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# STIMULATED SCATTERING OF LIGHT BY PLASMONS AT LARGE GRADIENTS OF THE MEDIUM DENSITY

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Stimulated Raman scattering by electron Langmuir oscillations is considered at large gradients of the plasma density. It is shown that the scattered Stokes component is amplified in this case only in a definite interval of angles between the direction of the density gradient of the medium and the wave vector of the pump wave, and is proportional to the characteristic length of the plasma inhomogeneity.

In connection with the suggested [1] possibility of laser heating of a plasma to obtain a thermonuclear reaction, it is of great interest to investigate stimulated scattering of light by collective oscillations of ions and electrons (decays of the "photon" → "phonon" + "photon or of the "photon" → "plasmon" + "photon" type) [2]. Such decays can influence strongly the kinetics of plasma heating and, in particular, lead to an appreciable reflection of the laser energy.

The characteristic parameters of these processes depend strongly on the state of the scattering medium (distributions of the density or of the ion and electron temperatures, etc). The present paper deals with stimulated scattering of light by electron Langmuir oscillations at large values of the gradient of the equilibrium density $\rho_0$ of the plasma, such that $c|\nabla\rho_0|/\rho_0 \gg \nu$, where $\nu$ is the longintudinal-oscillation damping due to the Cerenkov absorption and collision of the particles. This relation can be satisfied, for example, in the case of a target in the form of a drop, where the characteristic radius $\Delta r$ of drop decrease is of the order of $10^{-1}$- $10^{-2}$ cm (see, e.g., [3]). As will be shown below, under these conditions the scattering process has a number of significant features in comparison with the analogous process in a homogeneous and weakly-inhomogeneous ($c|\nabla\rho_0|/\rho_0 \ll \nu$) plasma (the latter case is considered in [4]).

We consider a one-dimensional model of a collisionless plasma whose equilibrium electron density $\rho_0$ varies along the z axis (with $\rho_0 \leq \rho_c/4$, where $\rho_c$ is the critical electron density). The perturbation of the density $\rho$, neglecting the ion motion, can be expressed in the hydrodynamic approximation (see, e.g., [5]) in the form

$$\begin{cases} \dfrac{\partial^2\rho}{\partial t^2} + \omega_n^2\rho - \dfrac{e}{m_e}E_n\nabla\rho_0 = -\left(\dfrac{\partial\epsilon}{\partial\rho_0}\right)_T \rho_0\Delta\dfrac{E_0E_{-1}}{8\pi} \\ \operatorname{div} E_n = -4\pi\dfrac{\rho e}{m_e} \end{cases} \quad (1)$$

Here $\vec{E}$ and $\vec{E}_{-1}$ are respectively the amplitudes of the incident and scattered Stokes waves, $\vec{E}_n$ is the field intensity of the longitudinal wave, and $\omega_n^2 = 4\pi(e^2/m_e^2)\rho_0$ ($m_e$ is the electron mass). The equation for $E_{-1}$ is

$$\Delta E_{-1} - \frac{1}{c^2}\left[1 - \frac{\omega_n^2}{\omega_{-1}^2}\right]\frac{\partial^2 E_{-1}}{\partial t^2} = \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\left[\left(\frac{\partial\epsilon}{\partial\rho_0}\right)_S \rho E_0\right]. \quad (2)$$

We investigate stationary back-scattering[1]), which has the largest gain, and assume for simplicity that $\vec{E}_0$ and $\vec{E}_{-1}$ are linearly polarized in a plane perpendicular to the z axis and have the same polarization directions. Then we can seek a solution of (1) and (2) in the approximation of the given field $\vec{E}_0$, in the form

$$\begin{aligned} E_0 &= a_0 \exp[ik_0 z - i\omega_0 t - i\int k' dz] + c.c. \\ E_{-1} &= a_{-1}(z) \exp[-ik_{-1}z - i\omega_{-1}t - i\int k' dz] + c.c. \qquad (3) \\ \rho &= a_2(z) \exp[i(k_0 + k_{-1})z - i(\omega_0 - \omega_{-1})t] + c.c. \end{aligned}$$

where $k' = \omega_n^2/c\omega_0 \simeq \omega_n^2/c\omega_{-1}$. (By virtue of the condition $\rho_0 \leq \rho_c/4$, the dependence of the pre-exponential factor $\vec{a}_0$ on z can be neglected in the WKB approximation). Substituting (3) in (1) and (2), we obtain for the intensity $\vec{I}_{-1}(z) = |\vec{a}_{-1}|^2$ of the scattered wave

$$I_{-1}(z) = I_{-1}^{\circ} \exp\left\{\left(\frac{\partial\epsilon}{\partial\rho_0}\right)_T \left(\frac{\partial\epsilon}{\partial\rho_0}\right)_S \frac{k_0^4}{2\pi}\frac{\rho_0}{\omega_n^2}|a_0|^2 \times \int_z^q \rho_0 \frac{d\rho_0}{dz} \frac{dz}{\left(\frac{d\rho_0}{dz}\right)^2 + k_0^2\left[\rho_0 - \frac{(\omega_0 - \omega_{-1})^2}{\omega_n^2}\rho_0\right]^2}\right\}, \qquad (4)$$

where $I_{-1}^0$ is the intensity of the spontaneous source of frequency $\omega_{-1}$, located at the point $z = q$.

It follows directly from (4) that if $\nabla\rho_0$ is directed opposite to the wave vector of the incident light beam ($d\rho_0/dz < 0$), then the propagation of the scattered wave is accompanied by attenuation. In the opposite case, spatial amplification of the wave takes place[2]). The effective line width $\Delta\omega_b$ is determined by the denominator of the integrand in (4) and is of the order of $\Delta\omega_b \simeq c|d\rho_0/dz|/4\rho_0$. For the parameters of the drop-shaped target this yields $\Delta\omega_b \simeq 10^{-1}$-$10^{-2}$ cm$^{-1}$, which exceeds greatly both the usual laser-emission width and the stimulated scattering line width due to collision damping, $\nu$.

To estimate the integral (4), we approximate the density $\rho_0$ by the function $\rho_0 = \bar{\rho}_0 e^{z/\Delta r}$ and obtain the asymptotic intensity $\vec{I}_{-1}(z)$ as $z \to -\infty$. We assume here that the frequency detuning $\omega_0 - \omega_{-1} - \omega_n$ at the point q is equal to zero. From (4) we obtain after integrating and putting $(\partial\epsilon/\partial\rho_0) = -4\pi(e^2/m_e^2)$:

$$I_{-1}(-\infty) = I_{-1}^{\circ} \exp\left[\frac{\omega_n^2}{\rho_0 c^4 k_0}\frac{|a_0|^2}{4}\Delta r\right]. \qquad (5)$$

It follows from (5) that the maximum gain of the scattered wave is proportional to the characteristic length $\Delta r$ of plasma-density variation. For the parameters of the drop-like target at $|a_0| \sim 10^7$ cgs esu this yields $\vec{I}_{-1}(-\infty) = I_{-1}^0 e^3$. The intesnity of the spontaneous sources is thus amplified only 20 times over the entire interaction length, meaning in practice that there is no reflectio of the incident light beam.

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[1]) We note that under the considered conditions, owing to the presence of a term proportional to $\nabla\rho_0$ in (1), a stationary scattering regime can be realized also as $\nu \to 0$.

[2]) In the general case, taking into account possible noncollinearity of $\nabla\rho_0$ and $\vec{k}_0$, the condition for amplification of the scattered component can be written in the form $(\nabla\rho_0 \cdot \vec{k}_0) > 0$.


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