in visible range. The visible light can't pass through the metal because the plasma frequency of electrons in metal falls in ultraviolet region. For frequencies in UV, metals are transparant.

The earth's ionosphere reflects Radio waves for the same reason, though the analysis is not so straightforward. The electron densities at various heights in the ionosphere can be inffered by studying the reflection of pulses of radiation transmitted vertically upwards. Also, the broadcast of various Radio signals in communication on Earth is possible only because of reflection from the ionosphere.

## Plasma Oscillations

The story of these plasma oscillations begins with Langmuir's observations in low pressure mercury vapur discharge tube. He observed that under a wide range of conditions, there were many electrons with abnormally large velocities, whose voltage equivalent is greater than the total voltage drop across the tube. There was an even larger number of electrons with Kinetic energies lower than the average KE, so the group as a whole has not acquired extra energy, but there has been a redistribution of energy. One such mechanism for such rapid transfer of energy between the electrons was suggested as scattering of electrons due to rapidly changing electronic fields.Dittmer obtained evidence pointing in this direction and Penning observed such oscillations of radio frequencies in low pressure mercury and argon vapor discharges. Finally, Tonks and Langmuir came up with a simple theory and experimental observations of these oscillations.

Now coming to back to our main topic, we will consider two main interactions, that of radiation with plasma and that of a beam of electrons with the plasma. When radiation of frequency $\omega$ is incident on a plasma, three modes of oscillation can be supported. Two are transverse and one longitudinal. We assume that the electrons are so mobile that the motion of ions is negligible and the electrons are embeded in a sea of immobile ions.

### Plasma Electron Oscillations

If we displace a layer of electrons by a distance $\xi$ in $x$ direction, then the change in density of electrons is given by $\delta n = n\frac{\mathrm{d}\xi}{\mathrm{dx}}$

Originally the net charge is zero, so after the displacement, Poisson's equation gives

$\frac{\mathrm{dE}}{\mathrm{dx}} = 4\pi e\delta n$

eliminating $\delta n$, we get

$\frac{\mathrm{dE}}{\mathrm{dx}} = 4\pi ne\frac{\mathrm{d}\xi}{\mathrm{dx}}$

Integrating, we get the electric field as $E = 4\pi ne\xi$

Hence, for the restoring force on the electrons, we get

$m_e\xi'' = -4\pi ne^2\xi$

This is the equation for simple harmonic motion. The frequency of oscillation is $\nu_e = \sqrt{\frac{ne^2}{\pi m_e}} = 8980\sqrt{n}$

Thus, displacement of a layer of electrons gives rise to a collective phenomena in plasma, that of oscillations of the displaced charges. These oscillations are in the direction of propogation vector, and hence the electric field also points in the same direction. Also, note that $\frac{\mathrm{d}\omega}{\mathrm{d}k} = 0$ hence these are not travelling waves, no energy is transported.

## Plasma Ion Oscillations

Electric forces of same magnitude act of ions, but the ions being 2000 times heavy, experience that much less acceleration. In the case of Ion oscillations, the cutoff frequency turns out to be two orders of magnitude lower.

$\nu_e \simeq 9 * 10^8$ , whereas $nu_p \simeq 1.5 * 10^6$

The ion oscillations essentially behave like electrostatic sound waves.

If we define the electron thermal speed to be $v_e \equiv (kT/m_e)^{1/2}$, then $\omega_p \equiv v_e/\lambda_D$. Thus, thermal electron travels about a Debye length in a plasma period. Just as the Debye length functions as the electrostatic correlation length, so the plasma period plays the role of the electrostatic correlation time.

# Warm Plasma Waves

Note that the Plasma oscillations discussed in earlier section are not travelling waves, but stationary oscillations at a particular frequency, $\omega_p$. These oscillations become propagating waves when we take the electron pressure to be non-zero. For the electron pressure, we can u[illegible]diabetic relation $p_e = Cn_e^\gamma$.

The Euler equat[illegible]

$$m_e n_e \left[\frac{\partial \vec{V}_e}{\partial t} \quad [illegible] \nabla)\vec{V}_e\right] = -\nabla p_e + q_e n_e \left(\vec{E} + \frac{\vec{V}_e}{c} \times \vec{B}\right)$$

Linearising, we get

$$m_e n_0 \frac{\partial \vec{V}_e}{\partial t} = -\frac{\gamma p_0}{n_0} \nabla n_1 + e n_0 \vec{E}_1$$

The equation of continuity is

$$\frac{\partial n_e}{\partial t} + \nabla \cdot (n_e \vec{V}_e) = 0$$

Linearizing, we get

$$\frac{\partial n_1}{\partial t} + n_0 \nabla \cdot \vec{V}_1 = 0$$