J. Plasma Fusion Res. SERIES, Vol.1 (1998) 222–225

Neoclassical Ambipolar Radial Electric Fields in H-1NF

DETTRICK Sean[1]*, GARDNER Henry[2] and DEWAR Robert
Theoretical Physics Department, RSPhysSE, Australian National University, ACT 0200, Australia
[1]Naka Fusion Research Establishment, Ibaraki 311-0193, Japan
[2]Department of Computer Science, Australian National University, ACT0200, Australia

(Received: 30 September 1997/Accepted: 12 February 1998)

Abstract

A Monte Carlo neoclassical transport code has been developed to solve for the equilibrium ambipolar radial electric field in the H-1NF Heliac. The code is applied to the conditions surrounding the Improved Confinement Mode transition in H-1NF, and it is found that the transition is not inconsistent with neoclassical theory. The Monte Carlo code is also used to investigate the ion-electron root transition. Positive radial electric fields are found, and it is suggested that the electron root may be easier to obtain in the H-1NF than in a conventional stellarator of the same size.

Keywords:

stellarator, ambipolarity, radial electric field, neoclassical transport, H-mode, electron root

1. Introduction

Ambipolar radial electric fields have been calculated previously using analytic models [1, 2] and Fokker-Planck codes [3, 4]. The analytic model used here is a slightly modified version of the neoclassical transport model which appears in references [5] and [1]. Geometric parameters in the model were used to tailor it for H-1NF, by fitting it to Monte Carlo (MC) results [6], and extrapolating the resulting fit over the plasma radius using the functional dependence of ε_h and ε_t. The MC code used to calculate E_r is based on a MC transport code due to Refs. [7, 6]. Detailed descriptions of the calculations can be found in Ref. [8].

In the MC code, the density and temperature profiles are not self-consistent, and particle sources are modelled by assuming the plasma is in a steady state. Both RF heating and inelastic collision processes are neglected, using the assumption that their associated heat fluxes exactly cancel. The radial particle fluxes are measured on a radial grid, and the electric field is determined at the grid points using an iterative procedure. In each cycle of the iteration, electrons and the ions are propagated along their drift orbits, with an arbitrarily fixed background E_r. After a time $t_{1a} > \max(\tau_{90a}, 2\pi/\Omega_{Ea})$ ($a=i,e$, and Ω_{Ea} is the electric field drift frequency of species a), the particles are stopped and E_r is updated to minimise the radial current. The electron radial flux profile is calculated from the Monte Carlo diffusion coefficient $D(r_j)$ and thermal diffusivity $\chi(r_j)$ at each of the grid points. The radial ion fluxes are calculated directly from the radial ion test particle fluxes at the grid points r_j. The electric field between the grid points is specified using a cubic spline, which makes it possible to specify boundary conditions at the ends of the $(0,a_p)$ interval.

2. Improved Confinement Mode

We calculate ambipolar radial electric fields in conditions similar to those observed experimentally; after the transition to ICM, $n_0 = 0.02 \times 10^{20}$ m^{-3}, $T_{i0} =$ 60 eV and $T_{e0} = 10$ eV, and before the bifurcation to ICM, $n_0 = 0.01 \times 10^{20}$ m^{-3}, $T_{i0} = 40$ eV and $T_{e0} = 10$ eV. Three cases are studied here, with density and temperature profiles given in the left column of Figure 1.

*Corresponding author's e-mail: dettrick@ptl01.naka.jaeri.go.jp

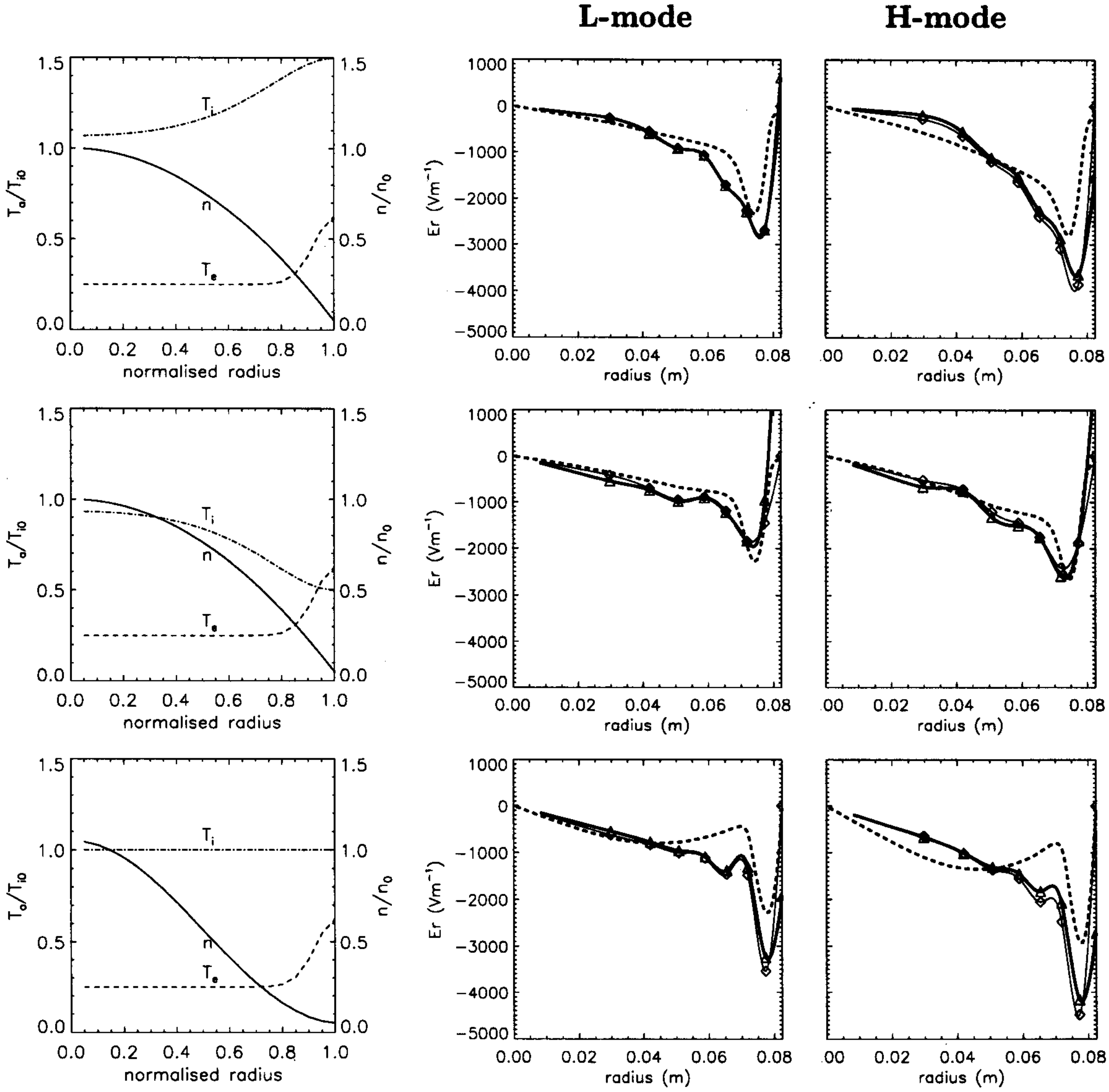

Fig. 1 ICM radial electric fields corresponding to the density and temperature profiles given in the left column: L-mode electric fields (middle column) and H-mode fields (right column.)

The main features of the experimental radial electric field are a zero field at the last closed flux surface (*lcfs*), a strong negative peak just inside the *lcfs*, a drop in magnitude by a factor of 5 or more within $r < a_p/2$, and an increase in magnitude, by 50–100%, after the transition to ICM. These tendencies can be observed in most of the plots shown here.

In the ICM conditions, the ion Larmor radius is approximately 5 cm and a strong positive radial electric field exists immediately outside the last closed flux surface, so FLR orbits may be lost if their gyration carries them beyond this surface. As a result, the ion loss rate in the outer 5 cm of the plasma can be expected to be higher, when FLR effects are included, than the ion loss rate predicted using gyroaveraged orbits. This would tend to make the electric field more negative at the plasma edge, in the FLR case.

The transition to ICM has also been associated with the suppression of fluctuations in the density and electrostatic potential [9]. We neglect these fluctuations, and simulate quiescent, equilibrium plasmas. Even with this simplification, we find good qualitative agreement with experimental results.

3. Ion/Electron Root Behaviour

After the first stage of the National Facility upgrade, it may be possible to observe a transition to the electron root in H-1NF. To address this possibility, we have calculated ambipolar radial electric fields for the 200 eV Hydrogen plasma which was studied (in a 1 tesla background field) in Ref. [6]. Figure 2 shows the MC results (connected diamonds) and the analytic results (smooth, solid curves,) at 5 radii: r_n=0.2, 0.4, 0.6, 0.8 and 1.0. For comparison, the analytic results for a model conventional stellarator with similar geometric parameters (R_0=1 m, a_p=0.124 m, $\varepsilon_h a$=0.35) are also given (the dashed curves.)

In the analytic predictions in Figs 2(a)–(e) there is a "point" pointing to the left, and the electric field is multivalued. This can be understood by plotting the ion diffusion coefficient as a function of the electric field: at intermediate collision frequencies a resonant peak in its value is observed (due to the resonance between the $\boldsymbol{E} \times \boldsymbol{B}$ and $\nabla B \times \boldsymbol{B}$ drifts) which allows the ion and

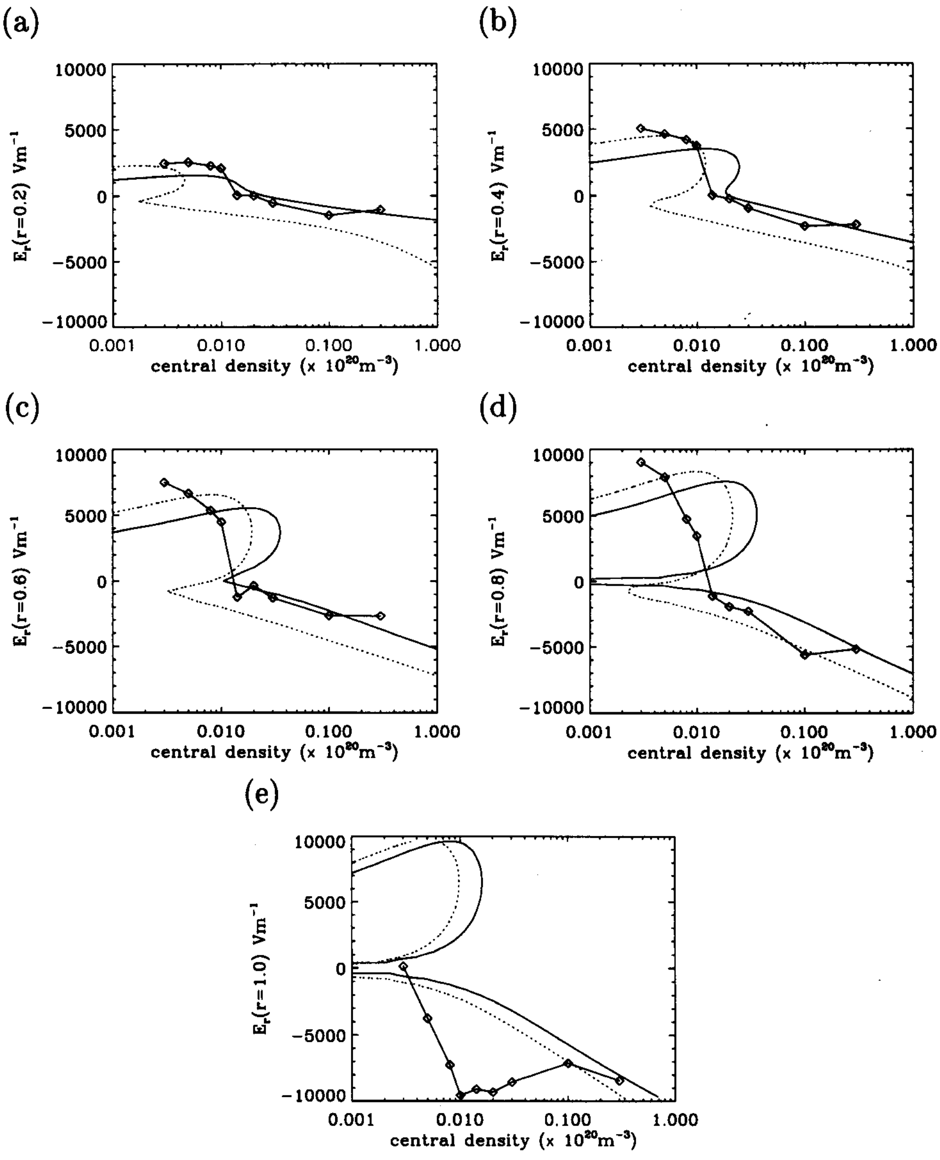

Fig. 2 Comparison of ambipolar radial electric fields calculated using the Monte Carlo (connected diamonds) and analytic (solid curves) models, for a 200 eV Hydrogen plasma in a 1 tesla background field in H-1NF. Results are shown at 5 radial positions, (a) r_n=0.2, (b) r_n=0.4, (c) r_n=0.6, (d) r_n=0.8, and (e) r_n=1.0. For comparison, the analytic results (dashed curves) are also shown for a model conventional stellarator with similar geometric parameters.

electron transport coefficients to be equal at several values of the electric field [10]. In the analytic results, H-1NF differs from conventional stellarators in that the above "point" is suppressed, to the extent that it no longer exists at the plasma core (Fig. 2(a)). This is because the helical ripple gradient $\partial\varepsilon_h/\partial r$ is approximately constant in H-1NF [8], while it is linear in r in our conventional stellarator model. This affects the shape of the ion resonant peak, so that multivalued ambipolar solutions do not occur in H-1NF near the plasma core.

The Monte Carlo result is single-valued throughout because it includes finite orbit width effects, but the suppression of the resonant point (in the analytic predictions) seems to determine the collision frequency at which the bifurcation to the electron root occurs in the Monte Carlo results: where $n_0 \lesssim 0.01$ in the MC results, the presence of the electron root in the core "drags up" the electric field at the plasma edge (Fig. 2(d) and (e)). This effect is less likely to occur in the conventional stellarator because the resonance is still strong at the plasma core. Because of this, and because the ion root exists over a smaller collisionality range in H-1, and the electron root exists over a larger collisionality range, it is likely that it will be easier to achieve the electron root in H-1NF than in a conventional stellarator of the same size.

In the ion root, the Monte Carlo results agree well with the analytic results for H-1NF, except at the plasma edge. In the electron root the field magnitudes do not agree so well, and are substantially larger at n=0.003, except at the plasma edge. The differences at the plasma edge may be due to difficulties in the calculation of D_e and χ_e there.

References

[1] D.E. Hastings, W.A. Houlberg and K.C. Shaing, Nuclear Fusion **25**, 445 (1985).

[2] H. Sanuki, K. Itoh and S.-I. Itoh, Journal of The Physical Society of Japan **62**, 123 (1993).

[3] W.D. D'Haeseleer, W.N.G. Hitchon and J.L. Shohet, Journal of Plasma Physics **42**, 133 (1989).

[4] J. Baldzuhn *et al.*, *10th International Conference on Stellarators*, CIEMAT, Madrid, No.30, p144 (1995).

[5] K.C. Shaing, Physics of Fluids **27**, 1567 (1984).

[6] S.L. Painter and H.J. Gardner, Nuclear Fusion **33**, 1107 (1993).

[7] S.L. Painter, Comp. Physics Comm. **77**, 342 (1993).

[8] S.A. Dettrick, *Drift Orbits and Neoclassical Transport in the H-1NF Heliac*, Ph.D. Thesis, Theoretical Physics Dept., RSPhysSE, Australian National University, 1997.

[9] M.G. Shats *et al.*, Phys. Rev. Lett. **77**, 4190 (1996).

[10] H.E. Mynick and W.N.G. Hitchon, Nuclear Fusion **23**, 1053 (1983).