§16. Dynamics of Plasma Particles to Spherical Probe in Weak Magnetic Field

Tomita, Y., Kawamura, G.,
Ishihara, O. (Yokohama National Univ.),
Tskhakaya, D. (Univ. Innsbruck)

Charged particle orbits of j-th species ($j = e, i$) in the uniform magnetic field are investigated in the cylindrical coordinates (ρ, θ, z), where the magnetic field B_0 is applied to the axial z-direction. The electric probe is located at the origin with the radius R_p and the applied voltage V_p. The charged particle with the charge q_j starts to move from the initial position ($\rho = b_{in}$, $\theta = 0$, $z = z_{in}$) with the velocity $(\upsilon_\rho = \upsilon_\theta = 0, \upsilon_z = \upsilon_{j,in})$. The plasma shielding effect due to the plasma sheath is introduced by the Debye-Hückel formula

$$\phi = \frac{R_p V_p}{r}\exp[-\delta_{sc}\frac{(r-R_p)}{\lambda_D}] \ : \ r \ge R_p , \tag{1}$$

where λ_D and δ_{sc} are the plasma Debye length and the shielding factor, respectively. The normalized equations of motion of the j-th charged particle in this system are following: ρ direction:

$$\frac{d^2\bar{\rho}}{d\bar{t}^2} = \frac{\alpha_j}{2}\bar{\rho}(\frac{1}{\bar{r}^3}+\frac{\zeta_{sc}}{\bar{r}^2})\exp(-\zeta_{sc}\bar{r}) + \frac{\mu_j^2}{4}\frac{1-\bar{\rho}^4}{\bar{\rho}^3}, \tag{2}$$

and z direction:

$$\frac{d^2\bar{z}}{d\bar{t}^2} = \frac{\alpha_j}{2}\bar{z}(\frac{1}{\bar{r}^3}+\frac{\zeta_{sc}}{\bar{r}^2})\exp(-\zeta_{sc}\bar{r}) . \tag{3}$$

where the distances, velocity and time are normalized by the impact parameter b_{in}, the initial speed $\upsilon_{j,in}$ and $b_{in}/\upsilon_{j,in}$, respectively. The system in the absence of magnetic field is determined by the parameter α_j,

$$\alpha_j \equiv \frac{q_j R_p V_p}{b_{in}} / \varepsilon_{in,j} \ , \quad \varepsilon_{in,j} = \frac{m_j}{2}\upsilon_{j,in}^2 , \tag{4}$$

which is the ratio of the electrostatic potential energy at the distance of the impact parameter to the initial kinetic energy $\varepsilon_{j,in}$ and the parameter ζ_{sc},

$$\zeta_{sc} \equiv \delta_{sc} / \bar{\lambda}_D , \tag{5}$$

which indicates the plasma shielding effect. The parameter μ_j indicates the effect of the static uniform magnetic field,

$$\mu_j \equiv b_{in} / \frac{m_j \upsilon_{j,in}}{|q_j B_0|} , \tag{6}$$

which is the ratio of the impact parameter b_{in} to the Larmor radius with respect to the initial speed $\upsilon_{j,in}$. Here m_j is the mass of the charged particle, r is the radial position of the particle $(r^2 = \rho^2 + z^2)$.

The parameter μ_e of the electron is much larger than that of the ion for the case of ions with the sound speed c_s and the thermal speed of the electron υ_{the}:

$$(\frac{\mu_e}{\mu_i})^2 = (\frac{m_i \upsilon_{i,in}}{Z_i m_e \upsilon_{e,in}})^2 \simeq (\frac{m_i c_s}{Z_i m_e \upsilon_{the}})^2 \simeq \frac{m_i}{m_e} \ll 1 , \tag{7}$$

where Z_i is the charge state of the plasma ion. This relation indicates the effect of the magnetic field on the ions is much smaller than that on the electrons. In this section we investigate the electron orbits and the electron absorption cross-section to the electric probe. The typical orbit of an electron near the probe with negatively applied voltage, which is located at the origin ($\rho = z = 0$), is shown in Fig. 1, where $\alpha_e = 1.0$, $\mu_e = 0.1$ and $\zeta_{sc} = 0$, which corresponds to dynamics in the Coulomb potential. The electron in the presence of the axial magnetic field (solid line in Fig. 1) approaches closer to the probe than that in the absence of magnetic field. Here the initial position is set far from the probe position, where the radial potential is negligibly small. The electron, which starts motion along the axial direction, gains a radial velocity due to the radial electric field of the probe. The Lorentz force due to the radial velocity pushes an electron to the azimuthal direction. Therefore, the magnitude of the azimuthal velocity is the first order of the strength of the magnetic field. This azimuthal velocity makes the centrifugal force and the radial Lorentz force due to the axial magnetic field. Therefore, these radial forces are the second order of the magnetic field. Thus the magnetic field has the second order effect on the orbit without magnetic field, see Eq. (2). As a result the radial force balance of the particle between a centrifugal force and a Lorentz force determines the radial motion of a charged particle.

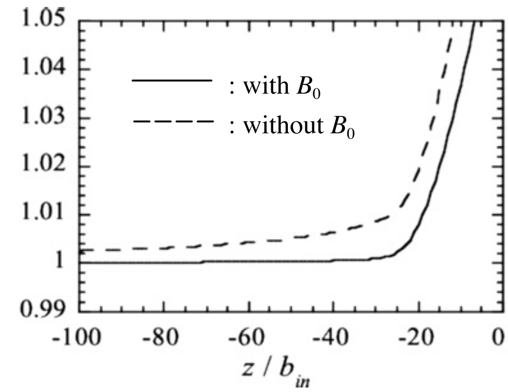

Fig.1 Typical orbit of an electron near the negatively applied probe voltage for the case $\alpha_e = 1.0$, $\mu_e = 0.1$ and $\zeta_{sc} = 0$. The solid and dashed lines are the orbits with and without magnetic field, respectively.