§2. Study of Plasma Dynamics Interacting with Neutral Flow

Tanaka, M.Y., Terasaka, K., Ogiwara, K., Itoh, Y., Kato, Y. (Kyushu Univ.),
Aramaki, M. (Nagoya Univ.),
Okamoto, A. (Tohoku Univ.),
Morisaki, T., Yoshimura, S.

In weakly ionized plasmas, there are two types of collisional interactions between ions and neutrals, i.e., elastic scattering and charge exchange scattering. In usual collision processes, small angle scattering is dominant and the resultant momentum change of ions is small, which makes us possible to consider the plasmas as collisionless. However, when we take into account charge exchange process, the momentum change of ions becomes large, and the force generated in this process may be the dominant force to build up the ion flow structure in the plasma.

Figure 1 shows an ion-neutral collision with and without charge exchange. As seen in Fig.1(a), the momentum change during the collision is small in the small angle scattering. However, when the charge exchange process occurs during the collision, the momentum difference of incident and resultant ion becomes large even in small angle scattering. This phenomenon is called Sena effect [1]. It should be noted that the density of neutral particles is much higher than the ion density in weakly ionized plasmas, the total momentum of neutral fluid is comparable or greater than that of ion fluid even though the neutral flow velocity is much smaller than the ion flow velocity.

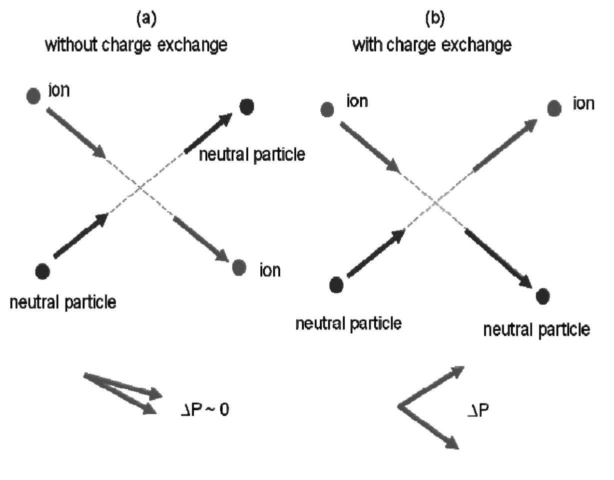

Fig.1 Ion-neutral collision process with and without charge exchange. Enhanced momentum exchange during charge exchange process is called Sena effect.

In the circumstances where the ion-neutral interaction is strong, the force generated in the ion-neutral collision may essentially modify the ion flow structure through $\boldsymbol{F}\times\boldsymbol{B}$ drift. Recently, it has been found that there is a class of vortices which counter-rotate to the $\boldsymbol{E}\times\boldsymbol{B}$ drift. The cause of counter-$\boldsymbol{E}\times\boldsymbol{B}$ rotation is considered to be the radial neutral flow from the wall. This means that the force acting on ion fluid is greater than the electric field in the plasma, and that the flow structure is determined by the $\boldsymbol{F}\times\boldsymbol{B}$ drift due to ion-neutral interaction.

To clarify the physics of counter-rotating vortices, we have developed a high resolution laser induced fluorescence spectroscopy system [2] and measured the slowly flowing neutrals of the order of several meters per second. Although measurement of small Doppler shift ($\delta f/f = 10^{-6}$) by LIF has not been established so far, we have demonstrated that the neutral flow velocity with a few m/s can be measured by combining saturated absorption spectroscopy (SAS) and the LIF spectroscopy. A strong inward (radial) flow of neutrals is found in the region where the counter-rotating vortex is present.

When the electric field is greater than the force generated in the charge exchange process, the resultant drift is determined by the $\boldsymbol{E}\times\boldsymbol{B}$ drift, while the force due to ion-neutral interaction is greater than the electric field, the flow structure may be built up by the ion-neutral interaction. These two forces are estimated by the electrostatic potential and the chemical potential of neutrals. The following quantity may be the key parameter of this phenomenon, i.e.,

$$\frac{\text{electric force}}{\text{force due to neutral flow}} \sim \left| \frac{e n_i \phi}{n_n \mu_n} \right|$$

where ϕ is the electrostatic potential, n_n the neutral density, and μ_n the chemical potential of neutral particles.

In conclusion, there are two types of flow structures in weakly ionized plasmas; "electrical structure" which is determined by the $\boldsymbol{E}\times\boldsymbol{B}$ drift and "chemical structure" which is driven by the neutral flow.

1. B. M. Smirnov, "Charged-particle Transport in Gases" in *Physics of Ionized Gases,* Weinheim, Wiley-VCH Verlag GmbH & Co., 2004, pp164-176.

2. M. Aramaki, K. Ogiwara, S. Etoh, S. Yoshimura, and M. Y. Tanaka: "High resolution laser induced fluorescence Doppler velocimetry utilizing saturated absorption spectroscopy", Rev. Sci. Instrum. **80**, (2009) 053505-1 – 4.