# TWO-LEVEL ADIABATIC APPROXIMATION CALCULATION FOR REACTION OF ISOTOPE EXCHANGE OF METASTABLE MESIC ATOM AND HYDROGEN ATOM

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The rate of a muon transfer from the lighter hydrogen isotope to the heavier one is a parameter determining the number of muon catalysis cycles. This is well known for the charge exchange from the μ-atom ground state /1,2/. The process of isotopic exchange between an ordinary atom and an excited muonic atom was less studied. Recently semiclassical calculations have been done for quasiresonant charge exchange of excited muonic deuterium on a tritium atom /3,4/. In some cases the obtained rates of a muon transfer are of the same order of magnitude as the mesic atom deexcitation rates and have an essential effect on the ground state population of the initial μ-atom. This is a significant quantity of μ-catalysis kinetics.

The muon exchange from 2s-state plays a peculiar part because at collision energies ε below 0.2 eV (Lamb shift of 2s- and 2p-levels) the muon transition to the heavier isotope is in fact a single channel of the 2s-state decay. Therefore it is desirable to raise the reliability of theoretical predictions in this case.

We have performed the quantal calculation of the cross sections for muon transfer from mesic protium (pμ) and mesic deuterium (dμ) to deuterium (D) and tritium (T) atoms. The two-level approximation of the adiabatic framework was used. The necessary effective potentials for the three body problem were taken from the numerical tables /6/. The similar computation for reaction $p\mu(2s)+d\rightarrow$ $\rightarrow d\mu(2s)+p$ was performed previously /7/. Unlike paper /7/ we have taken into account the target electron shell and Lamb shift in mesic atom. These improvements have changed the asymptotical behaviour of effective potentials and proved to be essential for cross section values.

Energy dependence of the total cross sections for isotope exchange reaction is shown in table 1. Table 2 compares rates $\lambda_{2s}$ of muon transfer from $d\mu(2s)$ to T for semiclassical /4/ and quantal /5/ calculations. The latter exceed the former almost at all energies considered in consequence of which the number of cycles per muon will increase. Since this value is of great interest more accurate evaluations are needed for the charge exchange from excited states.

*Table 1*

**Calculated total cross sections for quasiresonant reaction of isotopic exchange**

| Colliding sistem | Total cross section ($10^{-20}$ cm$^2$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $\varepsilon$=0.004 | 0.01 | 0.02 | 0.04 | 0.06 | 0.10 | 0.5 | 1.0 eV |
| $d\mu(2s)+T$ | 74 | 46 | 40 | 27 | 17 | 10 | 4.4 | 2.3 |
| $p\mu(2s)+D$ | 130 | 41 | 29 | 26 | 26 | 16 | 3.2 | 1.7 |
| $p\mu(2s)+T$ | 27 | 36 | 15 | 15 | 12 | 10 | 2.6 | 1.3 |

*Table 2*

**Comparison of muon exchange rates normalized to liquid hydrogen density $N_0$ for $d\mu(2s)+T$ collision ($N_0=4.25\cdot10^{22}$ cm$^{-3}$)**

| Method of calculation | Muon exchange rate ($10^{11}$ s$^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $\varepsilon$=0.004 | 0.01 | 0.02 | 0.04 | 0.06 | 0.10 | 0.5 | 1.0 eV |
| Semiclass. /4/ | 9.0 | 11 | 13 | 15 | 16 | 17 | 9 | 7 |
| Quantal /5/ | 25. | 25 | 31 | 29 | 22 | 17 | 17 | 12 |

The table data are obtained neglecting the Stark transitions in the entrance reaction channel. It is quite correct while the collision energy is below 0.2 eV /3/. However at $\varepsilon \geqslant 0.5$ eV the rate of the Stark 2s—2p mixing is large ($\sim 10^{12}$ s$^{-1}$ /8/). As a result a mesic atom can be found in the 2s-state with probability of 1/4 no matter what state of n=2 family happened to be at the beginning. Then the rate $\lambda$ of muon exchange from any state of n=2 equals 1/4 $\lambda_{2s}$ because $\lambda_{2p}$ is negligible when colliding mesic atom and hydrogen atom (for collision with a molecule one should take account of muon exchange from 2p-state /3/, then $\lambda = 1/4\lambda_{2s} + 3/4\lambda_{2p}$).

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