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FIRST MEASUREMENTS OF $dt\mu$ CYCLE CHARACTERISTICS IN LIQUID H/D/T MIXTURE

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1 Introduction

In the last years interest to the triple mixture of hydrogen isotopes arises mainly due to first observation in [1] of unexpected high rate of $dt\mu$ catalysis in a such mixture. Analysis of experiment [1] indicates on important role of the epithermal tμ atoms on dtμ molecule formation [2]. Compared to D/T mixture in triple mixture additional epithermal dμ and tμ appears because of muon transfer processes from hydrogen with very high rates ($\sim 10^{10}$ s^{-1}). The reduction of elastic scattering dμ and $t\mu$ on hydrogen atoms in $\sim$1 eV region by Ramsauer-Townsend effect leads to increase in number of mesic atoms with epithermal energies. Under this conditions it becomes possible to form dtμ molecules through the strong resonances at energies 0.2-0.8 eV with high rate as it was shown in [2]. Especially high epithermal $dt\mu$ formation rate is predicted on HD molecules which exceed thermalyzed rate about two orders. Moreover, the muon transfer rate from epithermal dμ atoms to tritium is higher due to its strong rise with energy. All these processes could increase the muon catalyzed fusion cycling rate (λ_c). However adding hydrogen to D/T mixture puts in the kinetics pdμ and ptμ cycles in which the muon loss probability is close to 100% and hence it is restrictive factor for dtμ catalysis yield.

The purpose of our experiment is to obtain main characteristics of muon catalyzed dt fusion process in a liquid triple mixture. In our investigations we take advantage of the new experimental method [3] developed at JINR (Dubna). Experiment with liquid triple mixtures has been performed at JINR phasotron during 1997.

2 Experimental setup and method

Scheme of the experiment is showed on Fig. 1. The cylindrical target filled with H/D/T mixture is placed in the center of the setup. It is surrounded by the fast cylindrical multiwire proportional chamber 4+5 (MWPC) which detects electrons from muon decay. Several wires of MWPC (4) are allocated for registration of

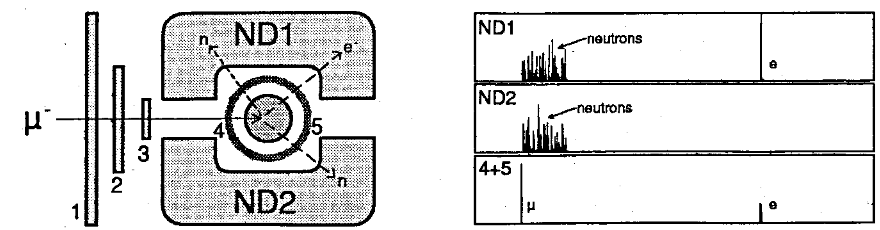

Figure 1: Setup and experimental event

incoming muons. System of scintillation counters 1, 2, 3 and the part of MWPC 4 are intended for an exact determination of the muon stop in the target. The trigger demands one decay electron in the target during 20 μs after the muon stop excluding first 200 ns to suppress the background from muon stops in the target walls. The neutron spectrometer (plastic scintillator) consisting of two detectors ND1 and ND2 is destined to detect neutrons from dt fusion reactions with high efficiency ($\varepsilon_n \simeq 70\%$ at lowest threshold). Signals from detectors were digitized on FADCs (8 bit $\times$ 2048 samples, 100 MHz) and charge collected from neutrons then was analyzed.

The target vessel was filled with mixture of hydrogen isotopes extracted from the metalhydrid gas generator. To achieve the high target purity on admixtures with $Z > 1$ the mixture is purified before filling in the palladium filters up to 0.1 ppm. To determine molecular concentrations in the target we preformed chromatography analysis of the mixture before filling and after evacuation. More detailed information about filling system, apparatus and tritium target one can find in Refs. [4, 5, 6].

High dtμ cycling rate and high neutron detection efficiency cause frequent pile-ups of neutron signals (see Fig. 1). To solve this problem the new analysis method has been developed. In this method the main parameters of dtμ catalysis were obtained from the summarized neutrons charge time spectrum. This spectrum is proportional to the well-know neutrons time spectrum used in previous methods but it is created without requirement of individual neutron signal. The neutrons charge time spectrum is described by formulae

$$N_q(t) = \overline{q} N_\mu \varepsilon_n \lambda_c \varphi \, e^{-(\omega\lambda_c\varphi + \lambda_0)t}, \qquad (1)$$

where $\overline{q}$ is an average charge per one neutron obtained from calibration experiment, N_μ is the normalized factor, φ is the relative hydrogen density (in LHD), ω is the total sticking probability, λ_0 is the muon decay rate.

3 Results

The measurements were done with four sets of isotope concentrations at temperature 22 K. The collected time spectra for electron and fusion neutrons are shown on Fig. 2. In the analysis we took only events with coincidence of electron signal in MWPC and electron signal in one of the neutron detector parts that allows to separate electron signal from neutron signals and suppress background. The electron time spectrum is a sum of two exponents the fastest of which (τ=200 ns) is caused by decay of the muons captured in the target walls and parts of the design. Parameters of this background were investigated in experiment with empty target. Under analysis it is subtracted by the appropriate fit procedure of the electron time spectrum. From the same fit we obtained normalized factor N_μ in formulae (1) as square under the slow exponent which is caused muon decay in the target. Slope of the slow exponent was obtained λ_{exp}=0.457$\pm$0.002 μs^{-1} which is very close to the free muon decay rate λ_0=0.455 μs^{-1}. Thus the summarized concentration of oxygen and nitrogen in the target is not greater then 0.5 ppm.

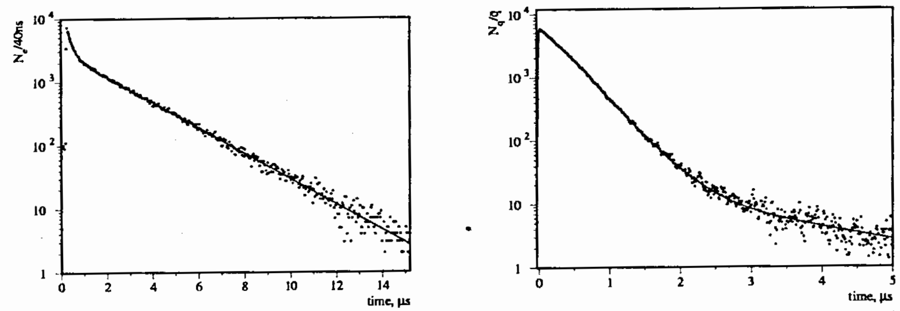

Figure 2: Electron time and neutrons charge time spectra

The neutrons charge time spectrum consists of two components, the first one corresponds neutrons from dtμ catalysis and is described by (1). The second component is caused by gamma quants from nuclear reactions in pdμ and ptμ molecules and neutrons from dtμ cycles that follow these nuclear reactions in case muon rejuvenation. This component has a slope closed to λ_0 and its influence on values of the main parameters is negligible under conditions of the experiment. Effect of pdμ and ptμ cycles manifests itself on value of total sticking probability (ω). To obtain main parameters of dtμ catalysis the neutrons charge time spectrum was fitted with sum of formulae (1) and exponent having free amplitude parameter.

Results of the analysis on main parameters of dtμ catalysis (neutron yield, cycling rate and total sticking probability) in triple mixture are shown in Table 1. Values

Table 1: Experimental results in liquid H/D/T mixture

Run	1	2	3	4
Concen-trations, %	C_p=32.1(1.7) C_d=57.2(1.7) C_t=10.7(0.3) C_{D_2}=32.5(0.9) C_{HD}=37.5(0.6)	C_p=55.8(1.1) C_d=37.0(1.1) C_t=7.2(0.2) C_{D_2}=14.3(0.3) C_{HD}=40.0(0.8)	C_p=22.1(1.6) C_d=52.1(1.6) C_t=25.8(0.8) C_{D_2}=28.9(0.8) C_{HD}=21.2(0.6)	C_p=50.4(1.0) C_d=34.2(1.0) C_t=15.4(0.3) C_{D_2}=11.3(0.2) C_{HD}=35.0(0.7)
Density (φ), LHD	1.12(0.03)	1.08(0.02)	1.14(0.03)	1.10(0.02)
Y_n, $\frac{neutrons}{muon}$	13.6(0.8)	3.78(0.23)	29.8(1.7)	8.1(0.5)
λ_c, μs^{-1}	34.8(2.5)	15.3(1.1)	75(5)	29.7(2.0)
ω, %	6.2(0.4)	23.7(1.4)	2.82(0.17)	8.1(0.5)

of errors in the table take into account the error of neutron detection efficiency calculation assumed equal 5% [7].

Available results have demonstrated general decrease of dt fusion yield as compares with D/T mixture Fig. 3. For example the measured also in the same experiment neutron yield in D/T mixture $Y_n \simeq 115$ at C_t=35% [8] drastically decreased to

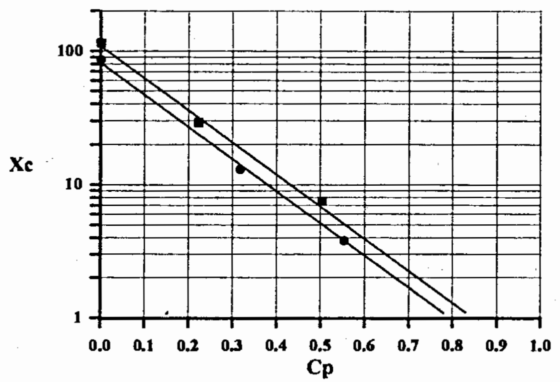

Figure 3: Neutron yield X_c as a function of protium concentration C_p in a triple H/D/T mixture. The upper line corresponds to $C_t/C_d = 0.5$, the lower line corresponds to $C_t/C_d = 0.2$

value $\simeq$30 with adding 22% of hydrogen in run 3.

Preliminary analysis of λ_c dependence on concentrations indicates that dtμ formation in liquid H/D/T mixture occurs mainly on D_2 molecules as in liquid D/T mixture. So in runs 2 and 4 with less D_2 concentration, cycling rate is less then one in run 1 having similar tritium and HD concentration but larger amount of D_2 molecules. Even more in run 1 the tritium concentration is 1.5 times less then in run 4 but cycling rate is higher due to most D_2 molecules concentration. Consequently the epithermal mechanism of dtμ formation is not so intensive in the liquid H/D/T mixture as it was expected. Our estimation gives the contribution of the epithermal processes in λ_c about 15-25% of its value.

As it is seen from the table the value of total sticking probability (ω) is much higher then in D/T mixture [8]. That is caused by the presence of pdμ and ptμ cycles in which muon loss probability is high. Slow component of the neutrons time spectrum is also caused by these cycles (mainly by pdμ one). It is supposed that advanced kinetics analysis of the neutron time spectra will give information about detailed kinetics parameters in H/D/T mixture. This work is in progress.

4 Conclusion

In the experiment the first investigation of the muon catalyzed dt fusion in liquid H/D/T mixture was carried out. Values of the main parameters of dtμ catalysis in H/D/T mixture were obtained by the new analysis method. General decrease of fusion yield in the liquid H/D/T mixture as compares with D/T was established.

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