SEARCH FOR NUCLEAR FUSION REACTION IN $^3He\mu d$ - SYSTEM

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Among the nuclear fusion reactions potentially suitable for energy production the reaction

$$d + {}^3\mathrm{He} \rightarrow {}^4\mathrm{He}\ (3.66\ MeV) + p\ (14.64\ MeV)$$

looks especially attractive as an example of a "clean" energy source with big energy release.

The interest to this reaction has increased even more after significant amount of ^{3}He was observed at the Moon surface [1]. An additional opportunity to study this reaction has appeared in the research of muon catalyzed fusion and related mesomolecular processes. Calculations of the rates of muon transfer from hydrogen mesoatoms to helium nuclei pointed to existence of the "molecular" mechanism of transfer [2], with the rate 100 times higher than the rate of direct transfer [3].

In a mixture of deuterium and helium-3 this process looks like

$$d\mu + {}^3\mathrm{He} \rightarrow [\ {}^3\mathrm{He}\mu\, d\ ]^* \rightarrow {}^3\mathrm{He}\mu + d,$$

where $[\ {}^3\mathrm{He}\mu d\ ]^*$ is an intermediate bound state. Now this mechanism of muon transfer is experimentally confirmed. The existence of the $[\ {}^3\mathrm{He}\mu d\ ]$ bound system justifies the estimation of the ^{3}He$-\mu-d$ fusion rate in this molecule. There are several calculations of the nuclear fusion rate, λ_f, that differ widely. The first estimation in [4] was $\lambda_f \approx 10^2\ s^{-1}$, it has practically killed the interest to this reaction. But later [5,6] some arguments were suggested allowing the existence of the high fusion rate ($\lambda_f \approx 10^8\ s^{-1}$ and even higher). We

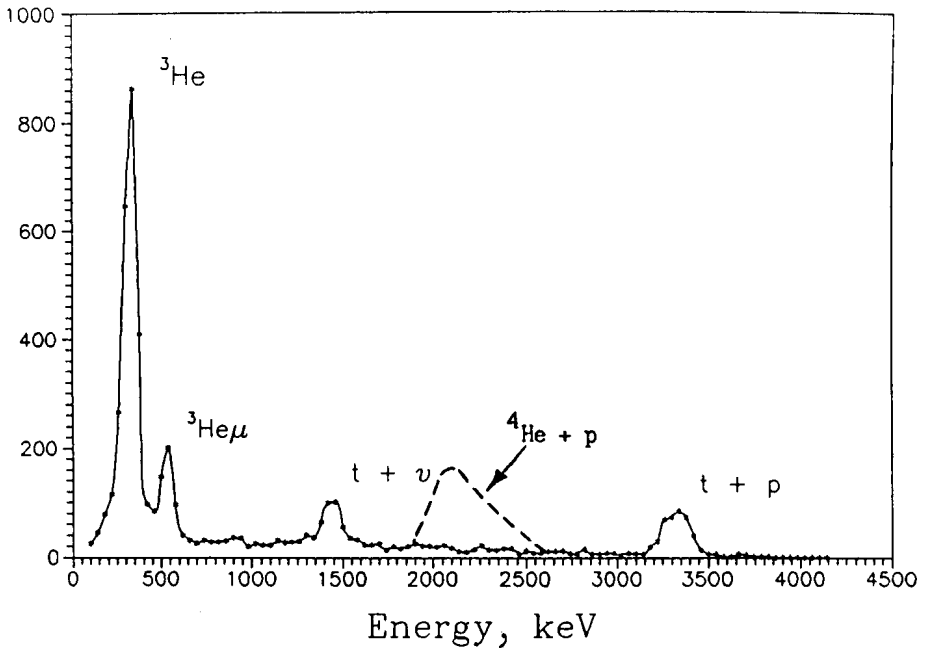

Fig.

have performed an experiment that made it possible to determine the upper limit of the fusion reaction in the ^{3}Heμd molecule. The ionization chamber [7] filled with the mixture of deuterium and 11% of helium-3 of 89 *atm* pressure was exposed at the muon beam of the LNPI synchrocyclotron. The energy spectrum of the charged particles registered with the chamber is shown in fig. One can see the well known spectrum of the $d-\mu-d$ fusion events, together with the peak due to triton emerging after capture of muons in ^{3}Heμ atoms. These atoms are formed partly due to initial population and also due to decay of the [^{3}Hμd] complexes.

The dashed curve shows the expected spectrum from the $d + {}^3$He fusion reaction. To estimate the number of the fusion events, $N_{\alpha+p}$, we used the formula

$$N_{\alpha+p} = \frac{\lambda_f}{\lambda_f + \lambda_{dec}} \cdot N^{3}_{\mathrm{He}\mu d}.$$

Here λ_f is the nuclear fusion rate averaged over the states of the system with different angular momenta J; λ_{dec} is the decay rate of the [^{3}Heμd] system (considered roughly to be the same for all J).

The number of the ^{3}Heμd-molecules formed through muon exchange process was calculated with the formula:

$$N^{3}_{\mathrm{He}\mu d} = \frac{N^F_{dd}\lambda^m_{ex}\cdot C_{\mathrm{He}}}{\lambda_{dd\mu}(1 - C_{\mathrm{He}})}$$

Here N^F_{dd} is the number of registered $d-\mu-d$ fusion events, $\lambda_{dd\mu}$ is the $dd\mu$-molecule formation rate, λ^m_{ex} is the muon transfer rate from $d\mu$ to ^{3}He. The statistical error on the number of dd-fusion events in the energy interval 1.9-2.5 *MeV* was taken as the upper limit of the value of $N_{\alpha+p}$, 36 *events*. With the number of ^{3}Heμd (87410) and $\lambda_{dec} = 1.5\cdot 10^{11}\, s^{-1}$ [8] we have $\lambda_f < 7\cdot 10^7\, s^{-1}$. We should mention again that the above estimate is averaged over the different angular momenta:

$$\lambda_f = \beta_0 \lambda_f^{J=0} + \beta_1 \lambda_f^{j=1}.$$

Here β_0 and β_1 are the populations of the $J = 0$ and $J = 1$ states of the $^{\mathrm{He}}\mu d$-molecule. In the future we plan to achieve higher accuracy in λ_f estimation working at low temperatures, where the background reaction of the $dd\mu$-fusion is much less intensive while the muon transfer rate λ^m_{ex} is increasing.

The high-intensity muon beam at the PSI meson factory will allow to increase the statistics by 2 orders of magnitude. So the upper limit for λ_f can be pushed down to $\sim 10^6\, s^{-1}$.

References

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