§33. On Scaling Laws in Scrape-off-Layer Plasmas

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Among various issues of the plasma wall interactions, the problem of the high heat flux onto the divertor plate has been widely recognized. The prediction of the peak heat load in large devices is one of the most important tasks for the physics of plasmas in the scrape-off-layer (SoL). The influence of the choice of the model of thermal conductivity, κ , on the scaling law of SoL plasma parameters is discussed theoretically. The dependencies of the edge plasma temperature, T_b , thicknesses of the heat flow channel and temperature, and the fluctuation level, ϕ/T , are investigated.

Analytic estimate for the SoL divertor plasma is based on the balance between the parallel heat transfer and perpendicular diffusion. Introducing the radial widths of the heat channel and the temperature, Δ_h and Δ_T respectively, the parallel and perpendicular energy balance is written as

$$-\kappa_{\parallel} \nabla_{\parallel} T = \frac{B_t}{B_p} \frac{P}{2\pi \Delta_h R}$$

$$\frac{\kappa_{\perp} T_b}{\Delta_T} = \frac{P}{4\epsilon\pi^2 a R}$$

where $\kappa_{\parallel}$ and $\kappa_{\perp}$ are the parallel and perpendicular thermal conductivity, B_t and B_p are the toroidal and poloidal magnetic field, a and R are the minor and major radii, respectively, subscript b indicates the plasma surface, $r = a$, and P stands for the total heat flow for one divertor leg.

The power balance equations are solved for various model of the thermal conductivities. We employ the power law models for $\kappa_{\parallel}$ and $\kappa_{\perp}$ as

$$\kappa_{\parallel} = \kappa_{\parallel 0} T^{\beta}$$

$$\kappa_{\perp} = \kappa_{\perp 0} T^{\alpha} (\nabla T)^{\gamma}$$

$$\kappa_{\perp 0} \propto n^{\delta} q^{\mu} R^{\nu}$$

where q is the safety factor. Substituting these expressions, we have [1]

$$T_b = F_1^{d(\gamma+1)} F_2^d P^{d(\gamma+2)}$$

$$\Delta_T = F_1^{d(\alpha+\gamma+1)} F_2^{-d(\beta+1)} P^{d(\alpha-\beta+\gamma)}$$

$$\frac{\phi}{T} = \frac{\kappa_{\perp 0} B_t}{n} F_1^{d(\alpha-\gamma-1)} F_2^{d(\alpha+\beta\gamma+2\gamma-1)} P^{d(2\alpha+\beta\gamma+\gamma-2)}$$

where $d = 1/(\alpha + (\beta+2)(\gamma+1))$, and F_1 and F_2 are defined as

$$F_1 = \frac{(\beta+1)^2 B_t L}{2 B_p \kappa_{\parallel 0} \pi R}$$

$$F_2 = \frac{1}{4\epsilon\pi^2 a R \kappa_{\perp 0}}$$

In terms of the density n_b , power P , safety factor q and the typical system size R , quantities T_b , Δ_T and ϕ/T are expressed as

$$T_b \propto n_b^{-\delta d} q^{(2\gamma+2-\mu)d} P^{(\gamma+2)d} R^{-(\nu+2)d}$$

$$\Delta_T \propto n_b^{(\delta\beta+\delta)d} q^{(2\alpha+2+2\gamma+\mu+\beta\gamma)d} P^{(\alpha-\beta+\gamma)d} R^{(\nu+1)(\beta+1)d}$$

$$\phi/T \propto n_b^{(-\alpha-(\beta+2)(1+\gamma-\delta)+\delta)d} q^{(2\alpha-2-2\gamma+3\mu+\beta\gamma)d} \times P^{(2\alpha-2+\beta\gamma+\gamma)d} R^{(-2\alpha+2+(\beta+2)(\nu-2\gamma)+\nu)d}$$

These expressions are used to study the parameter dependencies.

Although the present database of the SoL fluctuations is very limited, the correlation seems to support the modelling such as constant χ or pseudo-classical type model.

It is confirmed that thicknesses depend strongly on the model of κ . The identification of κ in the present experiment is crucial for the prediction of the future devices and the prospective programme of the fusion research. It is found that the dependence of ϕ/T on the model of κ is most prominent, so that the experimental study on the fluctuations in SoL would be very effective in identifying the proper scaling of the SoL and divertor plasmas. It is shown that the simultaneous study on the temperature, gradient and fluctuation level is important to obtain a correct form of the transport coefficient in the SoL plasma.

Reference

- 1) Itoh S.-I., Itoh K. *Plasma Phys. Contr. Fusion* **36** (1994) 1845.