

Electron Transport Studies in the Compact Auburn Torsatron

The problem of cross-field plasma transport in the presence of stochastic magnetic fields has received considerable attention in the literature because of its importance in providing a potential explanation of the anomalous electron thermal conductivity χ_e in magnetic confinement devices such as tokamaks and stellarators. In terms of the magnetic fluctuation spectrum, which is assumed to be known, analytic formulas have been given for χ_e in essentially all parameter regimes of possible physical relevance [1]. However, confirmation of the theoretical models has not been done experimentally.

On the Compact Auburn Torsatron (CAT), a “stellarator diode” system [2] was adopted as a tool to provide a steady-state electron source. A set of helical coils was installed inside the CAT vacuum vessel to create resonant magnetic perturbation fields. The main components of the perturbation magnetic field spectrum are $n/m = 1/3$ and $n/m = 1/4$ modes, which will create magnetic islands on the rational surfaces of rotational transform at $\iota = 1/3$ and $1/4$. The vacuum magnetic field configuration was chosen so that the average minor radius for the $n/m = 1/4$ surface is at about 5 cm, and the average minor radius of the $n/m = 1/3$ surface is at about 8 cm. With sufficient externally applied resonant fields, the islands will overlap and create stochastic regions in the magnetic fields which enable study of the stochastic transport of the electrons.

The subsequent motion of the electrons leaving the space charge sheath near the hot filament is diffusive along and across the magnetic field, mainly involving

collisions of electrons with neutral particles of residual gas. In cylindrical approximation, the electron flux across the magnetic surfaces is given by

$$\Gamma = \frac{I_{em}}{4\pi^2 R r e},$$

where r is the minor radius, R is the major radius, and I_{em} is the emission current of the hot filament. The diffusivity of the electrons is determined by [3]

$$D_{\perp} = \frac{\Gamma}{|\nabla n_e + e n E_{\perp} / T_e|} = \frac{I_{em}}{4\pi^2 R r e |\nabla n_e|}$$

for $|\nabla n_e| \gg e n E_{\perp} / T_e$.

Here n_e is the electron density, T_e is the electron temperature, and E_{\perp} is the perpendicular electric field.

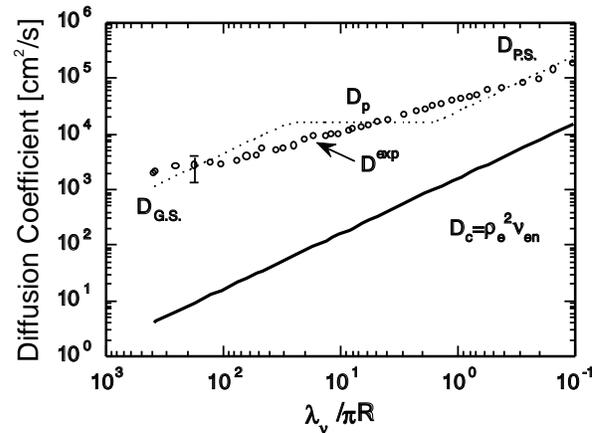


Fig. 1. Electron diffusion coefficient across good magnetic surfaces as a function of the electron-neutral collisionality. Also plotted are the classical (solid line) and the conventional calculations of the neoclassical tokamak transport diffusion coefficient for the electrons (dotted line).

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The stellarator diode method is used to measure transport in stochastic magnetic fields in CAT. 1

The spatial distribution of the electrons in the torsatron was monitored by a miniature movable probe with a diameter of 0.25 mm and a length of 1 mm. The equal electron density contour surfaces are found in good agreement with magnetic flux surfaces. A small Retarding Field Energy Analyzer (RFEA) [4] was used to measure the electron parallel energy distribution.

The electron diffusion coefficient across the good magnetic surfaces is plotted in Fig. 1 as a function of the electron-neutral particle collisionality, that is represented by the ratio of the electron mean free path λ_v over πR . The change of the electron-neutral collisionality is achieved by changing pressure of the helium gas in the vacuum vessel chamber. Plotted also in Fig. 1 is the classical $[D = (\rho_e)^2 v_{en}]$ and conventional calculation of the neoclassical tokamak transport diffusion coefficient of the electrons, where the coulomb collision frequency ν has been replaced by the electron-neutral collision frequency ν_{en} . Here $D_{G.S.} = (R/r)^{3/2} (2\pi/t)^2 (\rho_e)^2 v_{en}$ is the Galeev-Sagdeev diffusion coefficient, and $D_{P.S.} = (2\pi/t)^2 (\rho_e)^2 v_{en}$ is the Pfirsch-Schluter diffusion coefficient. In these expressions, $\rho_e = v_{\perp} / \omega_{ce}$ is the electron Larmor radius, and ω_{ce} is the electron gyrofrequency. We assumed $v_{\perp} = \bar{v}_{e\parallel}$ in the estimation of the neoclassical transport coefficients with $\bar{v}_{e\parallel}$ the mean parallel electron velocity as measured by the RFEA. Although the classical diffusion coefficient is much less than the experimental measured values, good agreement was found between the neoclassical transport and measured values.

The electron transport in the stochastic magnetic field is shown in Fig. 2, where the electron diffusion coefficient is again plotted as a function of the electron-neutral collisionality ($\lambda_v / \pi R$). The perturbation field current is set at $I_h = 100$ A, which yielded an island overlap parameter $\delta = (\Delta_{mn} + \Delta_{m'n'}) / (2|r_{mn} - r_{m'n'}|) \sim 2$. Here r_{mn} , $r_{m'n'}$ are the radii of the adjacent islands and Δ_{mn} , $\Delta_{m'n'}$ are the island widths. The data are taken in the middle region between the 1/3 and 1/4 island radii where the field lines are most stochastic. The trend of the decreasing D_{\perp} with increasing collision frequency is due to gradient increasing with increasing collision frequency ν_{en} .

The experimental results are compared with the predictions of the four analytic models. The four analytic models, in order of the increasing collisionality, are the collisionless D^C , the Rechester-Rosenbluth D^{RR} , the Kadomtsev-Pogutse D^{KP} , and fluid D^F models. The horizontal bars above the figure show the relevant applicability regimes for the four analytic models. The experimental measured value of the transport coefficient is about a factor of 3 – 5 larger than the predictions of the four models. However, good qualitative agreement be-

tween the experimental results and the predictions of the four analytic models can be found. The scaling of the data with the collisionality agrees well with the predictions of the four analytic models in each of their applicable regimes.

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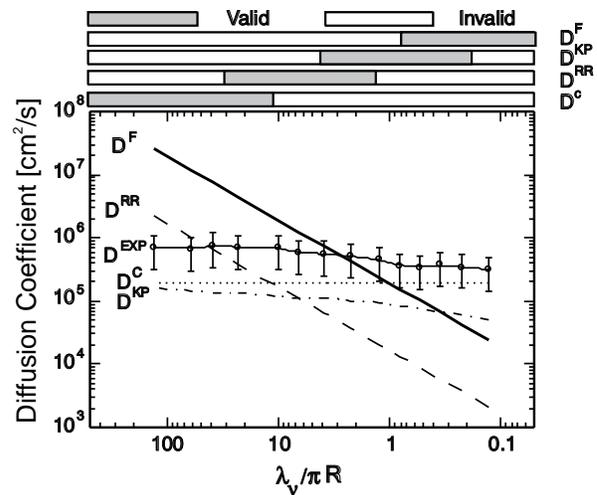


Fig. 2. Electron diffusion coefficient in the stochastic magnetic fields as a function of the electron-neutral collisionality. The experimental results are compared with the predictions of four analytic models. The horizontal bars above the figure represent the relevant applicability regime of each model.