UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualification:-

M.Sci.

Physics 4461: Plasma Physics

COURSE CODE	:	**PHYS4461**
UNIT VALUE	:	**0.50**
DATE	:	**07-MAY-03**
TIME	:	**14.30**
TIME ALLOWED	:	**2 Hours 30 Minutes**

03-C1091-3-30

TURN OVER

Answer THREE questions.

The numbers in square brackets in the right-hand margin indicate the provisional allocation of maximum marks per sub-section of a question.

Permittivity of Free Space $\varepsilon_o = 8.8 \times 10^{-12}$ F m^{-1}

Electronic Charge: $e = 1.6 \times 10^{-19}$ C

Permeability of Free Space: $\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1}

Proton Rest Mass: $m_p = 1.67 \times 10^{-27}$ kg

1. A positive point charge Q is slowly inserted into a plasma.

Discuss the effective screening for a

(i) **cold plasma** and (ii) **hot plasma** [4]

Using Boltzmann's equation, derive the equation

$$\nabla^2\phi = 2\lambda_D^{-2}\ \phi$$

where ϕ is the plasma potential and λ_D is the Debye length. [8]

A fusion plasma with an effective thermal energy of 1 kev has an electron density of $10^{19}\ m^{-3}$. Determine λ_D. [2]

Discuss the role of λ_D in producing

(i) **coherent** and (ii) **incoherent** oscillations in the plasma. [6]

2. Sketch the geometry of a Tokamak showing the

(i) Toroidal and Poloidal directions

(ii) Major (R_o) and Minor (r_o) radii

(iii) Electron path in absence of trapping. [5]

Electron trapping with $V_z = 0$ in an inhomogenous magnetic field B will occur when

$$B > B_0 V_0^2 (V_{\perp 0})^{-2}$$

where B_0 is the field on the outside of the toroidal surface and V_0 and $V_{\perp 0}$ are the initial total and initial perpendicular velocities respectively. The z direction is the axis of symmetry. [2]

(i) Give an expression for the dependence of B on R_0, r_0, and the poloidal angle θ

(ii) Show that the toroidal velocity V_z is given by

$$V_z^2 = V_0^2 - V_{\perp 0}^2 \, (1 - \varepsilon \cos \theta)(1 - \varepsilon)^{-1}$$

where ε is the inverse aspect ratio. [4]

(iii) Derive the condition for the establishment of **Passing** and **Trapped** electrons. Why is it necessary to apply a Poloidal field in addition to the Toroidal field? [9]

3. In a cold plasma the dielectric tensor ε for the propagation of electromagnetic waves of frequency ω and amplitude ***E*** is given by

$$\varepsilon = \boldsymbol{I} + i(\varepsilon_0\omega)^{-1}\sigma$$

where σ is the conductivity tensor and ***I*** is an identity matrix.

(i) Show that the general wave equation is

$$\nabla^2 E - \nabla(\nabla \bullet E) + \frac{\omega^2}{c^2}\,\varepsilon \bullet E = 0$$ [4]

(ii) Derive the dispersion relationship for the propagation of transverse modes in the plasma [4]

In a cold magnetic plasma the velocity ***V(t)*** of mode propagation is given by

$$V(t) = a \bullet E$$

where ***E*** is the electric field and a̲ is a 3 × 3 tensor funtionally dependent on the radiation frequency ω and the electron cyclotron frequency ω_{ce}. Derive the tensor a. You may assume that $\omega \neq \omega_{ce}$. [12]

4. Consider a perfectly conducting incompressible fluid moving with velocity $\boldsymbol{V}$ with respect to a laboratory frame. Magnetic and electric fluid exist in the laboratory frame.

(i) Show that the evolution of $\boldsymbol{B}$ in the fluid is given by

$$\frac{\partial B}{\partial t} = \nabla \times (\boldsymbol{V} \times \boldsymbol{B}) \qquad [4]$$

(ii) Using the equation of continuity, derive the velocity condition for an incompressible fluid. [4]

(iii) Hence show that $\frac{dB}{dt} = (\boldsymbol{B} \bullet \nabla)\boldsymbol{V}$ [4]

(iv) Consider the fluid element at (t, x_i) and subsquently at $(t + \Delta t, x_j)$

Derive the Stress Tensor relating $\boldsymbol{B}$ at $\boldsymbol{i}$ and $\boldsymbol{j}$. [8]

5. An intense laser field of wavelength λ, angular frequency ω and amplitude E interacts with a

neutral atomic gas producing a plasma:

(i) Distinguish between Multiphoton ionization and Barrier Supression Ionization. [2]

(ii) Explain how the Pondermotive Potential, ϕ influences the multi photon ionization process. [2]

(iii) Derive the expression

$$\phi = \frac{e^2 E_0^2}{4m\omega^2}$$

stating clearly any approximations used. [4]

(iv) An electron is bound by a Coulomb potential to the nucleus of charge z with an ionization potential V. Show that the threshold laser electric field required to produce Barrier Suppression ionization is

$$\boldsymbol{E_T} = Z^3/16nt$$

where n is the principle quantum number. [4]

(1) When $\boldsymbol{E} < \boldsymbol{E_T}$ show that the tunnelling probability is proportional to

$\boldsymbol{exp(-V^{3/2}/E)}$.

State clearly any approximations used. [8]

END OF PAPER