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ENERGY PRODUCTION DUE TO THE μ-CATALIZED DT FUSION PROCESS IN A MIXTURE OF DEUTERIUM AND TRITIUM*

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Recent study of the μ mesonic molecular formation of DTμ(1) through an excited rotational-vibrational level (J=1, v=1), which has a low binding energy of ε_{11} = 0.7 eV, has been encouraging as a possibility of μ-catalized DT fusion for energy production.(2,3) This reaction can take place at a much lower temperature than that required for magnetic confined fusion because of the small Bohr radius (2.56×10^{-11} cm) caused by the large mass of muon which is 207 times as heavy as an electron. Although the high energy costs of muon production generally make it impractical for energy production, it has been considered that substantial energy gains can be achieved from the fissile fuel bred by the neutrons produced in a μ-catalized fusion reaction or the high energy spallation, fission and evaporation reaction.

The general scheme of the mesonic-molecular process in the $D_2 + T_2$ mixture is shown in Figure 1. The μ^- meson which has a decay constant, $\lambda_0 = 0.455 \times 10^6$ sec^{-1} is the decay product of π^- or K^- mesons. These π^- and K^- mesons are produced by high energy nuclear reactions. After slowing down, the μ^- meson is captured by the K-orbit to form the mesonic atoms Dμ and Tμ at the rate of λ_a. Some μ^- are transferred from the deuterium to the tritium at the rate of τ_{DT}, and the mesonic atom Tμ collides with the deuterium and forms a mesonic molecule

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$DT\mu$. This rate of $\tau_{DT\mu}$ is much faster than the rate of formation of $DD\mu$ or $TT\mu$ molecules. Therefore, the dominant fusion reaction is the DT reaction. After the DT fusion reaction, most μ^- are ejected with negligible energy with the probability $(1-W_s)$. The free μ^- mesons are recaptured by deuterons or tritium, and the cycle is repeated. However, some of the μ^- mesons cannot escape the He atom, the non-escape probability being given by W_s (sticking factor). This causes the cycle to be terminated. Because of the very short life of the μ^- meson ($\lambda_0^{-1} = 2.2 \times 10^{-6}$ sec), the number of fusions catalized by the μ^- meson depends on the formation rates of mesonic atoms and molecules ($\lambda_a, \lambda_{DT\mu}$) and the transfer rate λ_{DT}, which are functions of the density and temperature of the D_2 and T_2 mixture. These reaction rates are proportional to their density N. Thus, $\lambda = \lambda^0 \phi$ where $\phi = N/No$ is the ratio of the nuclei mixture (N) to the density of liquid hydrogen $No = 4.25 \times 10^{22}$ cm^{-3}) and the λ^0 is the reaction rate at liquid hydrogen density. In Figure 1, C_D and C_T are concentrations of the deuterium and tritium nuclei ($C_D + C_T = 1$). The number of μ^- catalized fusions that occur per one μ^- meson produced (X_c) is an important value for the evaluation of energy production, and is obtained by solving the kinetic equation for the reaction process[4,5] shown in Figure 2. Due to the slow molecular formation rates of $DD\mu$ and $TT\mu$, the DT fusion is dominant and the value of X_c is expressed as

$$X_c = \left(\frac{\lambda_0 + \lambda_a}{Q_M} - 1 \right) \Big/ (1 - W_s) \qquad (1)$$

where

$$Q_M = (\lambda_0 + \lambda_a) + \left(\frac{\lambda_f (1 - W_s)}{\lambda_0 + \lambda_f} \right) \left(\frac{\lambda_{DT\mu} C_D}{\lambda_0 + \lambda_{DT\mu} C_D} \right) \cdot \left[\left(\frac{\lambda_{DT} C_T}{\lambda_0 + \lambda_{DT} C_T} \right) \lambda_a C_D + \lambda_a C_T \right] \qquad (2)$$

Figure 2 shows the values of X_c as a function of the tritium concentration C_T for various $D_2 + T_2$ mixture densities ($\phi = 10^2 \sim 0.1$) for typical values of $\lambda_a^o = 10^{10}$ sec^{-1}; $\lambda_{DT}^o = 2.7 \times 10^8$ sec^{-1}; $\lambda_{DT\mu}^o = 1.0 \times 10^8$ sec^{-1}, and $W_s = 10^{-2}$.

At liquid hydrogen density, X_c becomes 50 at $C_T = 0.4 \sim 0.6$, but as the density increases to $\phi = 10^2$, X_c approaches 100 ($\approx 1/W_s$). This occurs even when the concentration of tritium is as small as 1%. If we can reduce the sticking factor W_s from 10^{-2} to 5×10^{-3} or 1.0×10^{-3} by using the photo mesonic reaction, the value of X_c increases in inverse proportional to the sticking factor W_s at high density mixture shown in Figure 2. However, at liquid hydrogen densities, the effect is not as substantial and has no effect at all in low density mixtures. This suggests the possibility of using the parallel applications of implosion of target material with μ^- catalized fusion. Lasers, relativistic electron or heavy ion bombardments could be used to create the implosion.

Sensitivity studies of different λ_{DT}^o and $\lambda_{DT\mu}^o$ indicate that $\lambda_{DT\mu}^o$ increases X_c at high concentrations of tritium (C_T) but not at low concentrations, and increase of λ_{DT}^o does not have much effect on X_c.

This study indicates the possible use of μ-catalized fusion for energy production. Further work needs to be carried out on the effect of target temperature and on reducing the high energy cost for producing μ^- mesons which are required.

References

1. V. M. Bystritsky et al., "Experimental Detection and Investigation of Muonic Catalyzed Fusion of Deuterium and Tritium", JETP Letters, 31(4), 229 (1980).

2. Yu. V. Petrov and Yu. M. Shabel'skii, "Estimate of the Expenditure of Energy in the Production of π^- Mesons by Nucleons in Light Nuclei", Sov. J. Nucl. Phys., 30(1), 66 (1979).

3. H. Takahashi et al., "Nuclear Fuel Breeding by Using Spallation and Muon Catalysis Fusion Reactions", Atomkernergie-Kerntechnik, 36(3), 195 (1980).

4. S. S. Gershtein et al., "Kinetics of Muon Catalysis Processes in a Mixture of Deuterium and Tritium", Sov. Phys. JETP, 51(6), 1053 (1980).

5. A. A. Harms and S. G. Lie, "Kinetics and Energetics of Muon-Catalyzed DT Fusion", to be published in Nuc. Sci. & Engrg.

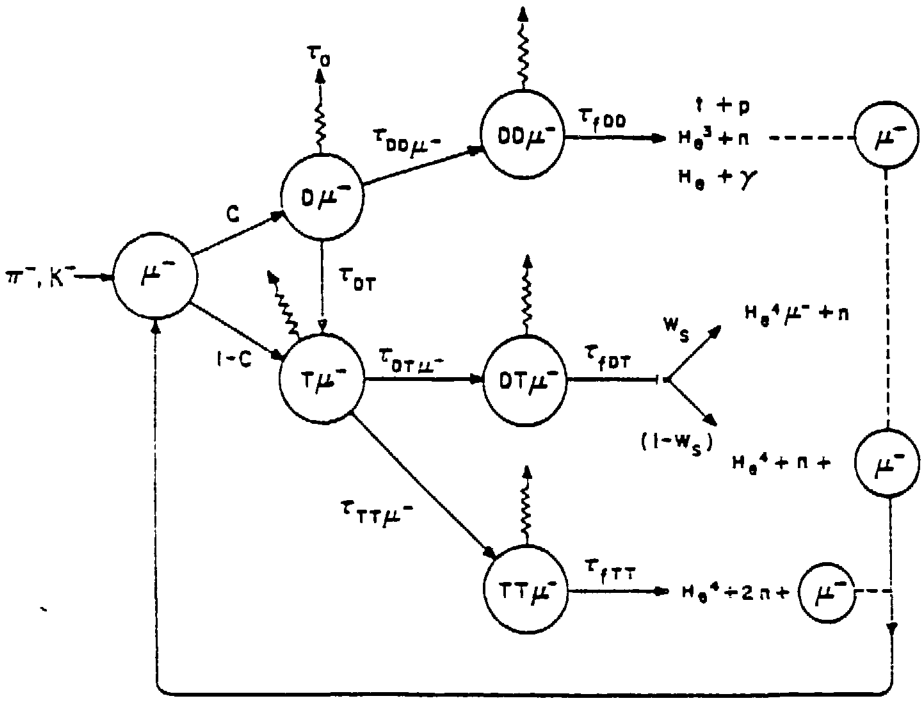

FIGURE 1

Diagram of possible nuclear reactions induced by μ^- meson in a mixture of deuterium and tritium.

The wavy lines correspond to the $\mu^- \rightarrow e^- + \nu_e + \nu_\mu$ decay.

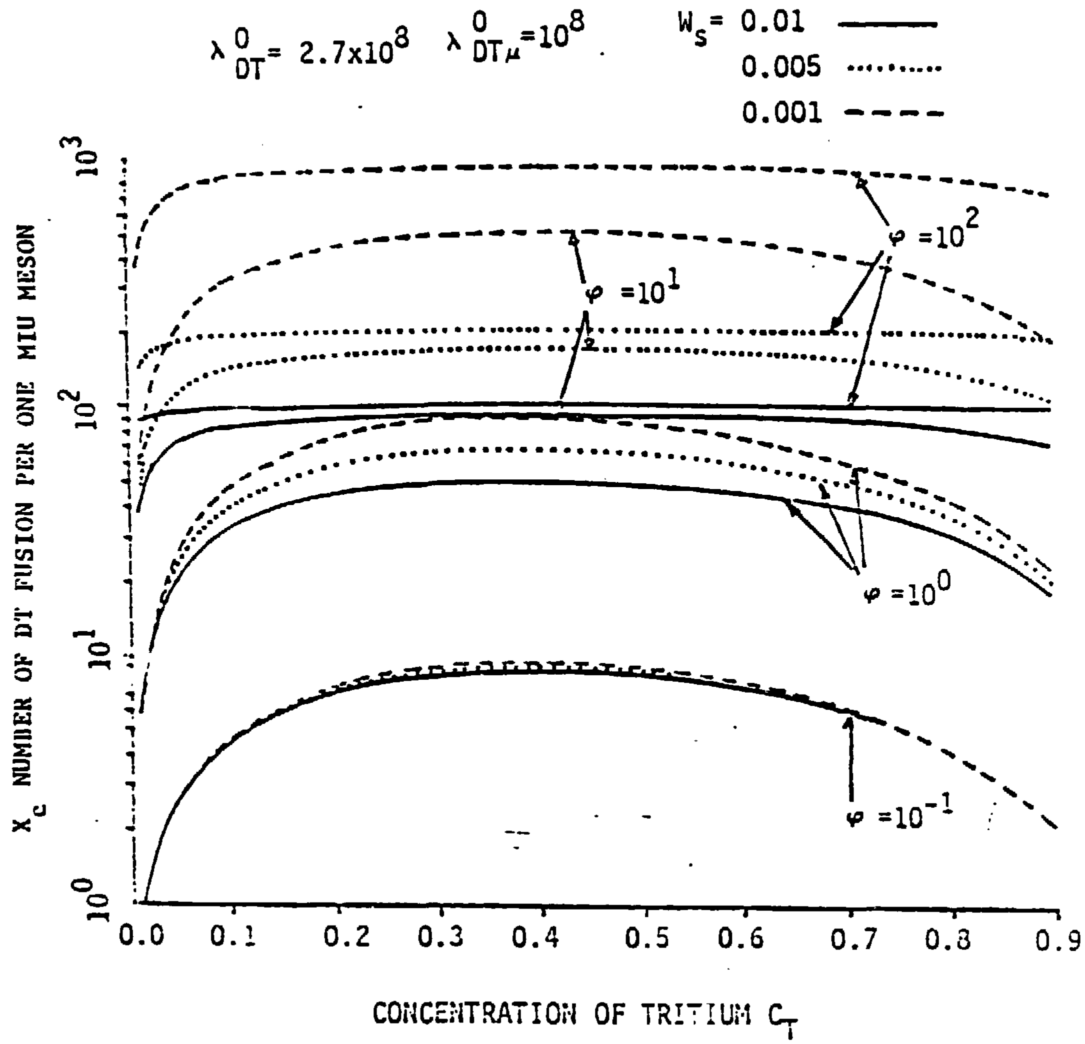

FIGURE 2. Number of DT Fusion Per One μ^- Meson