DECAY MODES OF HYDROGEN-HELIUM MESIC MOLECULES

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It is known that collisions of the muonic hydrogen atom in the ground state can lead to the formation of hydrogen-helium mesic molecules [1] in the excited state. Deexcitation of such a molecule leads to the dissociation of the molecule into the hydrogen nucleus and muonic helium atom (molecular charge exchange). The dissociation of the mesic molecule can be accompanied by the emission of the photon or electron with the energy ~ 6.8 keV [2]. Molecular mechanism of the muon transfer from the ground state of muonic hydrogen to helium is confirmed experimentally. Nevertheless the measured transfer rates in some cases differ from theoretical predictions. Besides, transfer rates obtained from the time distributions of muonic hydrogen atoms differ sometimes considerably from those obtained by measuring the photon yield. Significant difference in the photon yields from $d\mu^3He$ and $d\mu^4He$ molecules was observed by Nagamine [3]. This difference could not be explained by the difference in the mesic molecule formation rates.

These discrepancies can be explained by the presence of another deexcitation channel with the rate comparable with the radiative one. We calculated the rates of three decay modes of the muonic hydrogen-helium molecules: radiative (λ_γ), Auger (λ_e) and predissociation (λ_p). We obtained the following expressions for photon and electron spectra (we use the units $\hbar = e = m = 1$, $m^{-1} = m_\mu^{-1} + M_H^{-1}$, $H \equiv p, d, t$) :

$$\frac{d\lambda_\gamma}{d\omega} = \frac{8}{3\pi v}\left(\frac{\omega}{c}\right)^3 I_J^2 \tag{1}$$

$$\frac{d\lambda_e}{d\varepsilon} = \beta\frac{32}{3\varepsilon v}(m_e Z)^4 Q(\xi)\, I_J^2, \tag{2}$$

where J is the total angular momentum of the molecule, ω and ε are the photon and electron energies respectively, v is the velocity of the relative motion of nuclei, Z is the effective charge in the field of which the conversion electron is moving, β is the number of electrons in the molecule

$$Q(\xi) = \left[(1+\xi^2)(1-e^{-2\pi\xi})\exp\left(4\xi\arctan(1/\xi)\right)\right]^{-1},$$

$\xi = Z\,(m_e/2\varepsilon)^{1/2}$. The I-values are determined by the matrix elements of the dipole transition between the initial ($2p\sigma$) and final ($1s\sigma$) states. Total probabilities of the radiative and Auger dissociation were obtained by integrating eqs.(1) and (2) over the spectra.

The predissociation of the molecule is connected, in the quasiclassical approximation, with the existence of the branch point of the Q-type which joins the terms $2p\sigma$ and $1s\sigma$. In the vicinity of the branch point $U_{2p\sigma}(R) - U_{1s\sigma}(R) \sim \sqrt{R - R_c}$. The probability of the two-particle dissociation in this case is calculated as the probability of the subbarrier nonadiabatic transition

$$\lambda_p = \nu \exp(-2\delta),$$

where ν is the frequency of the nuclei vibration in the molecule, δ is the Massey parameter. Both these variables are expressed via the radial momentum $p(R) = [2M(\varepsilon_J - U) - J(J+1)/R^2]^{1/2}$:

$$\nu = \left[2M \int_{R_1}^{R_2} \frac{dR}{p(R)}\right]^{-1}, \tag{3}$$

where R_1, R_2 are the turning points for the nuclei motion in the molecule,

$$\delta = \left|\mathrm{Im} \int_C p(R)\, dR\right|, \tag{4}$$

the integration contour begins and ends at $R = R_1$ going around the branch point $R_C = 1.21 + 1.36\,i$.

The Table contains calculated oscillation frequencies of mesic molecules ν, as well as the rates of three decay modes.

Table

Oscillation frequencies ($10^{16}\,s^{-1}$) *and dissociation rates of hydrogen-helium mesic molecules* (10^{11}, s^{-1})

$J = 0$	$p\mu^3He$	$p\mu^4He$	$d\mu^3He$	$d\mu^4He$	$t\mu^3He$	$t\mu^4He$
ν	7.70	7.81	7.39	7.55	6.74	6.90
λ_γ	2.11	2.24	1.80	1.94	1.70	1.84
λ_e	0.56	0.58	0.47	0.49	0.44	0.46
λ_p	47.3	35.4	3.58	1.85	0.79	0.31
$J = 1$						
ν	6.42	6.82	6.74	6.48	6.50	6.82
λ_γ	1.74	1.89	1.58	1.74	1.53	1.70
λ_e	0.45	0.47	0.41	0.43	0.39	0.42
λ_p	31.6	24.8	2.77	1.38	0.66	0.27

The Auger-dissociation rates are given for the molecule $(H\mu\,He)^+$. If the molecular ion has enough time to become neutral, the Auger rates will be greater by a factor ~ 1.25. The two-particle, in contrast with the radiative and Auger decays, decay rate has a sharp isotopic dependence, which is usual for subbarrier transitions for sufficiently large Massey parameters. The rates λ_p are an order of magnitude higher than λ_γ for $p\mu\,He$ system and

are comparable with λ_γ for $d\mu He$ one. This fact allows one to explain the results of experiments, where the formation rate for $H\mu He$ molecule was claimed to be several times lower than the theoretical prediction, as well as the isotopic difference of photon yields, observed in [3].

REFERENCES

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