Ex/PG/SC/CBS/PHY/TH/301/2023

M. Sc. Physics Examination, 2023

(2nd Year, 2nd Semester)

Plasma Physics

Paper – 301

Time : 2 hours Full Marks : 40

The figures in the margin indicate full marks.

Candidates are instructed to give their answers in their own words as far as practicable.

Answer any ***four*** questions. 4×10=40

1. Plasma is a collection of charge particles (mainly electrons and ions) in which collective effects dominate due to long range Coulomb forces. One example of plasma collective behaviour is 'Debye shielding'. Consider a plasma is in equilibrium, and we introduce a test charge Q_T inside the plasma.

   a) Explain physically the effects of the test charge Q_T on the equilibrium plasma particles.

   b) Prove that the potential due to the test charge Q_T obeys the formula $\phi(r) = \frac{Q_T}{4\pi \in_0 r} e^{-r/\lambda_D}$, where $\lambda_D = \sqrt{\in_0 k_B T_e / n_0 e^2}$ is known as Debye length and all other symbols have their usual meanings.

   c) Roughly sketch a curve $\phi(r)$ vs. r, clearly showing whether the potential due to the test charge falls off much faster in plasma than in vacuum or not.

[Turn over

2+6+2

2. In the context of motion of charged particles in uniform electric and magnetic fields $\left(\vec{E} \perp \vec{B}\right)$, we have learnt that both the ions and electrons experience $\vec{E} \times \vec{B}$ drift with same drift velocity $\vec{v}_d = \frac{\vec{E} \times \vec{B}}{B^2}$. Consider a plasma is immersed in an external uniform magnetic field which points along the z direction in a Cartesian coordinate system, i.e, $\vec{B} = B_o\vec{k}$ .Moreover, we now take the electric field to be non-uniform and it is along the x direction, i.e. $\vec{E} = E_0 \cos(\alpha x)\hat{i}$, where α^{-1} is the scale length of variation of non-uniform electric field.

   a) Prove that, in the presence of such a non-uniform electric field, the above expression of the drift velocity will be modified to give $\vec{v}_d = \frac{\vec{E} \times \vec{B}}{B^2}\left(1 - \frac{1}{4}\alpha^2 r^2\right)$, where the second term in the first bracket is called the finite Larmor radius effect, with r denotes the Larmor radius.

   b) Hence physically explain what will happen if somehow a density clump occurs inside the plasma due to the presence of a non-uniform electric field.

   c) Does the plasma drive any current in the presence of the non-uniform electric field and uniform magnetic field? 7+2+1

3. We focus on the macroscopic fluid description of plasmas. Together with Maxwell's equations, the fluid approach can almost provide a complete dynamic evolution of plasmas. Moreover, the fluid model can explain most of the laboratory experiments, thereby making it popular among the plasma physics community.

   a) Write down the basic 1D Maxwell-fluid equations that describe the dynamics of electron plasma oscillations in a cold collisionless unmagnetized plasma.

   b) Hence by employing the usual linearization procedure obtain the dispersion relation for the electron plasma oscillations.

   c) What do you mean by the 'cold plasma approximation' and the 'collisionless approximation' of plasmas. 3+5+2

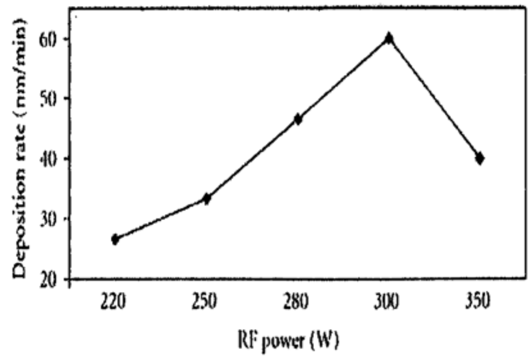

Figure 1: Variation of the disposition rate with the Radio Frequency (RF) Power. [Refer to Question 6. (d)]

4. The celebrated KdV equation describing weakly nonlinear long wave propagation in dispersive media reads as

$$\frac{\partial u}{\partial t}+6u\frac{\partial u}{\partial x}+\frac{\partial^3 u}{\partial x^3}=0 \text{, where } u\equiv u(x,t).$$

   a) Identify the roles the terms $6u\,\partial u/\partial x$ and $\partial^3 u/\partial x^3$ plays here.

   b) Show that the above KdV equation offers a single 'solition' solution in the form:

$$u(x-Vt)=\frac{V}{2}\text{sech}^2\left[\frac{\sqrt{V}}{2}(x-Vt)\right]$$

   where V denotes the phase speed of the solition.

   c) Hence point out the salient features of a soliton.

2+6+2

5. a) During the breakdown of gases, how the current is grown in the presence of secondary processes as per Townsend theory?

   b) What is Paschen's law? How the knowledge of Paschen's law can help you to get an idea about the breakdown condition in a glow discharge plasma within a vacuum chamber?

   c) Why plasma formation of gases is preferred for different material processing and other applications?

6+3+1

6. a) What is the necessity of vacuum during the plasma formation for material processing?

   b) How plasma diagnostics can help to optimize the material properties in a shorter time?

   c) For high resistive material processing which type of plasma between DC and RF is preferred and why?

   d) The following graph (see Figure 1) shows the effect of radio frequency (RF) power on the deposition rate for a sputtering process. Describe the nature of the curve with possible explanations. Why deposition rate decreased at higher RF power? 2+3+2+3

7. a) What is the basic difference between plasma deposition and plasma etching? Name some processes of plasma deposition and plasma etching.

   b) What are the input control parameters for the formation of glow discharge plasma during semiconductor material deposition? How input parameters affect the plasma parameters, material properties and device performance?

   c) How Optical Emission Spectroscopy can be utilized for the end point detection of a plasma process?

3+4+3