§11. Theoretical and Experimental Studies on the Contribution of Wave-Particle Interactions to Radial Transport in a Strongly Magnetized Non-neutral Plasma

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Rotating-wall technique has been commonly used for controlling the radial transport of particles in non-neutral plasmas in order to maintain a stationary density distribution against radial diffusion or to increase the on-axis density by compression.[1] The purpose of the last aim is to increase the generation rate of anti-hydrogen from anti-protons and positrons trapped in a nested Penning trap[2] The rotating wall stands for azimuthally rotating electric field driven by RF voltages applied to an azimuthal array of wall segments with a periodic phase shift. It worked quite well though the physical mechanism was not fully understood.

The purpose of our study was to explore the fundamental processes relevant to the radial transport induced by the rotating electric field. Combining preliminary experimental results in our laboratory and work reported in archives, we constructed a theoretical model in a closed form.[3]

The model is based on a drift-kinetic equation of magnetized electrons radially bounded by a conducting wall via a vacuum region. The rotating electric field is assumed to belong to the Trivelpiece-Gould mode with non-zero mode numbers both in the azimuthal and axial directions. The radial flux is evaluated by the axial-velocity integration of the time-averaged product between the **ExB** drift on fluctuating electric fields and the perturbation of the velocity distribution function. The net radial flux appears as a contribution of the particles axially resonant with the T-G mode wave. The concentration of the same-sign particles associated with the radial flux was found to increase the potential energy of the particle system with an increment exactly equal to the work exerted by the torque of the azimuthal components of the rotating electric field. The increment of the angular momentum of the particle system due to the radial transport was proved also to correspond to the wave torque.

The resonant particles responsible for the radial transport are subject also to the Landau-damping. The associated increment of the kinetic energy in the axial particle dynamics was found to be exactly equal to the decrement of the wave energy minus the increment of the potential energy associated with the radial transport at each radially sliced shell. This means within the framework of this theoretical model the Landau-damped energy of the wave is fully converted to the radial compression and the axial heating with a radially-varying branching ratio that is determined by the wave frequency and by the local frequency of equilibrium rotation.

Most of the features predicted by the model were confirmed in experimental examinations of the wave-driven profiles of a pure electron plasma at least as long as the wave amplitude is much smaller that the electron temperature.[4] Experimental confirmations were made on the dispersion relation of the waves driven by the phased RF voltages and propagating in the bulk plasma to belong to the T-G mode.

By combining the measured amplitude of the image current on the wall and the radial structure of the eigen-mode wave calculated on the basis of the observed density distribution, an evaluation is carried out for the absolute value of the wave amplitude propagating in the plasma. The quasi-linear radial flux evaluated by substituting the observed parameters into the model-derived equation was found to agree within a factor of three with the observed density distribution that is compressed by the wave as the time elapses. The compression rate was observed to be roughly proportional to the square of the observed wave-amplitude as the quasi-linear theory predicts.

An interesting observation that had not been predicted by the theoretical model was that the ratio of the wave frequency linearly ramped up with time to the on-axis plasma frequency is latched to a constant value around 0.2 during the period while the plasma is compressed efficiently.

The observation that a rapid expansion of the radial edge of a flattop distribution occurs when the sense of the rotation of the wave is reversed against the equilibrium **ExB** rotation is what the model predicts and the observed parameters are also quantitatively consistent with the prediction of the model.[4]

An novel and interesting parameter incorporated in the theoretical model is the momentum of the electro-magnetic field associated with the charge distribution and the homogenous magnetic filed corresponding to the azimuthal **ExB** flow. Though the electro-magnetic momentum appears only to belong the basic concept of the theory of electromagnetism[5] and not to be directly observable, the model indicates that the observed density distributions of magnetized electrons represent visually the distribution of the electro-magnetic angular momentum that changes in time absorbing the momentum of the plasma wave.

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