Nuclear Fusion and Plasma Physics
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Solutions to Problem Set 10

Exercise 1 - The tokamak Scrape-Off Layer

The Scrape-Off Layer (SOL) is the outer layer of the plasma in direct contact with the material wall. It is a very important region of the tokamak, as it regulates the interactions between the hot plasma and the material walls. The SOL thickness is a crucial parameter, and results from a balance between cross-field and parallel dynamics.

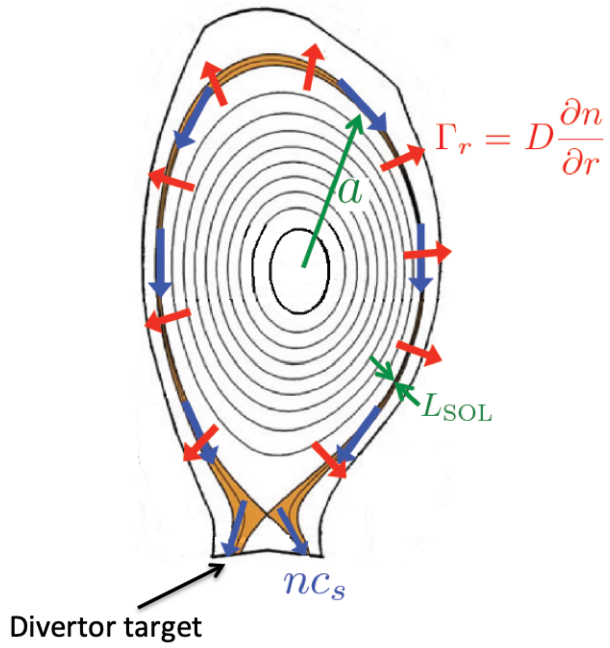
a) Using simple dimensional analysis, and considering that the plasma flow speed along the magnetic field is the sound speed $c_s \sim (T_e/m_i)^{1/2}$, derive a simple expression for the SOL thickness, L_{SOL}, in terms of the cross-field diffusion coefficient D, the plasma radius a and the electron temperature.

Note: Γ_r is the density flux of particles travelling across poloidal field lines.

b) Evaluate L_{SOL} for ITER plasmas ($a \sim 2$ m, $R_0 \sim 6.2$ m, $T_e \sim 20$ keV, $D \sim 1\ m^2/s$, density $n \sim 10^{20}\ m^{-3}$).

c) If there were no expansion of the SOL thickness at the divertor target (at the bottom of the figure below), and no radiation, what would be the power flux on the target in high performance ITER plasma in W/m^2.

Indication: ITER typically produces 500 MW of fusion power with a gain factor of $Q = 10$.



Exercise 2 - Neutron irradiation damage in ITER and in a fusion power plant

In the lecture, we have mentioned that the expected value of dpa (measuring the neutron irradiation damage) in a fusion power plant would be about 100 times larger than in ITER. Such factor will make the materials problem much harder in the fusion power plant than in ITER.

Without going into nuclear physics calculations, and assuming that ITER and the fusion power plant use DT reactions and the same wall materials, justify the order of magnitude of this factor using simple and general arguments

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Exercise 3 - Choice of plasma facing component for high heat fluxes surfaces

The one dimensional Fourier equation for heat transfer is $q = -k\, dT/dx$, where q is the heat flux, k the thermal conductivity of the material, and dT/dx the temperature gradient. Assume a uniform layer of material of 10 mm facing the plasma, and consider that the material can be operated only up to a maximum difference temperature ΔT_{max}, between the substrate and the plasma facing side.

a) Using the table of values of ΔT_{max}, k, and the melting point temperature $T_{melting}$ for different materials, find the maximum heat flux that each material would be able to withstand.

b) Based on theses values, which material would you choose for TCV (no DT fuel) and for ITER (DT fuel) ?

	Iron (Fe)	Tungsten (W)	Beryllium (Be)	Copper (Cu)	Graphite (C)
$T_{melting}$ ($°C$)	1538	3422	1287	1085	3600
ΔT_{max} ($°C$)	513	1141	430	362	2000
k ($W/m/K$)	80	173	200	401	60