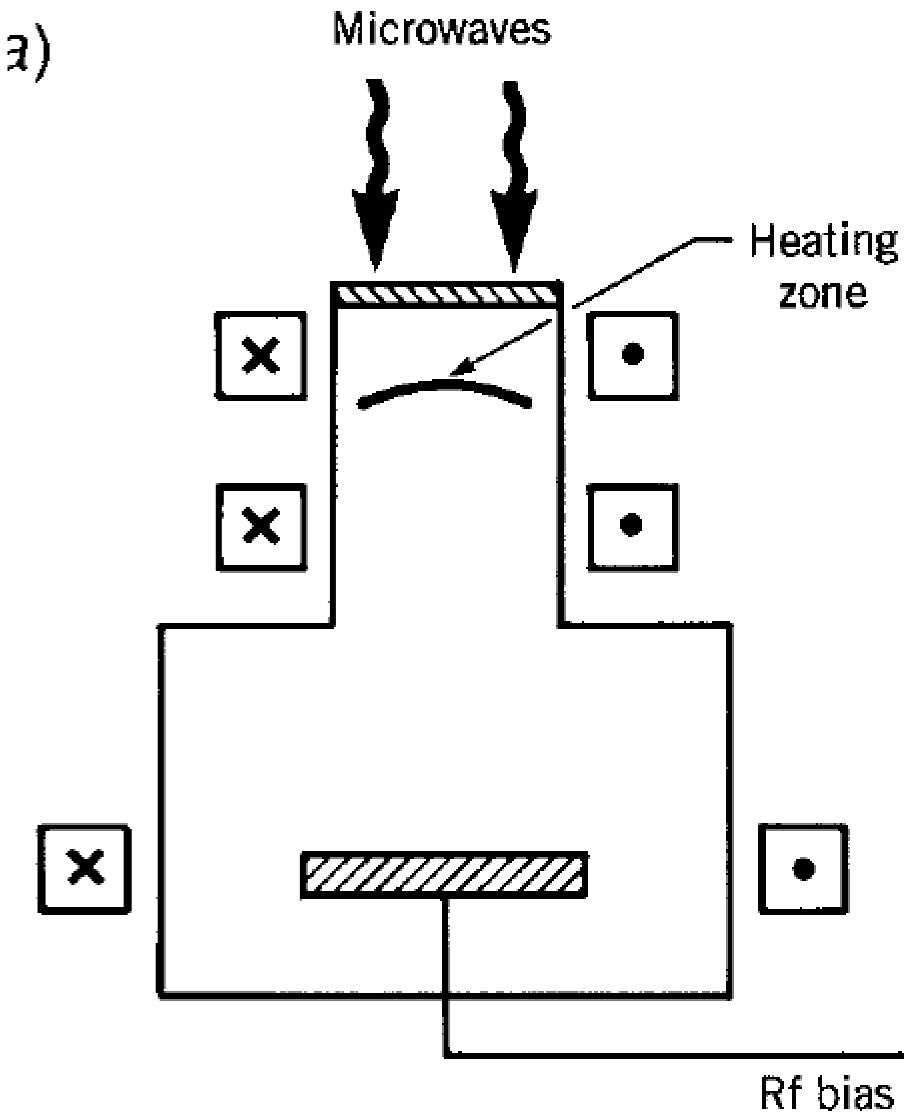
Лекция 8

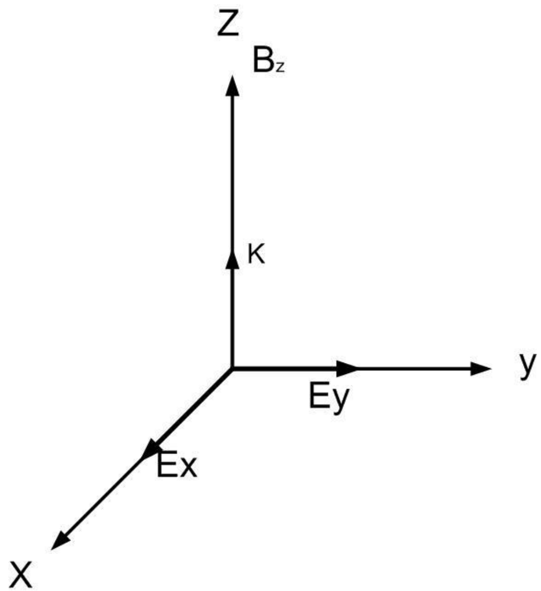
Разряды в замагниченной плазме.

1. Электронный циклотронный резонанс.

2. Геликонные волны

Электронный циклотронный резонанс





$$E = E_{x,y} \cdot \exp(-i\omega t)$$

$$\begin{pmatrix} j_x \\ j_y \end{pmatrix} = \frac{\varepsilon_0 (\omega_p)^2}{(-i\omega + \nu)^2 + (\omega_c)^2} \cdot \begin{pmatrix} -i\omega + \nu & -\omega_c \\ \omega_c & -i\omega + \nu \end{pmatrix} \cdot \begin{pmatrix} E_x \\ E_y \end{pmatrix}$$

$$\nabla^2 E - \frac{\omega^2}{c^2} \frac{d^2 E}{dt^2} = -\mu_0 \frac{dj}{dt}$$

$$\begin{pmatrix} k^2 & 0 \\ 0 & k^2 \end{pmatrix} \cdot \begin{pmatrix} E_x \\ E_y \end{pmatrix} = \frac{\omega^2}{c^2} \cdot \begin{pmatrix} k_t & -ik_g \\ ik_g & k_t \end{pmatrix} \cdot \begin{pmatrix} E_x \\ E_y \end{pmatrix}$$

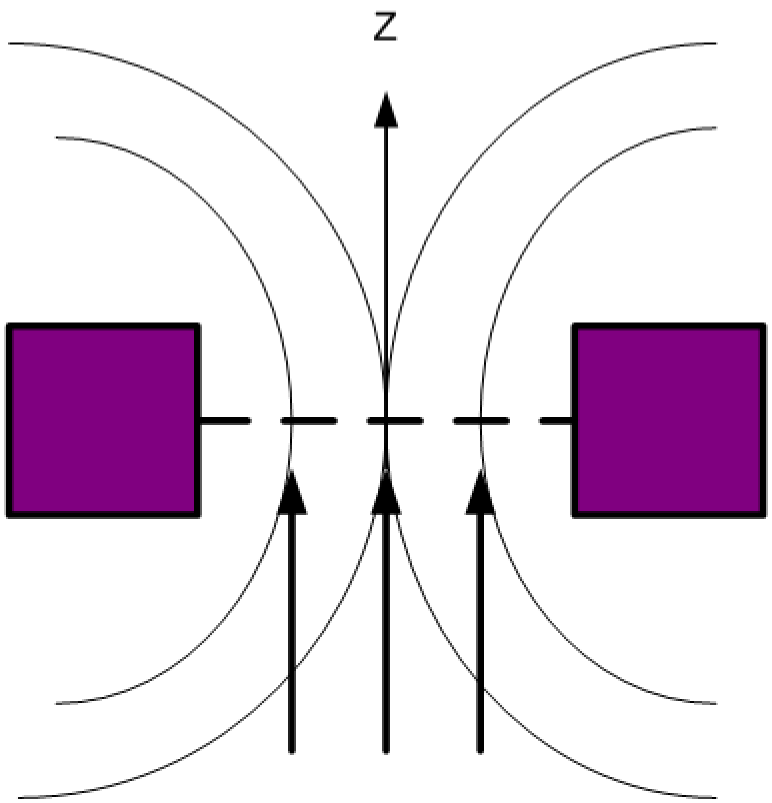
1. Право поляризованная волна. $E = E_x - iE_y$

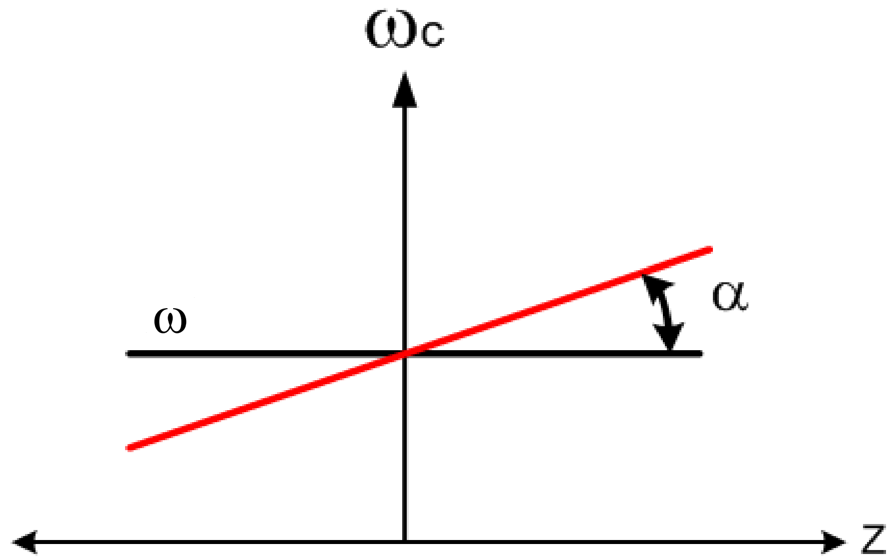
$$(k_r)^2 = \frac{\omega^2}{c^2}\left[1 - \frac{(\omega_p)^2}{\omega(\omega - \omega_c)}\right] \qquad \omega < \omega_c$$

2. Лево поляризованная волна. $E = E_x + iE_y$

$$(k_l)^2 = \frac{\omega^2}{c^2}\left[1 - \frac{(\omega_p)^2}{\omega(\omega + \omega_c)}\right]$$

$$\frac{dv_r}{dt} - i(\omega - \omega_c)v_r = \frac{-e}{m}E_r - \nu v_r$$





$$\omega_c(z) = \omega \cdot (1 + \alpha \cdot z)$$

$$z = v_p \cdot t$$

$$\frac{dv_r}{dt} - i \cdot \omega \cdot \alpha \cdot v_p \cdot t \cdot v_r = \frac{-e}{m} E_r$$

Решение однородного уравнения

$$v_r(t) = A(t) \cdot \exp\left(i \cdot \omega \cdot \alpha \cdot v_p \cdot \frac{t^2}{2}\right)$$

$$\Theta(t) = \omega \cdot \alpha \cdot v_p \cdot \frac{t^2}{2}$$

$$A(T) = A(-T) - \left(\frac{eE}{m}\right) \cdot \int_{-T}^{T} \exp\left(-i\Theta\left(t_1\right)\right.\ dt_1$$

$$v_r(T) \cdot \exp(-i\Theta(T)) = v_r(-T) \cdot \exp(-i\Theta(-T)) - \left(\frac{eE}{m}\right) \cdot \int_{-T}^{T} \exp\left(i\Theta\left(t_1\right)\right) dt_1$$

При условии $\quad T > \blacksquare > \left(\frac{2\pi}{\omega\alpha v_p}\right)^{\frac{1}{2}}$

$$\int_{-T}^{T} \exp\left(i\Theta\left(t_1\right)\right) dt_1 = (1 + i) \cdot \left(\frac{\pi}{\omega\alpha v_p}\right)^{\frac{1}{2}}$$

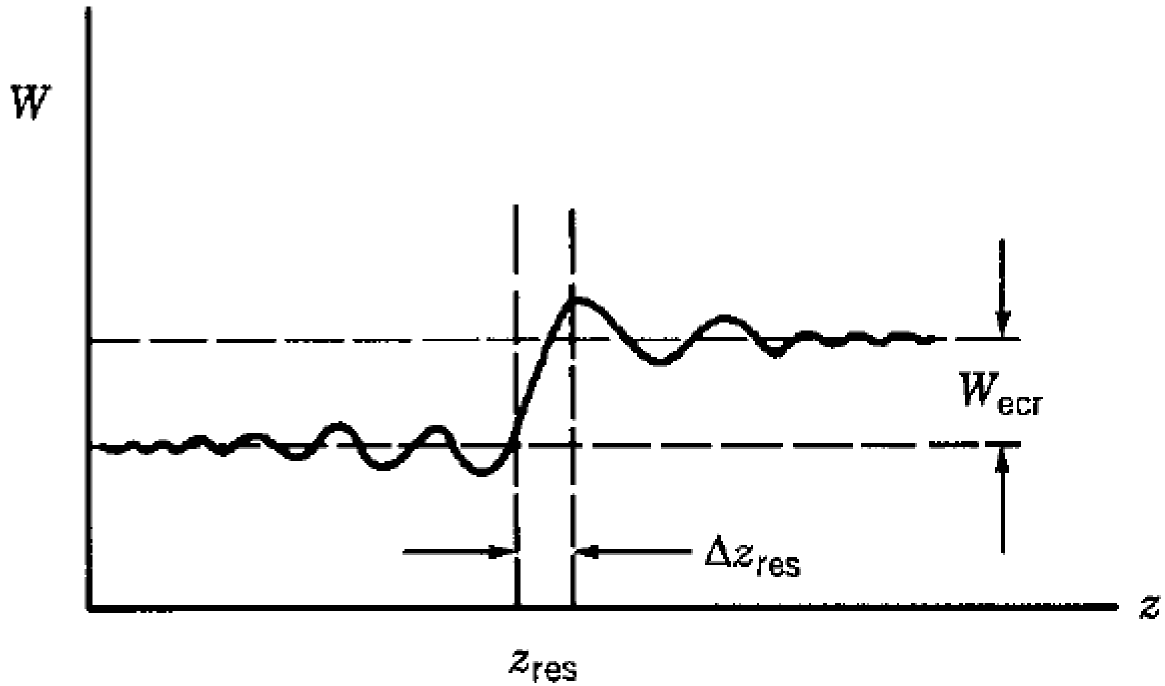
$$\left[\left|v_r(T)\right|\right]^2 = \left[\left|v_r(-T)\right|\right]^2 + \left(\frac{eE}{m}\right)^2 \cdot \frac{2\pi}{\omega\alpha v_p}$$

$$W_{ecr} = \frac{m\cdot\left(\left|\Delta v_r\right|\right)^2}{2} = \frac{\pi\, e^2\, E^2}{m\omega\alpha v_p}$$

$$\Delta v_r = \frac{eE}{m}\Delta t_{res}$$

$$\Delta t_{res} = \left(\frac{2\pi}{\omega\alpha v_p}\right)^{\frac{1}{2}}$$

$$P = W_{ecr} \cdot n \cdot v_p = \frac{\pi \cdot n\, e^2 E^2}{m\omega\alpha}$$



Геликонные волны.

$$(k_r)^2 = \frac{\omega^2}{c^2}\left[1 - \frac{(\omega_p)^2}{\omega(\omega - \omega_c)}\right]$$

$$\omega < \blacksquare < \omega_p$$

$$\omega < \blacksquare < \omega_c$$

$$k^2 = \left(\frac{\omega}{c}\right)^2 \cdot \frac{(\omega_p)^2}{\omega \cdot \omega_c}$$

$$k = \frac{\omega_p}{c} \cdot \sqrt{\frac{\omega}{\omega_c}}$$

$$\lambda = 2 \cdot \pi \cdot \frac{c}{\omega_p} \cdot \sqrt{\frac{\omega_c}{\omega}}$$

$\omega = 8.5 \cdot 10^7$ (13MHz)

$\omega_p = 2 \cdot 10^{10}$ $\left(n_e = 10^{17}\right)$

$f_c = 2.8 \cdot 10^8$ (100Gs)

$\lambda_0 = 22$

(m)

$\lambda = 0.17$

Поглощение геликонной волны

$$k^2 = \left(\frac{\omega}{c}\right)^2 \cdot \left[1 - \frac{(\omega_p)^2}{\omega \cdot (\omega - \omega_c + i \cdot \nu)}\right]$$

$$k^2 = \left(\frac{\omega_p}{c}\right)^2 \cdot \frac{(\omega_c - \omega + i\nu)}{(\omega_c - \omega)^2 + \nu^2} \cdot \omega$$

$$\omega_c > \blacksquare > \nu$$

$$k^2 = \left(\frac{\omega_p}{c}\right)^2 \cdot \frac{\omega}{\omega_c} \cdot \left(1 + i \cdot \frac{\nu}{\omega}\right)$$

$$k = k_r + i \cdot k_{im}$$

$$k^2 = (k_r)^2 - (k_{im})^2 + 2 \cdot i \cdot k_r \cdot k_{im}$$

$$(k_r)^2 - (k_{im})^2 = \mathrm{Re}(k^2) = \left(\frac{\omega_p}{c}\right)^2 \cdot \frac{\omega}{\omega_c}$$

$$2 \cdot k_r \cdot k_{im} = \mathrm{Im}(k^2) = \left(\frac{\omega_p}{c}\right)^2 \cdot \frac{\omega}{\omega_c} \cdot \frac{\nu}{\omega_c}$$

$$k_r = \frac{\omega_p}{c} \cdot \sqrt{\frac{\omega}{\omega_c}}$$

$$k_{im} = \frac{1}{2} \cdot \frac{\nu}{\omega} \cdot \frac{\omega_p}{c} \left(\frac{\omega}{\omega_c} \right)^{\frac{3}{2}} = \frac{1}{2} \cdot \frac{\nu}{\omega_c} \cdot k_r$$

$$k_r = \frac{2 \cdot \pi}{\lambda}$$

$$\alpha = \frac{1}{k_{im}} = \frac{2\,\omega_c}{\nu \cdot k_r} = \frac{\omega_c \cdot \lambda}{\pi \cdot \nu}$$

$$\alpha > \blacksquare > \lambda$$

$\nu = 5 \cdot 10^7$ (3mTorr)

$\alpha = 1$ $\lambda = 0.17$

Затухание Ландау