Report on plasma physics AY2022

Submit the report (file) through ITC-LMS. The deadline is July 30th. The image of handwriting report is OK as long as it is fine.

Q1: Plasma around galaxies

The plasma around galaxies shows the following parameters: temperature $T = 1$ keV, ion density=electron density= $n = 10^2\,\mathrm{m}^{-3}$, magnetic field $B = 10^{-10}$ T. Calculate the pressure $2nkT$ [Pa], magnetic field pressure $B^2/2\mu_0$ [Pa], hydrogen ion thermal speed v_i [m/s], the cyclotron radius at this speed ρ_i [m]. Electron thermal speed v_e, the cyclotron radius at this speed ρ_e [m]. Show the values with one significant digit. Note that the thermal motion is defined as $v = \sqrt{kT/m}$.

Q2: Drift

Consider an electron and a positive ion are executing cyclotron motions in xyz-space with z-directed homogeneous magnetic field B_z (>0).

(1) Draw the electron and ion cyclotron motions and orbits in xy-plane. Let z-axis directed from the report sheet toward you.

(2) A y-directed homogeneous electric field E_y (>0) is applied. Explain and illustrate the electron and ion ExB drifts with a drawing.

Q3: Runaway electron

The electric resistivity of plasma is calculated from the electron (mass: m_e, charge: $-e$) force balance where acceleration by the electric field E and collisional drag from ion balance. However, under a certain condition, the acceleration overwhelms the drag, and the electron is accelerated continuously. Such an electron is referred to as a runaway electron.

(1) Write the equation motion using electron parallel velocity v_e, electron-ion collision time τ_{ei}.

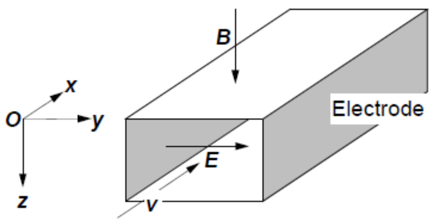
(2) Using the formula $\tau_{ei} = \frac{\varepsilon_0^2 m_e^2 v_e^3}{ne^4}$ (here, n is the density), derive the condition on E for the runaway electron generation.

Q4: MHD thruster

Consider a rectangular duct filled with MHD fluid with velocity $(v, 0, 0)$ as shown in the figure. When a static and homogeneous magnetic field $\boldsymbol{B}$=(0,0,B), B>0 and an electric field $\boldsymbol{E}$=(0,E,0), $E > 0$ is applied, a steady homogeneous current density $\boldsymbol{j}$=(0,j,0), j>0 and a steady flow $\boldsymbol{v} = (v, 0, 0), v > 0$ are induced in the fluid.

(1) To keep the velocity $\boldsymbol{v}$ steadily, we need an external force of $\boldsymbol{f}$ per unit fluid volume. Using the Ohm's law $\boldsymbol{E} + \boldsymbol{v} \times \boldsymbol{B} = \eta \boldsymbol{j}$, express $\boldsymbol{f}$ with $\boldsymbol{E}, \boldsymbol{v}, \boldsymbol{B}, \eta$.

(2) The work done by the MHD fluid against the external force per unit fluid volume per unit time is $-\boldsymbol{f} \cdot \boldsymbol{v}$. The supplied power to the MHD fluid per unit fluid volume per unit time is $\boldsymbol{E} \cdot \boldsymbol{j}$. Explain the power balance using equations.



Q5: Wave

The squared refractive index $N_{R,L}^2$ of R- and L-waves propagating along a field line is written as

$$N_{R,L}^2 \approx 1 - \frac{\Pi_e^2}{\omega^2} \pm \frac{\Pi_e^2 \Omega_e}{\omega^3} \quad \left(\Pi_e^2 = \frac{ne^2}{m_e \varepsilon_0}, \Omega_e \equiv \frac{eB}{m_e}\right)$$

Here ω is the angular frequency of the waves. Calculate the phase difference between those of R- and L-waves when they propagate a distance L in plasma with a homogeneous magnetic field strength B and density n, which is sufficiently low. Describe the dependence of the phase on B and n.

Q5: Artificial plasma

Pick up an artificial plasma and investigate it using references and etc. Explain it within one page. Add the reference list or source of the information.