General information

The exercise sessions will be held as blackboard sessions, where the participants will present their solutions to the group. As such, the problems should be set up and solved before the session. The focus of the exercises lies on analyzing and discussing the task at hand together with the group: thus, a perfect solution is not required to be awarded points. A point will be awarded for each question, and a person will be chosen to present their solution from the pool.

Exercise 1.
Stellarator to tokamak comparison

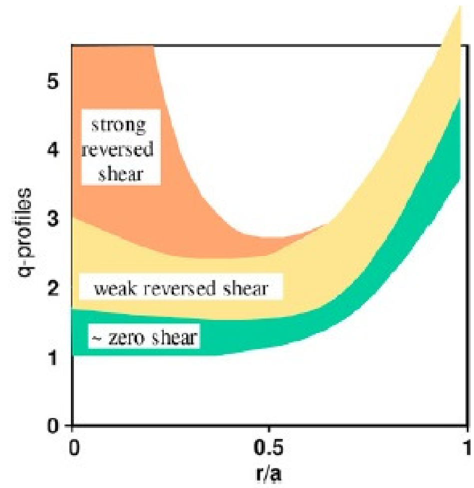
a) What is arguably the main difference between tokamaks and stellarators?

b) Outline the implications of the difference on the reactor design and operation, such as the advantages and disadvantages of stellarators compared to tokamaks.

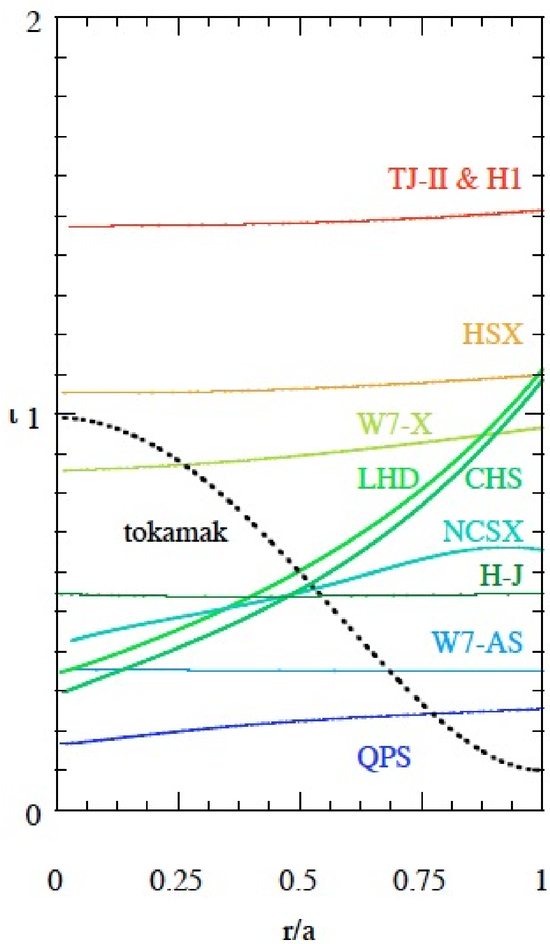
c) Can you find out estimated major and minor radii and magnetic field strengths of reactor scale stellarators? Compare to the values estimated for reactor scale tokamaks.

Exercise 2.

Stellarator concepts Give a broad overview of the various stellarator types and their characteristics. What are the implications on reactor design and operation on a general level? Can you name actual experimental devices that are based on each concept?



(a) Schematic q-profiles in tokamak plasmas with zero, low, and strong magnetic shear, as a function of the normalized minor radius of the device [1]. $r/a = 0$ stands for the magnetic axis and $r/a = 1$ for the edge of the plasma.



(b) Rotational transform in a baseline tokamak plasma, and in the various stellarator concepts [2].

Exercise 3.
Rotational transform and q-profiles in tokamaks and stellarators

a) In typical tokamak baseline, inductive plasmas, the q-profile increases (rotational transform decreases) towards the edge, as is seen in the figures 1 and 2. The safety factor profile as a function of the radius r is approximately

$$q_s \propto \frac{r^2 B_T}{R_0 I_{MA}} \propto \frac{B_T}{R_0 J},$$

where R_0 is the major radius, B_T is the strength of the toroidal magnetic field at the magnetic axis, I_{MA} is the current in MA, and J is the current density. Sketch the current and current density profile required to obtain the regular zero-shear q_s profile of figure 1(a). If the resistivity of the plasma scales approximately as $\eta \propto T_e^{-3/2}$ (Spitzer resistivity), which part of the tokamak plasma is the most conductive?

b) For stellarators, the rotational transform $\iota = 1/q_s$ is a common concept. The stellarator rotational transform generally increases (safety factor decreases) towards the edge, as seen in figure 1(b) for a variety of experimental devices, which is opposite to what we see for tokamaks. Explain this observation based on the fundamental differences between stellarators and tokamaks.

Exercise 4.

Neoclassical transport in stellarators and tokamaks

The transport in toroidal magnetic confinement devices is driven by classical collisional, neoclassical collisional, and turbulent transport. In the earlier exercises, the classical and neoclassical collisional transport coefficients in tokamaks were investigated, with the conclusion that the experimentally observed (turbulent) transport exceeds these classical and neoclassical levels by more than 2 orders of magnitude. On the other hand, in stellarators the neoclassical contribution, originating from the inhomogeneity of the magnetic field, can be the dominating cross-field transport mechanism, and, therefore, the principal factor limiting energy confinement.

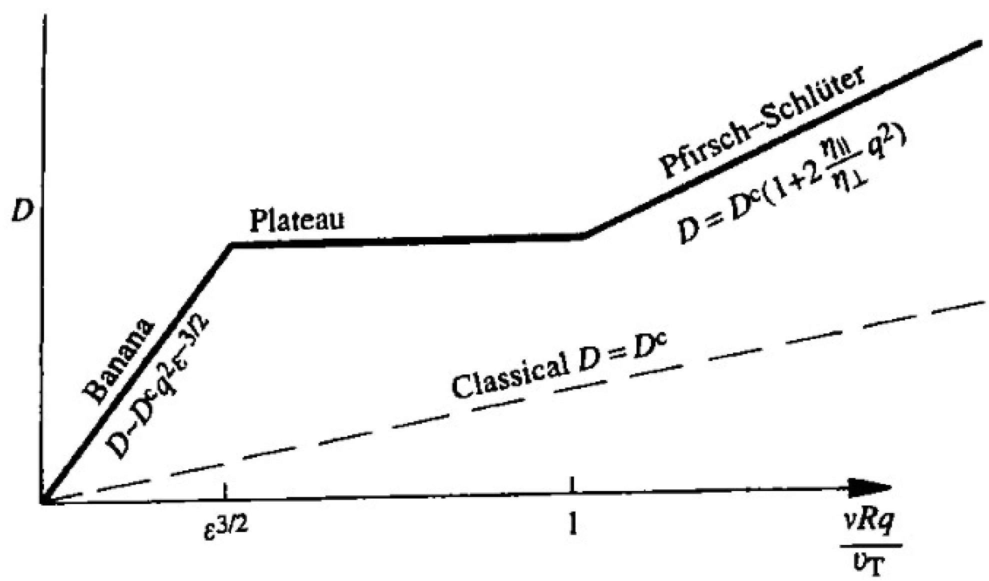


Figure 2: Neoclassical transport regimes as a function of plasma collisionality in axisymmetric toroidal magnetic confinement system [3].

a) Figure 2 shows the neoclassical transport as a function of the plasma collisionality (collision frequency normalized to banana orbit bounce frequency) in an axisymmetric toroidal magnetic confinement system (such as an ideal tokamak). The transport can be roughly divided into three regimes: Banana, Plateau, and Pfirsch-Schlüter. Explain what these regimes mean and why they exist? Chapters 4.6 – 4.7 in John Wesson's Tokamaks can come in handy, or alternatively Chapter 3.3 in the PhD thesis "*Turbulent and neoclassical transport in tokamak plasmas*" by Istvan Pusztai [4].

b) Figure 3 illustrates the neoclassical transport in a stellarator as a function of collisionality. At low collisionalities, the neoclassical transport is greatly enhanced in stellarators. Explain the reasons for this, and how this fact fits together with the ideal temperatures for fusion. How does radial electric field change the situation and why?

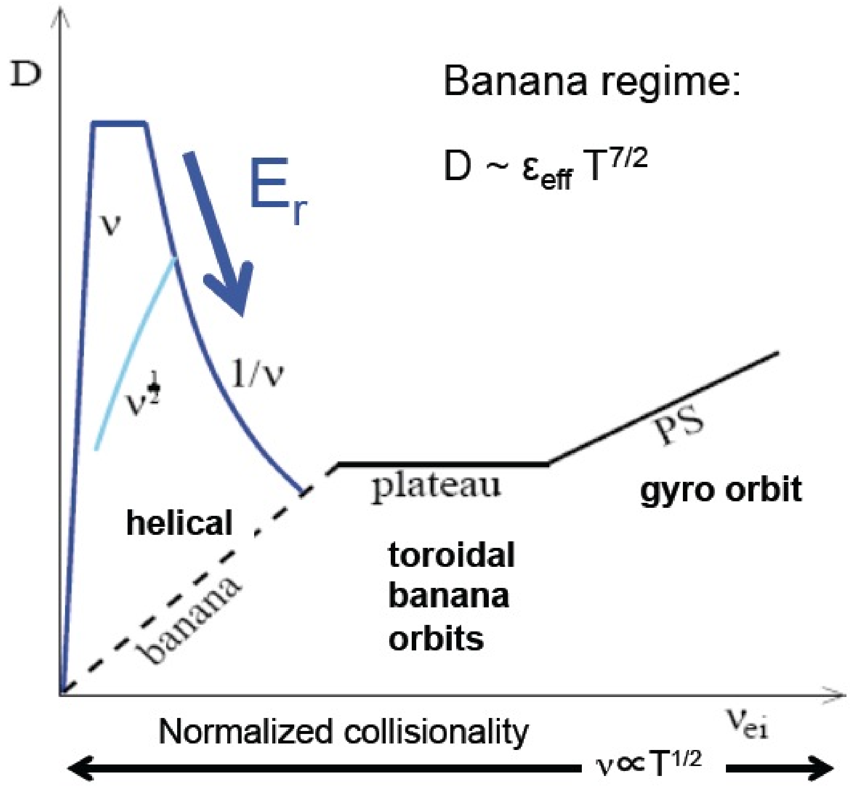


Figure 3: Identical to figure 2, with the observed diffusion in stellarators included. [5]

[1] Progress in the ITER physics basis – Chapter 1, Nucl. Fusion, (2007), 47, S1
[2] E. Ascasíbar, et al., 17th International Toki Conference on Physics of Flows and Turbulence in Plasmas and 16th International Stellarator/Heliotron Workshop 2007, Invited Talk 01.
[3] J. Wesson, Tokamaks, 3rd edition, p.168
[4] `https://research.chalmers.se/publication/147852/file/147852_Fulltext.pdf`
[5] Lecture slides, Stellarators, p.26