H-mode transition Analysis of NSTX based on the E_r formation mechanism by the gyrocenter shift

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One of the crucial obstacles of the nuclear fusion energy development is that the experimental cross-field transport is hundreds of times larger than the expected by the classical diffusion theory. As a result of the effort to overcome this anomalous transport the low confinement to high confinement mode transition (L/H transition) was experimentally discovered [1]. After decades of study of the L/H transition mechanism, the following gyrocenter shift current (comes from JxB as momentum exchange of the ion-neutral collisions) is suggested as the origin of the radial electric field which is regarded as the triggering parameter of L/H transition [2,3].

$$J^{GCS} = en_i \frac{r_{Li}}{\lambda_{cx}}[\frac{E}{B} - \frac{\nabla P_i}{eBn_i} + \frac{kT_i \nabla n_n}{eBn_n}] \quad (1),$$

where e is ion charge, n_i is ion density, r_{Li} is ion gyro-radius, λ_{cx} ion mean free path of charge exchange with neutrals, E is electric field, B is magnetic field, P_i is ion pressure, kT_i is ion thermal energy and n_n is neutral density. The three terms in the bracket of Eq.(1) constitute an effective velocity (υ^*), which is illustrated in Fig.1. The plasma pressure gradient term and the neutral density gradient term are the driving mechanism of J^{GCS} and the negative electric field is formed as the source of the return current to make an equilibrium condition. So in the ideal case such as the ambipolar electric field without turbulence, υ^* is close to zero, however when there is turbulence, the small scale ExB eddies induce the cross-field transport and the equilibrium condition is set with a smaller radial electric field than without turbulence case since ExB eddies also generate additional return currents. The cross-field transport induced by the turbulence eddies is described by the diffusion coefficient which is responsible for the turbulence induced anomalous transport [4]. The confinement time from the EFIT equilibrium of the National Spherical Torus Experiment (NSTX) is compared with the density

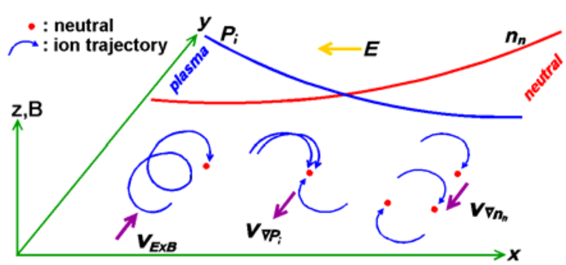

Fig.1 Three components of ion velocity that make momentum exchange (υ^*); $\upsilon_{E\times B}$ is ion ExB drift, $\upsilon_{\nabla P_i}$ is ion diamagnetic drift, and $\upsilon_{\nabla n_n}$ is the component of the effective ion velocity induced by the neutral density gradient. $\upsilon_{\nabla n_n}$ was firstly introduced by Lee [2] as the averaged ion collision velocity over a circle of gyro-motion (the case of collision with up direction is outnumbered by the case of collision with down direction).

fluctuation level measured by the Far Infrared Tangential Interferometry/Polarimetry (FIReTIP) to verify the turbulence induced diffusion coefficient (D) from the theory, which is illustrated in Fig.2 (a). One of the important results in the Ref. 4 is that the ion-neutral collisions include the inertia force and the friction force so that their ratio can be defined as Reynolds number which is described by the following,

$\mathrm{Re} \equiv \dfrac{n_i m_i \upsilon^{*2} / r_{Li}}{n_i m_i \nu_{cx} \upsilon^{*}} = \dfrac{\lambda_{cx}}{r_{Li}} \dfrac{\upsilon^{*}}{\upsilon_i}$ (2), where ν_{cx} is the charge exchange reaction rate, υ^{*} is the effective velocity and υ_i is the ion thermal velocity. When there is higher intensity turbulence, the magnitude of E becomes smaller and so does $\upsilon_{E\times B}$. Then υ^{*} becomes larger (since υ^{*} is the difference between $\upsilon_{E\times B}$ and the summation of other two terms in Eq.(1)). This relation of Reynolds number explains two important characteristics of the L/H transition. First, the Reynolds number is proportional to the magnitude of turbulence itself; therefore, when the Reynolds number of a turbulent plasma reaches down to the critical value (the same feature of critical Reynolds number of neutral fluids is applied here; Re* ~2300) not only it just turns into the laminar state (H-mode) but also makes more reduction of Reynolds number so that hysteresis is generated. Second, it explains the sudden increase of the radial electric field at the moment of the L/H transition because the reduction of turbulence require more of return current from the electric field to make a new equilibrium condition. A calculation of the Reynolds number from various measurements on NSTX plasma is shown in Fig.2 (b). When the plasma is L-mode Reynolds numbers are above the critical value (Re*) and when it becomes H-mode the Reynolds numbers are below the critical value around the region where the edge transport barrier forms. These results suggest that the gyrocenter shift is a reliable means of analysis for H-mode transitions and should be included in the systematic research on the tokamak turbulence and transport in the future, especially for the ITER relevant H-mode study such as transition power threshold ($P_{L/H}$) estimation.

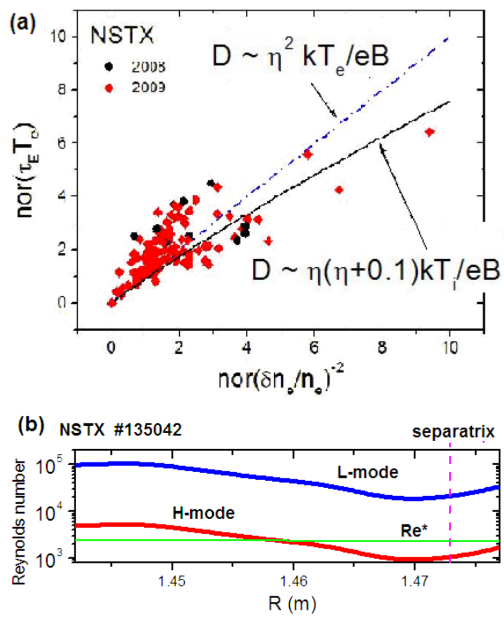

Fig.2 Experimental measurement of NSTX plasmas for the comparison with gyrocenter shift theory,(a)lines are from theory; η is density fluctuation level, (b)Reynolds number calculation for L-mode and H-mode

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References:

[1] Wagner F 2007 *Plasma Phys. Control. Fusion* **49** B1

[2] Lee K C 2006 *Phys. Plasmas*, **13**, 062505, invited talk, APS DPP meeting 2006

[3] Lee K C 2007 *Phys. Rev. Lett*. **99**, 065003.

[4] Lee K C 2009 *Plasma Phys. Control. Fusion* **51** 065023.