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MPHYCC-6

M.Sc. Sem II

Plasma Physics

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Paper - MPHYCC-6

: Plasma Oscillation :-

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A Plasma oscillation in a metal is a collective longitudinal excitation of the conduction electron gas. The term "plasma" was suggested in 1929 by Langmuir to describe the collective electrical properties that he noted in an ionized gas. Since that time, many of the phenomena observed for a gaseous plasma can be reproduced in the electron "gas" of a metal or a semiconductor. Thus the field of plasma physics in condensed matter systems has become well established, with several technological applications.

A plasma in a quantum associated with a plasma oscillation. While it has relatively few direct observation of energy losses, in multiples of $\hbar\omega_p$, where ω_p is the plasma frequency. When electrons are field through thin metallic film or by reflecting an electron or a photon from a film. However, the possibility of their excitation in any process involving an electron gas should always ~~become~~ borne in mind.

The frequency of the plasma oscillation can be found using a very simple argument. Suppose that an electron in the electron gas of a solid oscillates about its equilibrium position under the effect of an electrical restoring force, defined by the equation

$$m\,d^2\vec{r}/dt^2 = -e\vec{E} \quad \text{——} \quad (1)$$

Here e(m) is the electronic charge (mass), $\vec{r}$ is the electron displacement in 3D, and $\vec{E}$ is the

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electric field vector. For oscillations with a time dependence of the type $(-i\omega t)$, the Polarization field defined as the dipole moment of the electrons per unit volume, is given by

$$\vec{P}(\omega) = -ne\vec{r} = -ne^2\vec{E}/m\omega^2 \quad \text{—— (2)}$$

where n is the electron concentration. The dielectric function associated with the electron gas oscillation is then given (in SI units) by

$$\epsilon(\omega) = 1 + P(\omega)/\epsilon_0 E(\omega) = 1 - \omega_p \quad \text{—— (3)}$$

where the plasma frequency ω_p is defined by $\omega_p^2 = ne^2/\epsilon_0 m$. If the +ve ion background has a dielectric constant ϵ_∞, assumed to be essentially constant up to frequencies well above ω_p, then the plasma dielectric function becomes

$$\epsilon(\omega) = \epsilon_\infty (1 - \omega_p^2/\omega^2) \quad \text{—— (4)}$$

We observe from eqn (4) that the frequency-dependent dielectric function $\epsilon(\omega)$ is −ve for $\omega < \omega_p$ and +ve for $\omega > \omega_p$. The behavior of this dielectric function in terms of the frequency ratio ω/ω_p is plotted.

The frequency dependence has important Consequences dependence has important consequences for the Propagation of an electro-magnetic wave Through The Plasma. In particular at low frequencies when $\epsilon(\omega)$ is -ve, it follows from maxwell's equations That no radiation can Propagate on the other hand when $\epsilon(\omega)$ is +ve for $\omega > \omega_p$ the electro-magnetic radiation can propagate, and the medium should become transparent.

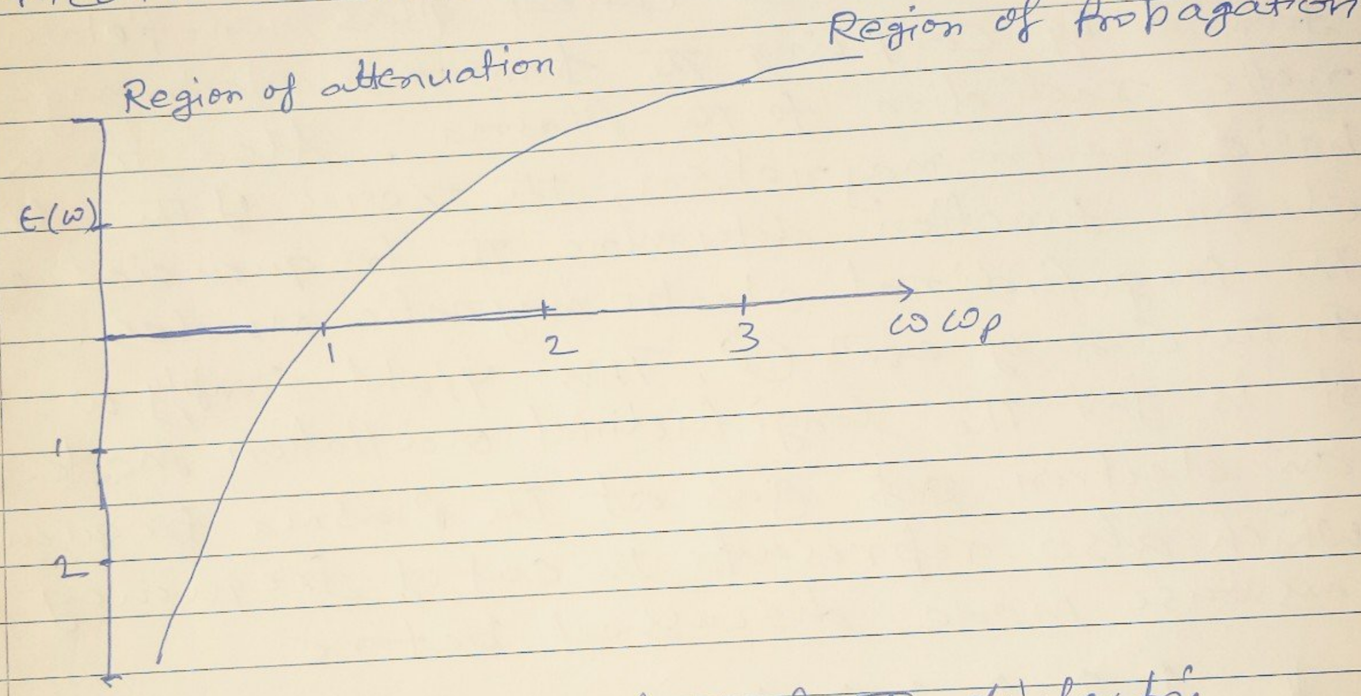

fig. 1 Behaviour of The dielectric Function for an electron gas, as denoted by eqn (4) with $\epsilon_\infty = 1$, as a function of ω/ω_p.

The above situation will be discussed more thoroughly ~~in~~ in later chapters on polaritons. However we may briefly comment here that the transverse electromagnetic mode in the plasma is defined by $k^2 = \epsilon(\omega)\,\omega^2/c^2$. Using eqn (4) in the case of $\epsilon_\infty = 1$, the expression can easily be rearranged as

$$\omega^2 = \omega_p^2 + c^2 k^2 \qquad (5)$$

where c is the velocity of light in vacuum. This is the dispersion relation for a mixed mode which is just the so-called plasmon-polariton formed by coupling the transverse electromagnetic radiation to the plasma. Also from basic electromagnetism, the zeros of the dielectric function determine the frequencies of the longitudinal electromagnetic modes. In the case of eqn (4), this yield simply $\omega = \omega_p$. It is just the longitudinal oscillation mode of an electron ~~gas~~ gas at the plasma frequency which also represents the cut of frequency of the transverse mode discussed before

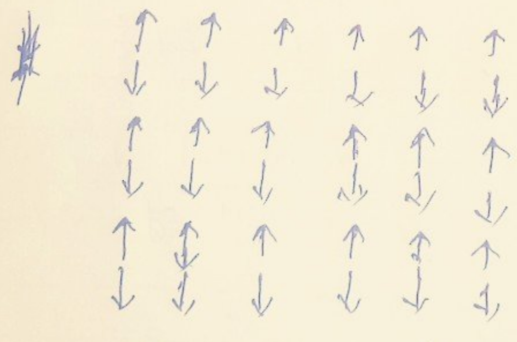

fig2 Longitudinal plasma oscillation.

The arrows indicates the direction of displacement of the electrons.