Detection of superheavy hydrogen isotopes in the reaction for the absorption of π^- mesons by ^{9}Be nuclei

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Correlation measurements of the pairs of charged particles, emitted at a 180° angle in the reaction in which stopped π^- mesons are captured by ^{9}Be nuclei, were carried out for the first time. Analysis of the spectra made it possible to identify the three-body reactions involving the superheavy hydrogen isotopes ^{4}H and ^{5}H. The ^{5}H state which was detected was found to have the following parameters: $E_r = 7.4 \pm 0.7$ MeV and $\Gamma = 8 \pm 3$ MeV.

Our goal in this study was to search for superheavy hydrogen isotopes and then to analyze them. The question of the existence of such states is of fundamental experimental importance, because at the present theoretical level an exact number of nuclei with stable nucleons cannot be predicted unambiguously from the known light isotopes. The question of the existence of nuclei of purely neutron origin, which can be estimated from the systematics of the lightest isotopes, specifically from helium isotopes, remains also unresolved.[1] In this respect, the systematics of superheavy hydrogen isotopes opens for us additional possibilities.

At present, the only reliable data are those on the resonant state[2–5] of ^{4}H. With regard to the heavier hydrogen isotopes, the possible existence of ^{5}H was reported only by Seth,[6] who studied the reaction $^6\text{Li}(\pi^-, p)X$. Two experimental studies of ^{6}H, in which the reactions with heavy ions were considered and which produced an unexpected result, have recently been published.[7,8] According to the results of these studies, ^{6}H is a more strongly bound system than ^{4}H and ^{5}H. There has so far been no experimental evidence for the existence of ^{7}H, for which a nucleon stability has been predicted under certain assumptions.[1]

In our experimental search for the superheavy hydrogen isotopes, we have considered the reaction in which stopped π^- mesons are captured by ^{9}Be nuclei. In contrast with the preceding studies, in which two-body reactions were used for this purpose, we studied the formation of such states in three-body reactions, looking for the hydrogen isotopes in the residual nucleus. In the experiment we detected pairs of charged particles (p, d, t) that were emitted at a 180° angle, making it possible to search for three-body reaction channels involving hydrogen isotopes from ^{3}H to ^{7}H:

$$\pi^- + {}^9\text{Be} \rightarrow t + t + {}^3\text{H}, \qquad (1)$$

$$\rightarrow d + t + {}^4\text{H}, \qquad (2)$$

$\rightarrow p + t + {}^5H$, (3)
$\rightarrow d + d + {}^5H$, (4)
$\rightarrow p + d + {}^6H$, (5)
$\rightarrow p + p + {}^7H$ (6)

The measurements were carried out with a low-energy pion beam of the synchrocyclotron of the Leningrad Institute of Nuclear Physics. We used a multibeam semiconductor spectrometer,[9,10] which made it possible to identify the charged particles and to measure their energy all the way to the boundaries of kinematically resolved region. The luminosity of the detecting semiconductor telescopes was 0.11 sr for threshold-energy particles and 0.04 sr for maximum energy protons. The monitoring system of the spectrometer, which consists of two semiconductor detectors situated in front of the target of thickness 136 mg/cm^2, made it possible to determine the stopping depths of the π^- mesons and to introduce the appropriate corrections to the energy loss of secondary particles in the target. The energy resolution of the spectrometer ($\sim$0.5 MeV) and the absolute energy matching ($<$0.4 MeV) were controlled by means of the reaction $\pi^- + {}^6Li \rightarrow t + t$ ($E_t = 61.6$ MeV).

Figure 1 shows the missing-mass spectra for the detected pairs. The sum of the mass of the triton and the masses of the corresponding neutrons is used as the reference point of the distributions. The peaks in the region of small missing masses for the events with *tt* and *dt* detected pairs correspond to the three-body channels of reactions (1) and (2). The position and width of the peaks are determined not only by the parameters of the final nuclear states but also by the parameters of the apparatus, in this case the energy and angular resolutions. To determine the parameters of the nuclear states corresponding to the observed peaks, the experimental missing-mass distributions were approximated by the sum of the distributions calculated from the phase volume for all possible finite systems, with allowance for the angular and energy resolutions. The resonant nature of the finite states in the three-body reaction channels was taken into account by means of the Breit-Wigner distribution. The calculation method was monitored by singling out reaction channel (1) for the events with *tt* pairs. The results for the parameters of the triton which we obtained—its mass which corresponds in this case to the position of the resonance, $E_r = -0.1 \pm 0.1$ MeV, and the width, $\Gamma = 0.0 \pm 0.1$ MeV, demonstrate that this method is correct and that there are no systematic shifts. The reaction yield in the angular interval $\Delta\theta = 164°–180°$, which corresponds to the angular capture of the spectrometer, is $Y_{\Delta\theta} = (5.2 \pm 0.4) \times 10^{-5}$ 1/stopped π^-. This value may also be used as an estimate of the lower limit of the yield of reaction channel (1).

A similar analysis of the missing-mass spectrum for the events with the detected *dt* pairs allowed us to determine the position and width of the resonant state of ${}^4H$: $E_r = 3.0 \pm 0.2$ MeV, $\Gamma = 4.7 \pm 1.0$ MeV, and also allowed us to determine the detected yield of reaction channel (2), $Y_{\Delta\theta} = (2.4 \pm 0.8) \times 10^{-4}$ 1/stopped π^-.

Analysis of the spectrum for the *pt* pairs (Fig. 1c) is less obvious. Attempts to explain the maximum on the basis of reflection of the ${}^4H$ resonance in the ${}^9Be(\pi^-, pt)$ ${}^4Hn$ channel and on the basis of the reaction involving the formation of two ${}^4H$ isotopes, where the detected triton always belongs to the resonant ${}^4H$ state, were

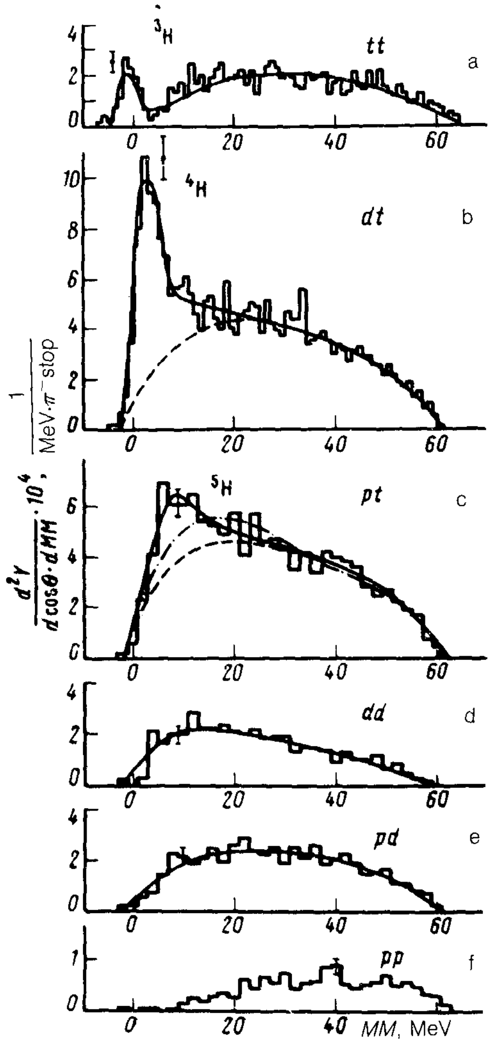

FIG. 1. The missing-mass spectra (MM) for the detected pairs of charged particles: $E_p \geqslant 12.3$ MeV, $E_d \geqslant 16.5$ MeV, $E_t \geqslant 19.6$ MeV. Solid curves—the result of an approximation: for *tt*, *dt*, and *pt* pairs with allowance for the contribution of three-body reaction channels in which ^{3}H, ^{4}H, and ^{5}H, respectively, are formed; for *dd* and *pd* pairs without regard for the three-body channels. Dashed curves for the *dt* and *pt* pairs—the reaction channels with $\geqslant 4$ final-state particles. Dot-dashed curve for the *pt* pairs—the result of an approximation by the sum of channels without regard for ^{5}H.

unsuccessful, since they lead to a maximum in a region much higher than 10 MeV. The experimental distribution can be reproduced satisfactorily by introducing a three-body channel (3) with the formation of a resonant ^{5}H state. The parameters of the resonant state of ^{5}H in this case are $E_r = 7.4 \pm 0.7$ MeV and $\Gamma = 8 \pm 3$ MeV and the corresponding yield for reaction channel (3) is $Y_{\Delta\theta} = (1.2 \pm 0.2) \times 10^{-4}$ 1/stopped π^-.

The missing-mass spectra for the events with *dd* and *pd* pairs can be described satisfactorily without the help of the reaction channels involving the hydrogen isotopes heavier than ^{4}H. The shape of the missing-mass distribution for the *pp* events suggests that the principal contribution to these reactions comes from the channels with a large multiplicity.

In our analysis we have thus been able to identify three reaction channels (1)–(3) with the formation of hydrogen isotopes as the residual nucleus. The ^6H and ^7H states were not detected in this experiment. The triton parameters obtained in channel (1) raise the hope that the results on ^4H and ^5H are correct. Our data on ^4H are in agreement with the data obtained previously.[2–5] At the same time, the result on ^5H is inconsistent with the estimate of Ref. 6, where the reaction ^6Li $(\pi^-, p)X$: $E_r = 11 \pm 1.5$ MeV, $\Gamma = 14$ MeV, was studied. It should be noted that this estimate was obtained by the author without regard for the reaction channel in which a known isotope, the ^4H isotope, is formed, an omission which may have affected the result appreciably.

It should also be noted that to detect the reactions involving the formation of superheavy ^5H and ^6H isotopes, we and the authors of Refs. 6–8 used calculations of the phase volume without any considerations of the dynamics of the reactions. For the ^4H state consistent results have already been obtained for a broad range of nuclear reactions, but a final conclusion regarding the existence of ^5H and ^6H and their parameters cannot yet be drawn because of the absence of data.

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