§31. Proton-Boron Fusion Reactor of LHD Type Helical Magnetic Field

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Main branch of the p-^{11}B reaction is neutron free

$$p +^{11} B \rightarrow 3\,^4He + Q_{\mathrm{F}}, \quad (Q_{\mathrm{F}} \simeq 8.7\mathrm{MeV}),$$

but the endothermal side reaction

$$p +^{11} B \rightarrow n\, +\, ^{11}C - \,2.8\,\mathrm{MeV}$$

produce slow neutrons. Under ICRF heating in LHD, it is expected that there is no ultra-high energy proton though the proton distribution function has high energy plateau tail. This situation is desirable for the highly efficient and neutron free fusion reactor. Then, we have studied the fusion reaction rate under the quasilinear plateau distribution function(QLPLDF) for protons.

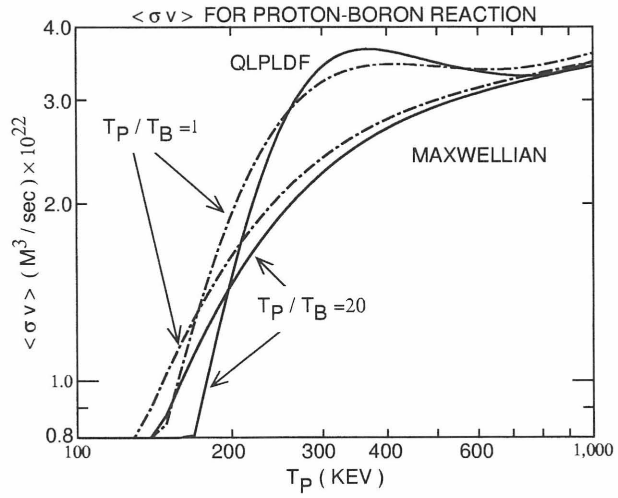

Figure 1: Vertical axis is reaction rate for the p-^{11}B reaction and horizontal axis is proton temperature. Boron is assumed to be Maxwellian velocity distribution with temperature T_B ($= T_P$ or $= Tp/20$). Proton is assumed to be quasilinear plateau distribution function (red line: QLPLDF) or Maxwellian(black line). T_P is defined by eq.(2) for the case of quasilinear plateau distribution function.

$$f(\boldsymbol{v}) \;=\; n \times \alpha \left(\frac{M}{2\pi T}\right)^{3/2} \times \;\exp\left[-\left\{\frac{E}{T} - \left(\frac{E}{T}\right)^2 + \frac{1}{3}\left(\frac{E}{T}\right)^3\right\}\right] \quad (1)$$

$$\frac{3}{2} n T_{eff} \;=\; \int d^3\boldsymbol{v}\, E\, f(\boldsymbol{v})\,, \quad E = \frac{1}{2} M\, \boldsymbol{v}^2 \qquad (2)$$

where $\alpha = 1/1.92420\cdots$ and $T_{eff} = T \times 0.959735\cdots$. The fusion reaction rate $< \sigma\, v >$ for p-^{11}B are obtained numerically based on the cross section data σ [1] (Fig.1).

To study the most basic self sustained burning condition, we have estimated a power balance relation between fusion power P_F, proton temperature T_P, electron temperature T_E, Bremsstrahlung loss P_B and slowing down process of proton by electron drug.

$$P_B = \frac{3}{2} N_p T_P \frac{1}{\tau_E} = \frac{1}{\eta} N_p\, N_B < \sigma\, v > Q_F \quad (\eta > 1)$$

$$\tau_E \simeq 0.5 \times 10^{18} \frac{T_e^{3/2}}{N_e}\ (\mathrm{sec}) \quad : \mathrm{T_e(keV)}$$

$$P_B \simeq 4.71 \times 10^{-37}\, N_e (Z_B^2 N_B + N_p) T_e^{1/2}$$

where τ_E is proton energy loss time due to electron drug and η is the ratio between the fusion output power and the ICRF power, that is needed to sustain the proton temperature. The numerical results are shown in Fig.2.

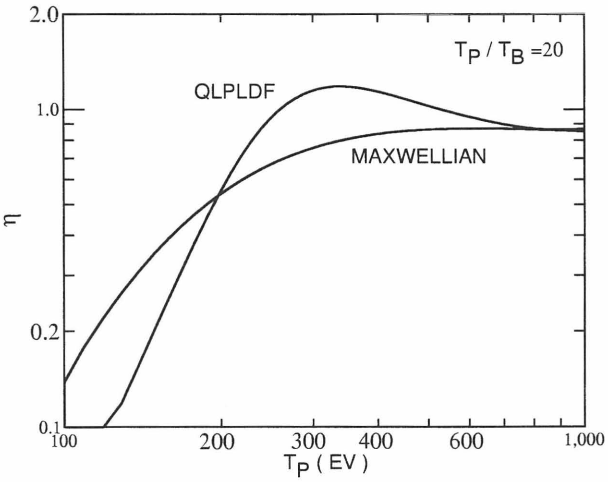

Figure 2: Vertical axis η is the ratio between the p-^{11}B fusion output power and the ICRF power. Horizontal axis is proton temperature. Boron temperature T_B is assumed to be $Tp/20$. The density ratio between proton and boron is fixed to optimal value ($n_B/n_P = 0.141858804\cdots$). Electron temperature T_e is given by $T_e = 14.9819\cdots \times \sqrt{T_P}$, where T_e and T_P are in keV unit. This figure shows that the possibility of self sustained burning of p-^{11}B fusion, if proton is in quasilinear plateau distribution function.

References

[1] R. Feldbacher, INDC(AUS)-12/G, vers. 1 (IAEA International Nuclear Data Comittee, 1987).