ISOTOPE EXCHANGE REACTIONS IN MIXTURE OF HYDROGEN ISOTOPES

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The processes of isotopic exchange in which the muon is transferred from a lighter to a heavier nucleus are essential in the kinetics of muonic hydrogen in mixtures of hydrogen isotopes. They are particularly important in studies of muon catalysed fusion [1]. For example, the most interesting case of μCF in deuterium-tritium mixtures involves $d\mu + t \rightarrow t\mu + d$ transitions which are followed by the formation of $dt\mu$ molecular ions. In more than 99% of fusion reactions in $dt\mu$, the muon is freed and becomes available to initiate another μCF cycle. The faster the isotopic exchange is, the shorter is the μCF cycle and the greater is the average number of reactions catalysed by a single muon during its lifetime. The exchange reactions may proceed between the ground atomic states as well as between the excited ones, i.e.

$$(d\mu)^*_n + t \rightarrow (t\mu)^*_n + d$$

where n is the principal quantum number.

The transitions between the excited states enhance the rate of isotopic exchange so the effective rate becomes: $\lambda = \lambda_{dt}/q_{1s}$, where q_{1s} is the fraction of muons reaching the ground state of $d\mu$. Muon transfer rates in the excited states exceed by about three orders of magnitude the rate of the isotopic exchange for n = 1, and the $n > 1$ rates are comparable with those of deexcitation processes. It was shown earlier [2—4] that the transitions in the excited states up to n=5 considerably influence the value of q_{1s}. It was assumed that for $n > 5$ muon transfer was much slower than deexcitation, so that it did not alter the value of q_{1s} which was determined considering only $n \leq 5$.

In present work we analyse q_{1s} including $n = 6$ and 7 and calculate q_{1s} as a function of energy [5] for the D—T, H—D and H—T mixtures. As before, we use the WKB method. The molecular terms corresponding to the initial and final states and their crossing points are evaluated in the complex plane of the internuclear distances R, electron screening is taken into account in the first order of perturbation theory.

In the WKB approach, the cross section is given as

$$\sigma = 2\pi \int_0^{\rho_{max}^2} (Ch^2\,\delta)^{-1}\, d\rho^2$$

where ρ is the impact parameter. The Massey parameter

$$\delta = |\, Im \int_c p_R\, dr\,|$$

where $p_R = p_R(\varepsilon,\rho)$ is a radial momentum and R is the inter-nuclear distance. The integration in δ is performed in the complex R plane over the contour C beginning at the real axis and going round the terms crossing point R_c. The value ρ_{max} is determined by the condition that p_R is real along the trajectory. After calculating the cross sections and the corresponding reaction rates $\lambda_n = \sigma_n V N_{22}$ (V is the relative velocity of atoms at infinite R, $N_0 = 4.25\times10^{22}\ cm^{-3}$ is liquid hydrogen density) the system of kinetic equations was solved to obtain q_{1s}-values. The calculations show that the inclusion of the muon transfer from higher excited states $n = 6$ and 7 affects the resulting q_{1s} values, especially for small densities and large concentrations of heavy isotope. The effect is as high as 30% for d—t mixture. The result contradicts the asumption made in [2—4] that for $n > 5$ muon transfer does not compete with deexcitation.

References

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