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On the Physics of Vortex Formation in Plasmas
プラズマ渦形成の起源と構造の解明

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Since the drift of ions is likely to generate vortical motion, magnetized plasma is a mine of vortex physics. We have observed a variety of vortices such as a plasma hole and a tipolar vortex, in a magnetized cylindrical plasma. An overview of vortex dynamics for these vortices is presented with emphasis on the formation mechanism and the physical significance.

1. Plasma Hole

Figure 1 is the end view image of a plasma hole. The central dark region in the figure indicates the density hole, the sizes of which are 6 cm in diameter and more than 100 cm in axial length. The density in the hole region is about one tenth of that in the ambient plasma, and the width of transition layer between the hole and ambient plasma is about 1.2 cm, which corresponds to several ion Larmor radii.

Fig.1 End view image of a plasma hole.

The flow velocity field of the plasma hole exhibits a monopole vortical structure with a sink in its center (see Fig.2). When the direction of the magnetic field is inversed, the azimuthal velocity also changes its direction of rotation, indicating that the azimuthal rotation is due to ***E*** x ***B*** drift. The remarkable characteristic of the plasma hole is the existence of radial flow, which remains unchanged under the field inversion. It is found that the radial

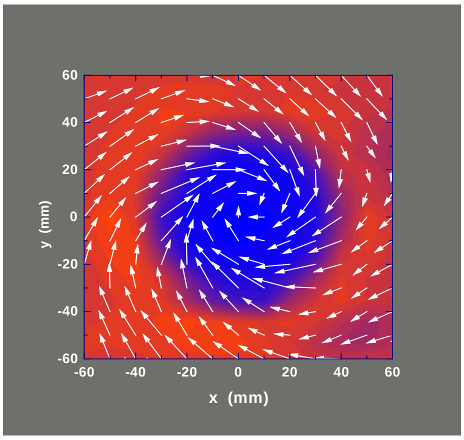

Fig.2 Velocity field of a plasma hole.

flow is a ***F*** x ***B*** drift, ***F*** being the viscous force due to shear in the azimuthal rotation. The vorticity distribution indicates a Gaussian shaped localization as shown in Fig.3 and is identified as a Burgers vortex [1-3], which is intrinsic in viscous fluids. The mechanism of central localization of vorticity is the balance between the inward transport and the viscous diffusion. The characteristic scale length of vorticity localization determines the effective viscosity, exhibiting an anomalously high value $10^6\ cm^2/sec$, which is three orders of magnitude higher than the classical value due to atomic collisions.

When we consider the interaction of viscous vortices, the existence of radial flow is of essential importance since it causes an attractive interaction between vortices. Consequently, the dynamical behavior of a system of viscous-vortices is qualitatively different from that of point vortices

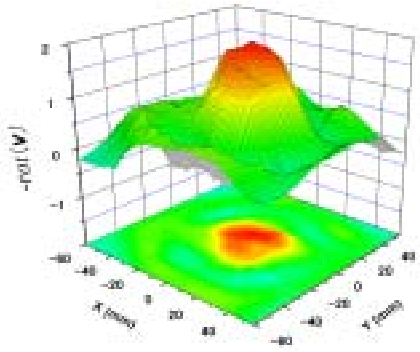

Fig.3 Vorticity localization of a plasma hole.

2. Tripolar Vortex

Tripolar vortex consists of three aligned vortices with alternate signs of polarity of rotation, and is regarded as a novel coherent structure in ordinary fluids and ocean. It was first observed in laboratory experiment and then in the Bay of Biscay [4]. Figure 4 shows a tripolar vortex in a plasma [5]. The bright regions are high density regions (density clump), and the potential profile is similar to that of the plasma density, indicating the existence of localized electric field and the resultant vortical motion due to the $\boldsymbol{E}\times\boldsymbol{B}$ drift.

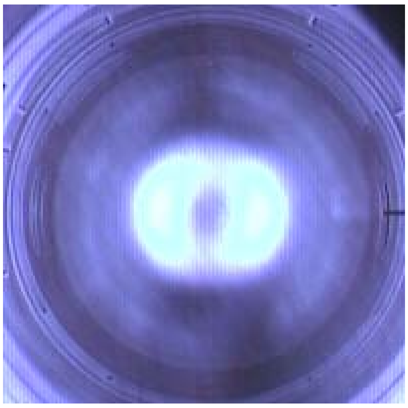

Fig.4. End view image of a tripolar vortex

The vorticity distribution determined from the velocity field shows a tripolar structure; a center vortex with positive polarity (counterclockwise rotation) and two satellites in both sides with negative polarity (clockwise rotation).

All the polarities of component vortices are surprisingly opposite to that of the $\boldsymbol{E}\times\boldsymbol{B}$ drift. This result means that there exists a new force acting on ions, which dominates the electric field. The visible spectroscopy of ArI and ArII revealed that the tripolar vortex always accompanies a steep density cave in the background neutrals (see Fig. 5). In this circumstance there exists an inward flow of neutrals due to the steep density gradient. Through the charge-exchange process, the directed motion (momentum) of neutrals is transferred into the ion fluid, producing an effective force and the subsequent vortical motion of ions. In this case, the logarithm of neutral density, log n_n, acts as a potential, and should be included in the fluid equation for ions. The theoretical analysis gives a tripolar solution, showing a quite well agreement with the experimental result [6].

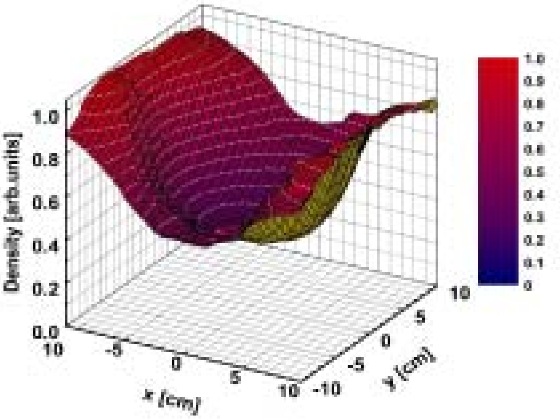

Fig.5. Neutral density profile with a tripolar vortex

The observation of anti-$\boldsymbol{E}$x$\boldsymbol{B}$ tripolar vortex shows that the dynamical behavior of the plasma may be modified through the coupling of ions to the flow of background neutrals. Hence, we may say that the plasma is coexistent with the flow of background fluid.

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