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Isotope Effect on Confinement in DT Plasmas

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Abstract

Isotope effect on the energy confinement time is discussed for the DT plasma. The transport theory which is based on the ballooning mode turbulence is applied. When the DT plasma is produced under the condition of $\beta_p > 1$, the energy confinement time of DT plasma (50% mixture) is expected to be about 1.2 times better than the D plasma with the same operation condition.

Keywords: DT-plasma, isotope effect, anomalous transport, high poloidal beta value improved confinement

The experiment of the DT plasma has become real on large tokamaks. The first DT operation was successfully done on JET [1] and, more recently, a full DT operation (50%-50% mixture of the deuterium and tritium) has been performed on TFTR. The primary objectives of the experiment contain the study of the isotope effect on the plasma confinement. The conventional argument, based on the hydrogen, deuterium and Helium discharges, employs the relation

$$\tau_E \propto (A/Z)^{\alpha} \tag{1}$$

where A is the mass number, Z is the charge and α is a number in between 0.2 and 0.5 [2]. The test of DT plasma has special importance, because the index α could be correctly determined by comparing the cases of the hydrogen, deuterium and tritium. In addition to this academic interest, the isotope effect on the confinement has vital influence on the achieved fusion power and on the design of future experimental devices as well. If one employs the index of α=0.2, the energy confinement time is only 1.05 times better in the D-T plasma compared to the D plasma.

We have recently developed a theory of the anomalous transport in tokamaks based on the theory of self-sustained turbulence [3]. The explicit formula of the thermal conductivity was obtained. The comparison with L-mode has been done, and a substantial agreement was found not only in the global confinement nature but also on the bahaviours of the local thermal conductivity. The model was extended to investigate the improved confinement mode [4,5]. It was pointed out, theoretically, that the plasma pressure and toroidal current show the self-organization of the plasma structure, leading to the improvement of the confinement for $\beta_p > 1$ [4]. The theoretical formula was approximately given as

$$\tau_E/\tau_{EL} \simeq \beta_p^{0.76} \tag{2}$$

for the high β_p plasmas, where τ_E is the energy confinement time of the *thermal* particles and τ_{EL} is the confinement time in the L-mode. The dependence of

$$\tau_{EL} \propto (A/Z)^{0.2} \tag{3}$$

was obtained theoretically. Note that this enhancement is realized without the gain associated with the edge pedestal profile as in the H-mode. This improvement is generated by the reduced geodesic curvature. This change is due to the reduced magnetic shear by the large Bootstrap current. (See [4] for the detailed argument for the mechanism of the improvement.) Based on this theoretical result, we employ a connection formula

$$\tau_E = \left(1 + \beta_p^4\right)^{0.19} \tau_{EL} \tag{4}$$

Using this formula, the isotope dependence is calculated. It is emphasized that the increment of τ_{EL} by the isotope effect is magnified by the improved confinement due to the high β_p effect. We estimate the energy confinement time of DT plasma by substituting A=2.5 and that for D plasma by taking A=2. In performing this comparison, other parameters (including the density profile and the heating profile) are assumed to be common to DT and DD plasmas.

Figure 1 compares τ_E(DT) and τ_E(DD) as a function of the β_p value of the D plasma. The heating power is varied to change β_p. It is found that

$$\tau_E(DT) \simeq 1.05\, \tau_E(DD), \quad \text{for } \beta_p \ll 1 \tag{5}$$

and

$$\tau_E(DT) \simeq 1.2\, \tau_E(DD), \quad \text{for } \beta_p \gg 1 \tag{6}$$

We see that the energy confinement time of the DT plasma could be 20% better than the corresponding DD plasma, when the experiment utilizes the high β_p condition.

This isotope effect is evaluated by keeping parameters common except the mass number. In the DT burning plasma, the profile of the alpha-heating is much localized to the center compared to the external heating. It has also been found that the central localization of the heating profile gives an additional enhancement factor of the confinement in this high β_p operation [4]. When the plasma come closer to ignition, the isotope effect will be much prominent. It should be also noted that the theory takes into account only the thermal component. In intense heating experiments, there is substantial contribution of the energetic particles. The energetic particles would further increase the improvement factor of τ_E over the L-mode value.

In summary, we showed that the energy confinement time in the DT plasma could be much better than the simple extrapolation based on the ansatz $\tau_E \propto (A/Z)^{\alpha}$ and $\alpha = 0.2 \sim 0.5$. The improvement of the energy confinement time in DT plasma over the DD plasma was obtained by the factor of 1.2 in high β_p limit. The isotope effect is much clearer than the conventional argument. This illumination of the isotope effect is the synergy of the improved confinement and favourable isotope effect on the thermal conductivity χ. This result gives some optimism for the next step devices. At the same time, the experimental test of the enhancement factor will contribute crucially to the understanding of the anomalous transport in toroidal plasmas.

Discussion with Dr. T. Ohkawa on high-β_p plasma was elucidating. One of the authors (KI) acknowledges the discussion with Dr. M. Sasao. This work is partly supported by the Grant-in- Aid for Scientific Research of Ministry of Education Japan.

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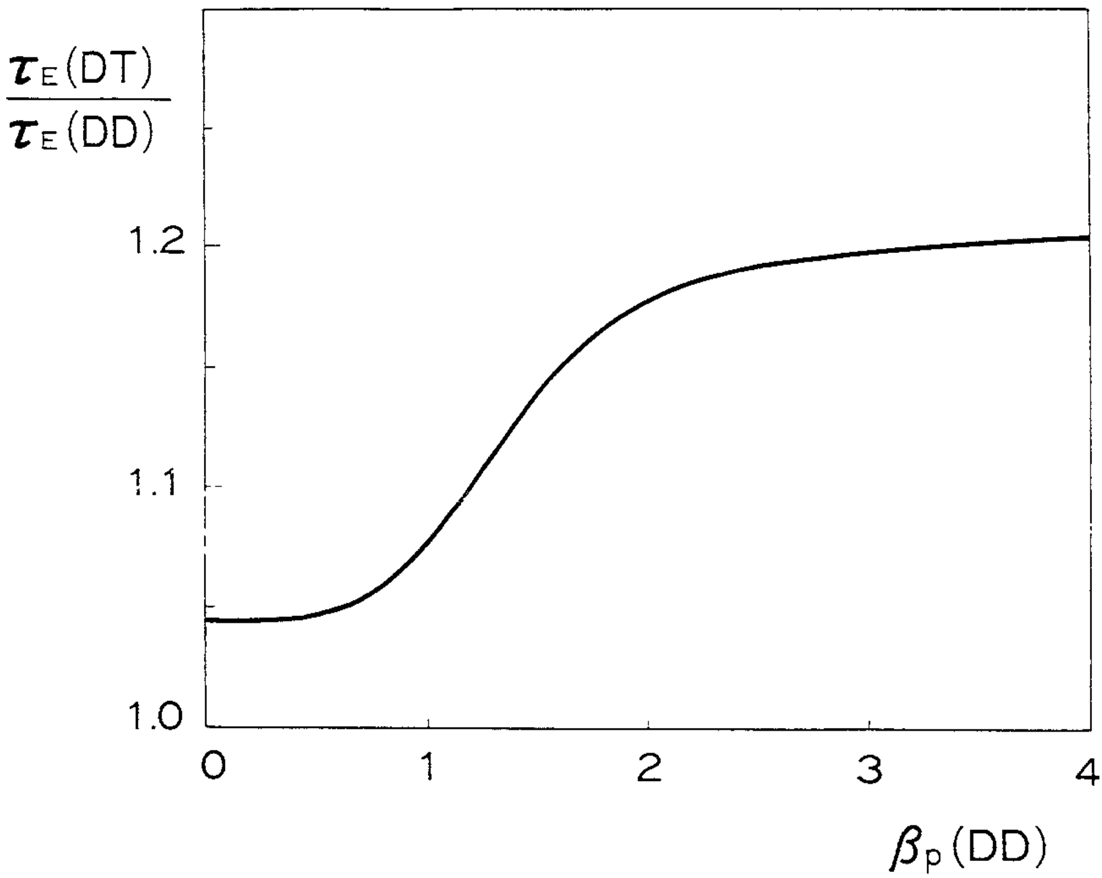
Figure Caption

Fig. 1 Ratio of the energy confinement times for DT and DD plasmas as a function of β_p of DD plasma. Note that only *thermal* components are taken into account.

Fig.1



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