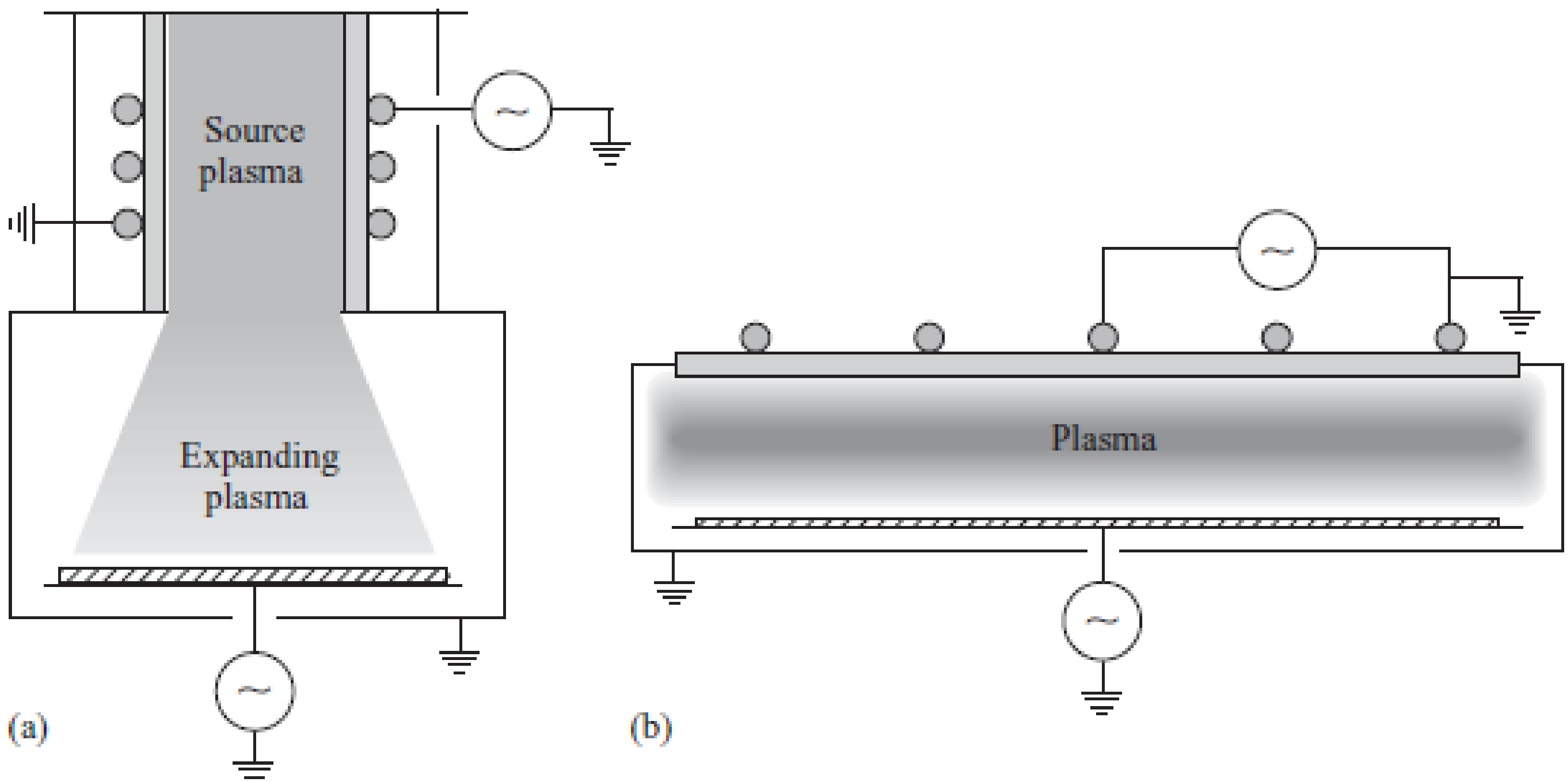
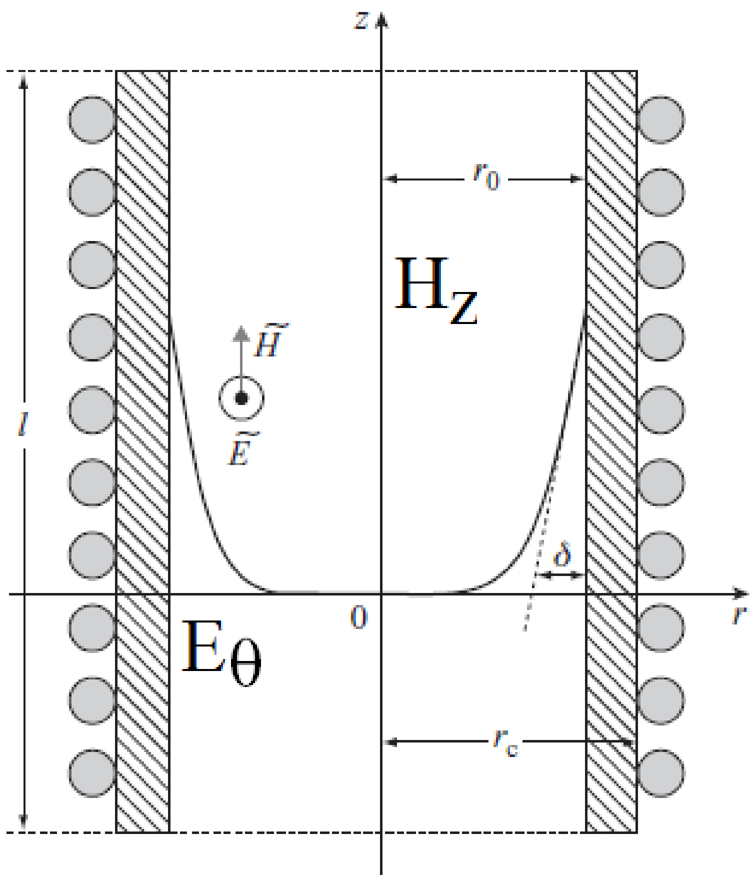
Лекция 7

Индуктивная плазма





$$\mathrm{rot}E = -\mu_0 \nabla_t H$$

$$\mathrm{rot}H = j + \varepsilon_0 \nabla_t E$$

$$\varepsilon_p = 1 - \frac{(\omega_p)^2}{\omega \cdot (\omega - i\nu_m)}$$

В цилиндрической системе координат

$$\mathrm{rot}A = \left(\frac{1}{r}\nabla_\theta A_z - \nabla_z A_\theta\right)\vec{r} +$$

$$\left(\nabla_z A_r - \nabla_r A_z\right)\vec{\theta} +$$

$$\left[\frac{1}{r}\nabla_r\left(r\cdot A_\theta\right) - \frac{1}{r}\nabla_\theta A_z\right]\vec{z}$$

Отличны от 0: E_z H_θ

$$\frac{1}{r}\cdot\frac{d}{dr}\left(r\cdot E_{\theta}\right) = -i\omega\cdot\mu_0\cdot H_Z$$

$$\frac{dH_Z}{dr} = -i\omega\varepsilon_0\cdot\varepsilon_p E_{\theta} \qquad E_{\theta} = \frac{i}{\omega\varepsilon_0\varepsilon_p}\cdot\frac{dH_Z}{dr}$$

$$\frac{d^2H_Z}{dr^2} + \frac{1}{r}\cdot\frac{dH_Z}{dr} + k^2\cdot H_Z = 0$$

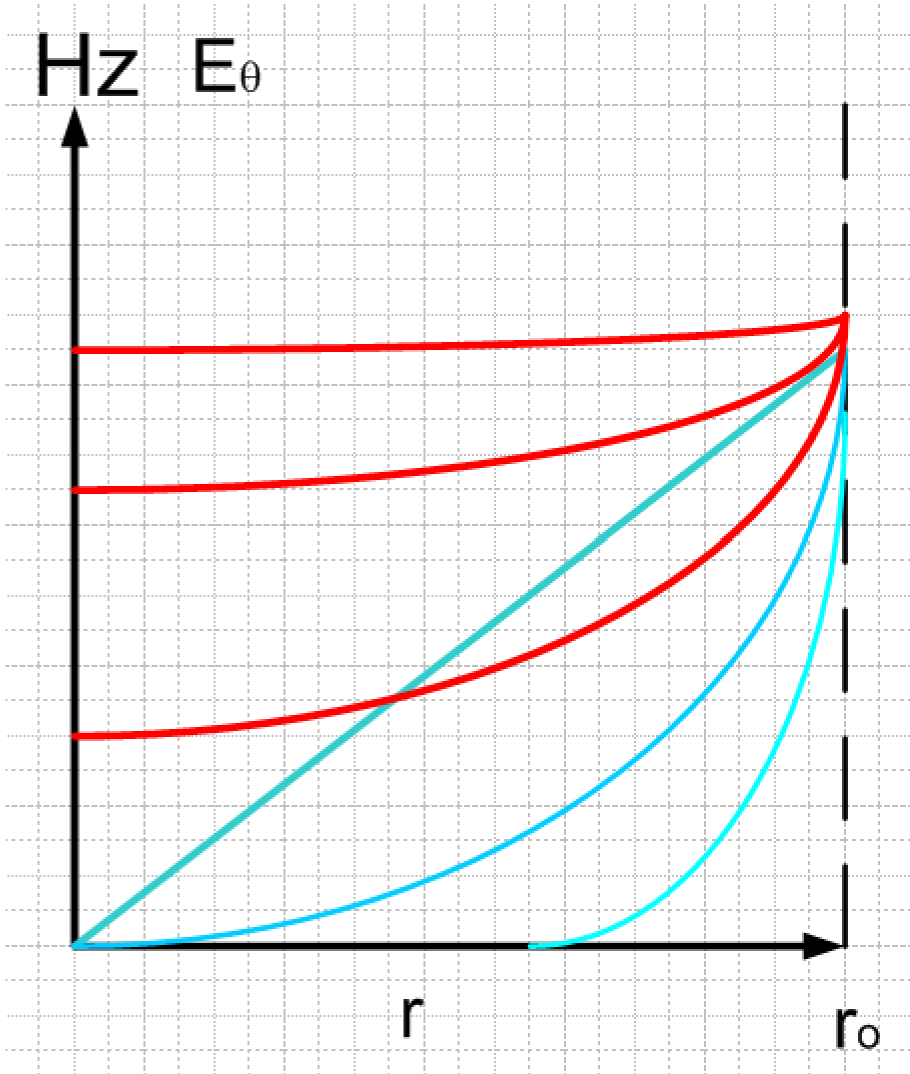
$$k^2 = \omega^2\varepsilon_0\mu_0\cdot\varepsilon_p = \frac{\omega^2}{c^2}\cdot\varepsilon_p$$

$$H_Z = H_{ZO} \cdot \frac{J_0(k \cdot r)}{J_0(k \cdot r_0)}$$

$$H_{ZO} = H_Z(r = r_0)$$

$$E_\theta = \frac{i}{\omega \varepsilon_0 \varepsilon_p} \cdot \frac{dH_Z}{dr} = \frac{k}{i\omega \cdot \varepsilon_0 \cdot \varepsilon_p} \cdot \frac{J_1(k \cdot r)}{J_0(k \cdot r_0)} \cdot H_{ZO}$$

$$\frac{dJ_0(x)}{dx} = -J_1(x)$$



Hz Eθ
r
ro

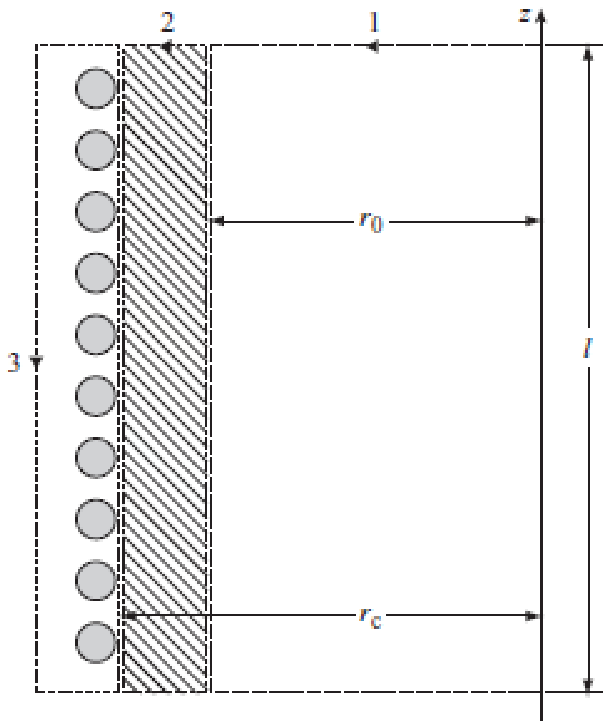
Ток в плазме

$$I_p = L \cdot \int_0^{r_0} J_\theta(r)\, dr$$

$$J_\theta = \mathrm{rot} H_z = j + \varepsilon_0 \nabla_t E_\theta = i\omega\varepsilon_0 \varepsilon_p \cdot E_\theta$$

$$J_\theta = k \cdot H_{zo} \cdot \frac{J_1(k \cdot r)}{J_0(k \cdot r_0)}$$

$$I_p = \frac{L \cdot H_{zo}}{J_0(k \cdot r_0)} \cdot \int_0^{kr_0} J_1(k \cdot r)\, d(k \cdot r)$$



$$I_p = L \cdot H_{zo} \cdot \left[\frac{1}{J_0(k \cdot r_0)} - 1 \right]$$

$$H_z(0) = \frac{H_{zo}}{J_0(k \cdot r_0)}$$

$$I_p = L \cdot \left[H_z(0) - H_{zo} \right]$$

$$\int H \, dl = \int j \, ds$$

$$L \cdot H_{zo} = N \cdot I_0$$

$$H_{zo} = \frac{N \cdot I_0}{L}$$

$$I_p = N \cdot I_0 \cdot \left[\frac{1}{J_0(k \cdot r_0)} - 1 \right]$$

Выделение энергии в плазме

$$\Pi_r = \left(\left|E \times H\right|\right)_r = -\left(\frac{1}{2}\right)\cdot E_\theta(r_0)\, H_{Zo}$$

$$P = 2\pi\, r_0 \cdot L \cdot \Pi_r$$

$$P = \frac{\pi N^2 (I_0)^2}{L \cdot \omega \cdot \varepsilon_0} \cdot \left[\frac{i \cdot k \cdot r_0 \cdot J_1(k \cdot r_0)}{\varepsilon_p \cdot J_0(k \cdot r_0)}\right]$$

$$P = \frac{1}{2}\left(R + i\omega L_i\right)\cdot\left(I_0\right)^2$$

$$R = \frac{2\pi N^2}{L\omega\varepsilon_0}\cdot\mathrm{Re}\left[\frac{i\cdot k\cdot r_0\cdot J_1\left(k\cdot r_0\right)}{\varepsilon_p\cdot J_0\left(k\cdot r_0\right)}\right]$$

$$L_i = \frac{2\pi N^2}{L\omega^2\cdot\varepsilon_0}\cdot\mathrm{Im}\left[\frac{i\cdot k\cdot r_0\cdot J_1\left(k\cdot r_0\right)}{\varepsilon_p\cdot J_0\left(k\cdot r_0\right)}\right]$$

$$I_0 = \frac{U_0}{R + i\omega L_i}$$

$$L_{io} = \frac{\mu_0 \pi \left(r_0\right)^2 \cdot N^2}{L}$$

$$x \rightarrow 0 \quad J_1 \rightarrow \frac{x}{2} \qquad J_0 \rightarrow 1$$

Бесстолкновительный нагрев электронов

$$\tau = \frac{2 \cdot \delta}{v_t}$$

$$\tau < \frac{1}{\omega} = \frac{T}{2\pi}$$

$$m\Delta v = eE_\theta \cdot \tau \qquad \Delta v = \frac{eE_\theta}{m} \cdot \frac{2\delta}{v_t}$$

$$\Delta\varepsilon = \frac{m}{2} \cdot \left(\frac{eE_\theta}{m} \cdot \frac{2\delta}{v_t} \right)^2$$

$$G = \frac{1}{4} \cdot n_e \cdot v_t$$

$$P = G \cdot \Delta\varepsilon = \frac{1}{2} \cdot \frac{n_e}{m \cdot v_t} \cdot \left(e \cdot E_\theta \cdot \delta\right)^2$$

$$\delta = \frac{c}{\omega_p} \cdot \sqrt{1 + \frac{{}^{2}\nu_m}{\omega}}$$

$$P_s = \frac{n_e}{m \cdot v_t}\left(e \cdot E_\theta \cdot \delta\right)^2 \cdot \Theta(\alpha)$$

$$\Theta(\alpha) = \frac{1}{\pi} \cdot \int_0^\infty \frac{\xi}{(\xi + \alpha)^2} \cdot e^{-\xi}\, d\xi$$

$$\alpha = \frac{1}{\pi} \cdot \left(\frac{2\omega\delta}{v_t}\right)^2$$