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Four-body calculation of energy levels of muonic molecule dtμe in muon catalyzed fusion

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Four-body calculation of energy levels of muonic molecule dtμe in muon catalyzed fusion

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Synopsis We investigate dtμe (= d + t + μ + e) four-body system which includes the most important bound states $(dt\mu)_{11}$ in muon catalyzed fusion (μCF). We directly estimate the energy shift more accurately than the previous perturbation calculation. The shift found to be one order of magnitude larger than previous calculation and to be more significant in the calculation of the μCF reaction rate.

A negatively charged muon (μ) has a lifetime of 2.2 μs and its mass is 207 times heavier than an electron. The muon can bind hydrogen nuclei in molecule which is less than several hundred fm in size. In the case of a deuterium (D_2) and tritium (T_2) mixture, the muon catalyzes a nuclear fusion reaction ($d + t \rightarrow \alpha + n + 17.6$ MeV) in the muonic hydrogen molecular ion dtμ. This phenomenon is so-called muon catalyzed fusion [1,2]. It has been observed that a muon can catalyze the d-t fusion reaction about 150 times during its lifetime. Though μCF researches had been stagnant due to low energy productivity, they become reevaluated because of recent progress in intense [3] and low cost [4] muon source.

Formation of $(dt\mu)_{v=1,J=1}$, which is the first excited state ($v = 1$) with total angular momentum of one unit ($J = 1$), in collision of a tμ atom and D_2 molecule is a resonance process and is one of the rate limiting processes. The muonic molecule $(dt\mu)_{11}$ forms inside the electronic molecule D_2, and is small enough to be regarded as a pseudo nucleus in the host electronic molecule. Since the excess energy due to the formation is used to the ro-vibrational excitation of the host molecule, the calculated rate of the resonance process is very sensitive to the binding energy of the $(dt\mu)_{11}$. In order to elucidate this μCF process and promote the fusion reaction, it is necessary to calculate the binding energy (2.7 keV) of the $(dt\mu)_{11}$ with an accuracy of 0.1 meV. The binding energy has been accurately calculated by many authors as non-relativistic Coulombic three-body problem. Moreover, some corrections to the three-body energy including relativistic and QED effects, particle spin (hyperfine) effects, nuclear electromagnetic structure effects, and energy shifts caused by the host molecule (finite size) have been calculated. The energy shift due to the sum of these effects is several tens meV, which is much larger than the required accuracy. In this study, we calculate $(dt\mu)_{11}$e system to estimate the finite size effect. Previous calculation for the energy shift [5] was done by the 2nd order perturbation method, but the 1st and 2nd terms were 18.253 eV and -17.752 eV, respectively. In order to improve the accurate of the calculation, we perform four-body calculation [6]. Since the deexcitation energy of the $(dt\mu)_{11}$ is larger than the binding energy of the electron, the $(dt\mu)_{11}$e system is a resonance state (Figure 1). We calculate the four-body system with a complex scaling method [7], and obtain both position and width of the resonance energy.

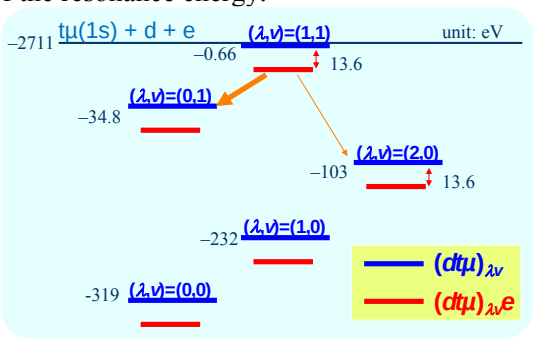

Figure 1. Energy levels of the dtμe system.

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