COULOMB DEEXCITATION OF MESIC HYDROGEN IN COLLISIONS WITH HYDROGEN NUCLIDES

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It is well known that the process of the deexcitation of muonic deuterium in deuterium-tritium mixture is very important for the problem of the muon catalyzed fusion, since the resulting value of the ground state population q_{1s} of muonic deuterium directly determines the efficiency of the catalysis process, i.e. the number of catalysis cycles per muon. The earlierst stages of the cascade are characterised by the small energy yield (few electron-volts) and are determined by chemical reactions, including the dissociation of the target molecule. At the further stages of the cascade the Coulomb deexcitation becomes important [1], as well as external Auger effect and, finally, for the lower states, radiative transitions. Besides deexcitation processes, in the mixture of hydrogen isotopes one should take into account the processes of the muon transfer from the lighter isotope to a heavier one. To calculate q_{1s} value, one needs the rates of all the processes involved. All these rates depend on the collision energy. Thus, one of the problems to decide here is: what is the value of this energy? The initial muonic atom energy amounts to about $1 \div 1.5$ eV. In the course of the deexcitation muonic atoms are slowed down as a result of elastic collisions. At the same time some of these processes, e.g. Coulomb deexcitation and charge exchange with deexcitation, can lead to the acceleration of the muonic atom because of the absence of the third light particle (photon or electron) which could bring off the most of the large energy yield.

The effective potential of the interaction of excited muonic hydrogen atom having parabolic quantum numbers $(n\, n_1 n_2 m)$ with a nucleus of the charge Z is determined asymptotically by a linear Stark effect $u(R) \simeq 3\ Z\, n\, (n_1 - n_2)/(2R^2)$, where R is the internuclear distance. Quasiclassical approximation for such a potential is valid for $n_1 \neq n_2$ so one may consider the motion of a mesic atom along a classical trajectory with the impact parameter ρ. The transition probability is completely determined by analytic properties of terms, corresponding to the initial and final states of the system, in the complex R plane, beeing large mainly in the region of the quasicrossing of the terms in question, i.e. in the region, close to the

singularities (branch points) of the terms. It is exponentially small, the exponent beeing determined by a Massey parameter

$$\delta(\varrho) = \left|\mathrm{Im}\int_C p(R)\,dR\right| = \left|\mathrm{Im}\int\limits_{ReR_c}^{R_c} \frac{\Delta u(R)dR}{v_R}\right|,$$

where $p(R) = [2M(\varepsilon - u(R) - \varepsilon\rho^2/R^2)]^{1/2}$ — radial momentum, $\varepsilon = M\,v^2/2$ — relative energy of colliding particles, C — integration contour, beginning and ending at the real axis and going around the complex crossing point of the terms R_c, $v_R = [p_1(R) + p_2(R)]/(2M)$ — mean radial velocity at the contour. The total transition probability is $w(\rho) = 2\,\exp(-2\delta)\,[1 - \exp(-2\delta)]$.

The cross section is equal to

$$\sigma = \pi\int_0^{\rho^2_{max}} w(\rho)\,d\rho^2$$

The reaction rate reduced to the liquid hydrogen density $N_0 = 4.25 \cdot 10^{22}$ cm^{-3} is equal to $\lambda = N_0\,\sigma\,v$, where v is the relative velocity of colliding particles.

We consider the following processes: Coulomb deexcitation in the monoisotope target

$$(H\mu)^*_n + H \to (H\mu)^*_{n-1} + H, \tag{1}$$

where $(H \equiv p, d, t)$;

Coulomb deexcitation of g-type:

$$(H\mu)^*_n + H' \to (H\mu)^*_{n-1} + H' \tag{2}$$

where $M_H > M_{H'}$; Coulomb deexcitation of u-type:

$$(H'\mu)^*_n + H \to (H'\mu)^*_{n-1} + H; \tag{3}$$

Coulomb charge exchange:

$$(H'\mu)^*_n + H \to (H\mu)^*_{n-1} + H'; \tag{4}$$

Inverse Coulomb charge exchange:

$$(H\mu)^*_n + H' \to (H'\mu)^*_{n-1} + H. \tag{5}$$

The branch points of a T-series, which connect the terms with parabolic quantum numbers (n, n_1, n_2, m) and $(n-1, n_1, n_2-1, m)$, are responsible for Coulomb deexcitation [2]. One should distinguish symmetric (gerade) g-states and antisymmetric (ungerade) u-states. Both g- and u-states have a T-series of branch points with the same Re R_T, but Im $R_T(u) \simeq 2$ Im $R_T(g)$, so the direct transition between u-terms is suppressed. In the mixture of hydrogen isotopes, e.g. $d - t$-mixture, $d\mu$-states correspond to u-states, while $t\mu$ ones correspond to g-states. In this case, besides the T-series, the branch points of the P-series related with the exchange interaction are important, P-points are responsible for charge exchange reactions. For isotopes masses in question Re $R_P >$ Re R_T.

We use also the semiclassical values for terms in question instead of the asymptotic expansion (which is not valid for the upper term in the vicinity of the T-point) to calculate Massey parameters with sufficient accuracy. Only attractive initial states were considered (with $n_1 < n_2$) which give the largest contribution due to the 'focusing' of the particles. The electron screening was taken into account.

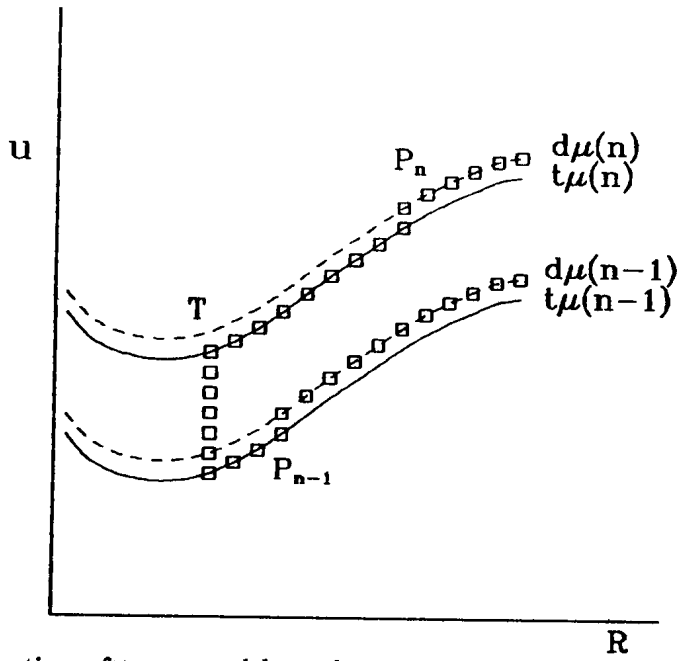

Fig.1. Configuration of terms and branch points of the T- and P-series for the $d-t$ mixture. Squares mark the path for the three-step process (3)

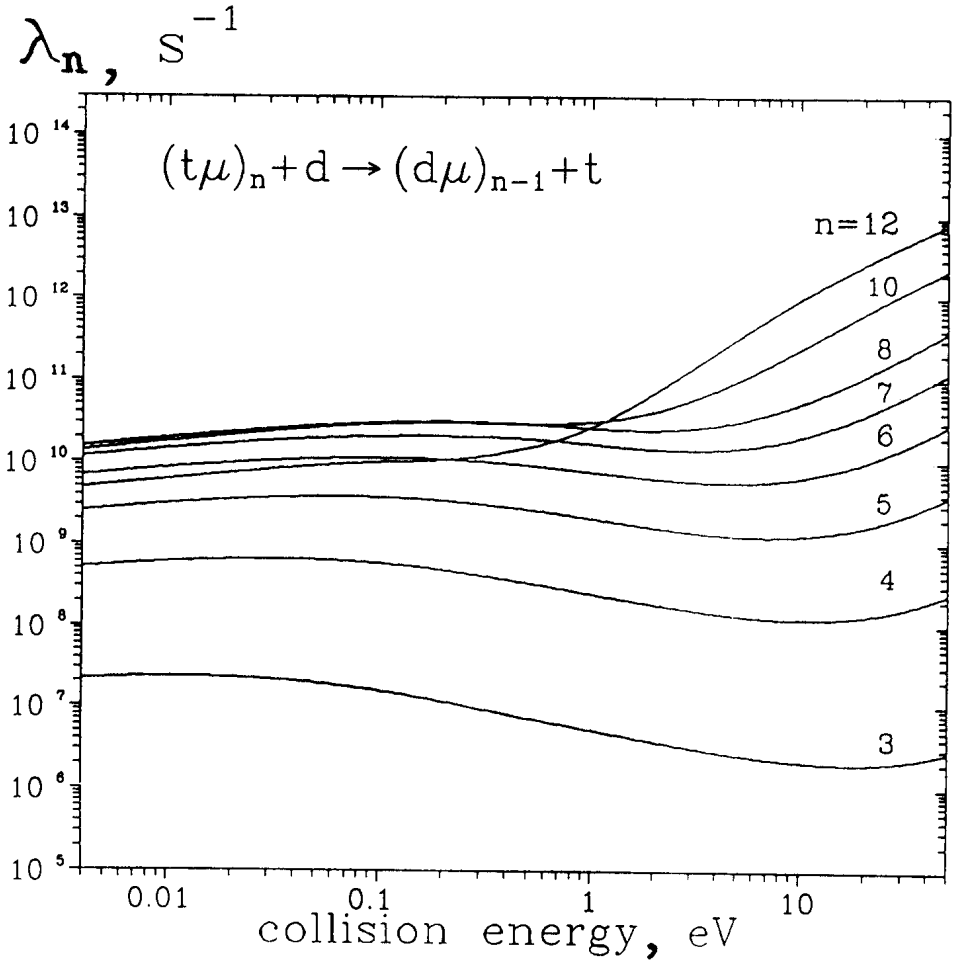

Fig.2. Rates for inverse muon transfer from tritium to deuterium as functions of energy for different n

The processes (1)–(2) are described by transitions via g-type T-points. The processes (3)–(5) are realized as three- or two-step processes, one of the step beeing the transition via P-point (Fig.1). The cross sections and rates for reactions (3)–(5) do not differ much from those for (1)–(2), since P-transition proceeds with the small Massey parameter, i.e. with large probability (Fig.2).

REFERENCES

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2. *Solovyev E.A.* Sov.Phys.Usp., 1989. V.32. P.228.