-nucleon systems.[3] In particular, this method has been used to find a description of the properties of a wide range of nuclei near the stability boundary, including the "helium anomaly" i.e., the increase in binding energy from ^{5}He to ^{7}He and from ^{6}He to ^{8}He (Ref. 3). Corresponding calculations for hydrogen isotopes predict a monotonic decrease in the binding energy from ^{4}H to ^{6}H and the presence of excited levels of ^{4}H in the region 3–7 MeV (Ref. 4).

In this situation, an experimental search for and a study of ultraheavy hydrogen isotopes would be worthwhile both for refining the experimental data and for testing theoretical predictions.

As part of research which we began with the nucleus ^{9}Be (Ref. 1), we have carried out measurements in a search for ultraheavy hydrogen isotopes in the two-particle channels for the absorption of stopped π^- mesons by ^{6,7}Li isotopes. These experiments, carried out in the P2 channel of the synchrocyclotron of the Leningrad Institute of Nuclear Physics with the help of a multilayer PPD spectrometer,[5] included inclusive measurements of the high-momentum component of the p, d, and t spectra and correlation measurements, involving a coincidence detection of the charged particles. In contrast with the corresponding studies in Ref. 6, the spectrometer detected all the reaction products (p, d, t) out to the kinematic boundaries in a total-absorption regime. The energy resolution was no worse than 1 MeV over the entire range of

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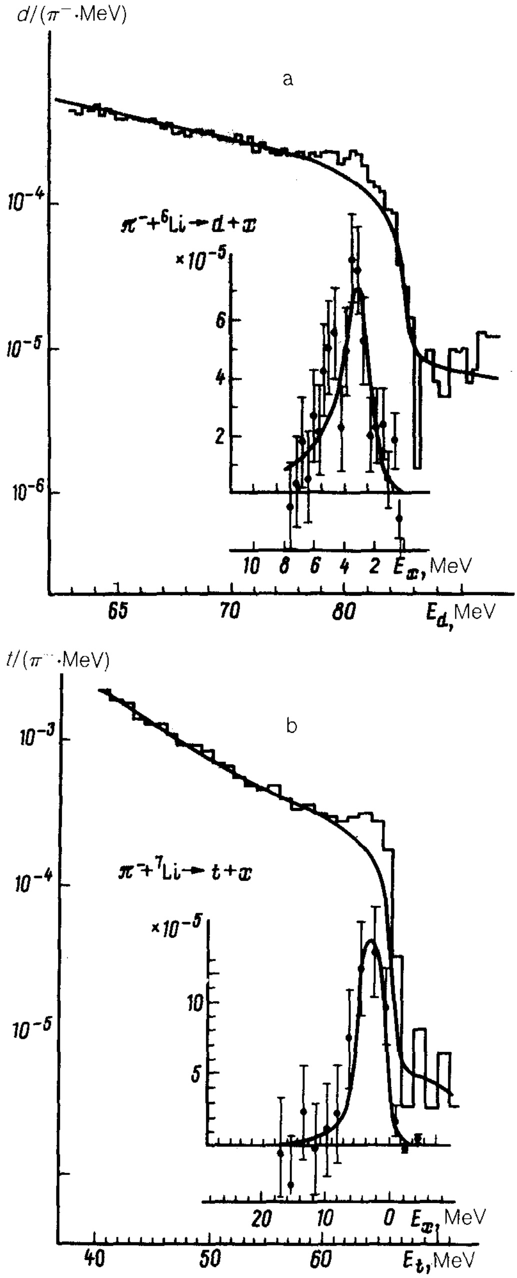

FIG. 1. Spectra of (a) deuterons ($\pi + {}^6\mathrm{Li} \to d + X$) and (b) tritons ($\pi + {}^7\mathrm{Li} \to t + X$). The curve shows the sum of phase volumes (see the text proper).

measurements, and the error in the energy calibration was ~200 keV (t) or ~500 keV (p, d).

Figures 1–3 show the results of the inclusive measurements of the high-momentum component of the p, d, and t spectra. The following procedure was used to search

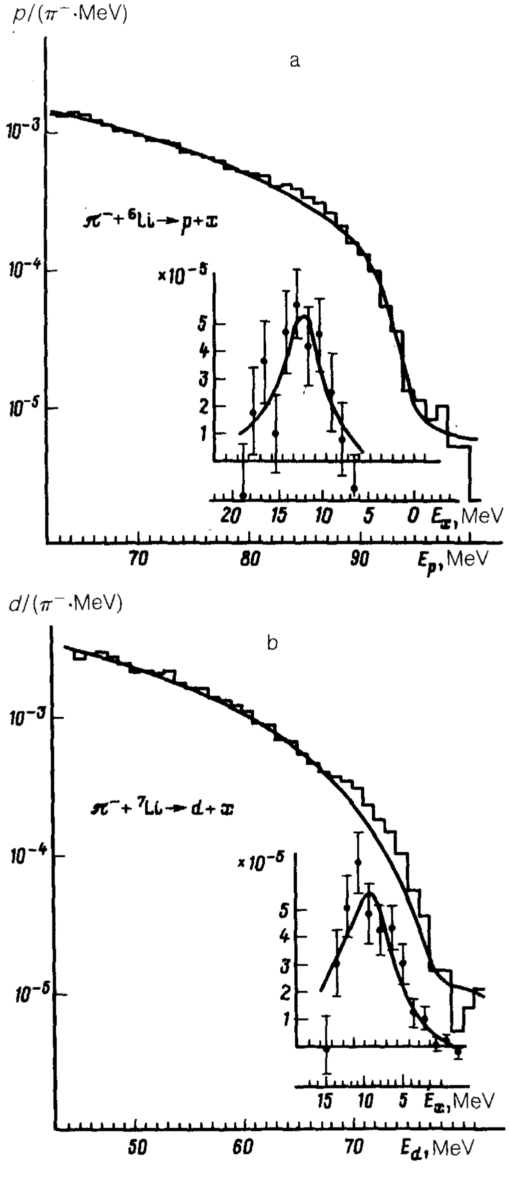

FIG. 2. Spectra of (a) protons ($\pi^- + {}^6\mathrm{Li} \to p + X$) and (b) deuterons ($\pi^- + {}^7\mathrm{Li} \to d + X$). The curve shows the sum of phase volumes (see the text proper).

for effects associated with manifestations of two-particle channels. The parts of the spectra corresponding to high excitations ($E_x \gtrsim 15$ MeV) of the residual system were described by the sum of phase volumes of all possible reaction channels except two-particle channels. We allowed for the possibility of a binary final-state interaction of neutrons (we took into account the ${}^2n$ channel, $E_r = 0$, $\Gamma = 0$; Ref. 7); for the spectra in Figs. 2 and 3, we also allowed for channels involving ${}^4\mathrm{H}$ ($E_r = 3.2$ MeV, $\Gamma = 1.0$ MeV). In fitting the results, we took into account the resolution of the apparatus and the contribution of background distributions, which was determined from the yield

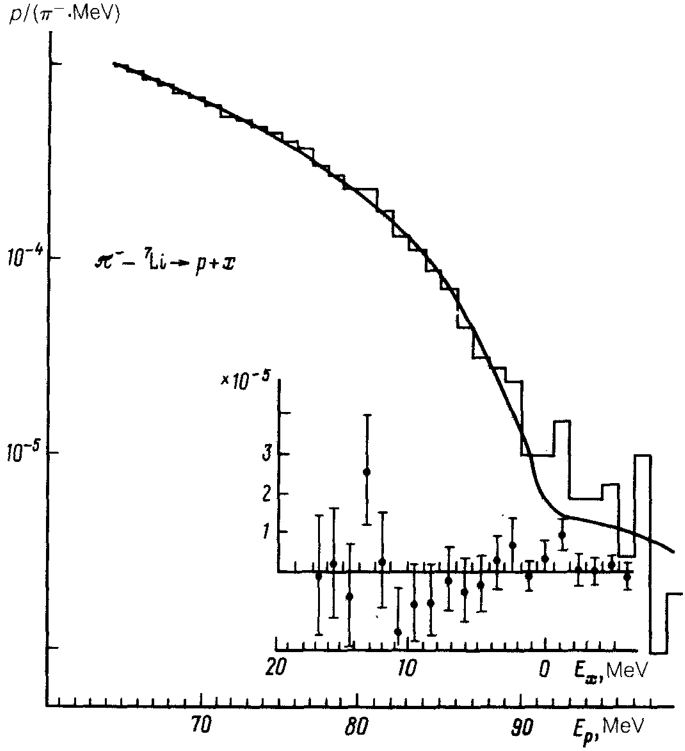

FIG. 3. Spectrum of protons ($\pi^- + {}^7\mathrm{Li} \to p + X$). The curve shows the sum of phase volumes (see the text proper).

outside the kinematic boundaries. We then analyzed the extent to which the experimental distributions exceeded the calculated distributions in the region of low excitations of the residual system. These differences are shown in the insets in Figs. 1–3; they are observed in all the spectra except that of protons from ^{7}Li. They were described by Breit-Wigner distributions with an energy-dependent width.[6] Note that the results of the analysis in terms of both the yields and the parameters of the resonant states are essentially independent of the choice of the limit E_x and agree with the results of joint fits by a sum of phase volume and a resonance curve.

From the analysis of the spectra of deuterons from ^{6}Li and tritons from ^{7}Li (Fig. 1) we found the following values of the yields and the properties of ^{4}H: $Y[{}^6\mathrm{Li}(\pi^-,d){}^4\mathrm{H}] = (1.5 \pm 0.3) \times 10^{-4}$ per stopped π^-, $E_r = 3.6 \pm 0.6$ MeV, $\Gamma = 3.1 \pm 0.7$ MeV; and $Y[{}^7\mathrm{Li}(\pi^-,t){}^4\mathrm{H}] = (5.1 \pm 1.4) \times 10^{-4}$ per stopped π^-, $E_r = 3.8 \pm 0.3$ MeV, $\Gamma = 3.4 \times 0.8$ MeV. In each case, the results obtained are close to the results of previous measurements[1] for the reaction $^9\mathrm{Be}(\pi^-,dt){}^4\mathrm{H}$ ($E_r = 3.0 \pm 0.2$ MeV, $\Gamma = 4.7 \pm 1.0$ MeV); there is also a good agreement in terms of reaction yields with the results of Ref. 6. On the other hand, the values which we found for the position and width of the ^{4}H state are slightly different from the data found in correlation measurements[6] with the ^{7}Li nucleus ($E_r = 2.7 \pm 0.6$ MeV,

$\Gamma = 2.3 \pm 0.6$ MeV). We might also point out that the experimental distributions can be described satisfactorily by a superposition of the ground and excited states of ^4H with the theoretical values of the resonance parameters.[8] The results which have been found thus do not rule out the possibility that the observed intensification can be explained by a contribution of unsplit ^4H levels.

The effects associated with the possible formation of the ^5H system are less apparent, because of the large widths of the structural features which are observed (Fig. 2). Analysis of the spectrum of protons from ^6Li and that of deuterons from ^7Li under the assumption of two-particle reaction kinematics yields the following values for the yields and characteristics of ^5H: $Y[^6Li(\pi^-, p)^5H] = (2.8 \pm 0.7) \times 10^{-4}$ per stopped π^-, $E_r = 11.8 \pm 0.7$ MeV, $\Gamma = 5.6 \pm 0.9$ MeV; and $Y[^7Li(\pi^-, d)^5H] = (3.4 \pm 0.7) \times 10^{-4}$ per stopped π^-, $E_r = 9.1 \pm 0.7$ MeV, $\Gamma = 7.4 \pm 0.6$ MeV. A similar broad state has been observed previously[9] in the reaction $^6Li(\pi^-, p)X$ at $E_p = 125$ MeV and $\theta = 20°$. In contrast with those data, however, and also in contrast with the results of a subsequent analysis,[7] the intensification which we observe cannot be explained by a contribution of channels in which ^4H is formed or by a final-state interaction of neutrons. Taking into account the results on ^5H at the nucleus ^9Be ($E_r = 7.4 \pm 0.7$ MeV, $\Gamma = 8 \pm 3$ MeV), we can discern certain changes in the characteristics of the observed states in the different reactions. We do not rule out the possibility that this variation stems from both the dynamics of the process and a difference in the initial states, which are particularly important in the case of the observation of broad states.[8,10] The latter question, however, apparently requires further study.

In contrast with the situation in the reactions which we have discussed, an analysis of the spectrum of protons from the nucleus ^7Li (Fig. 3) reveals no statistically significant deviations from the theoretical curve which might be attributed to the formation of ^6H in two-particle kinematics.

Information about the excitation spectrum of ^4H and the nature of these processes might possibility be refined and supplemented through an analysis of correlation measurements, which is presently being carried out. It is nevertheless apparent that the results which we have found (including the results for the nucleus ^9Be) are on the whole consistent with the general picture which follows from current theoretical calculations and which indicates a continuous decrease in the binding energy of these nuclear states with increasing A.

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