NONPOTENTIAL OSCILLATIONS OF AN ACTIVE MOLECULAR PLASMA IN AN ALTERNATING ELECTRIC FIELD

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Wave propagation in an active molecular plasma (AMP) is of interest in relation to the physics of high-power gas lasers and research on the processes in cosmic lasers. Recently, much attention has been given to electron-beam pumped lasers [1], where the plasma density may be high and a certain part is played in noise production by the interaction between the hf fields and the resonant levels in the molecular gas [2].

The interaction of free electrons with the active component of the plasma gives rise to various instabilities that may be undesirable in high-power gas lasers. Some of these instabilities have been considered previously [3-5].

It is of interest to examine the behavior of an AMP in an external field, since such fields can suppress certain instabilities.

Here we consider an AMP in a hf electric field. The active component is considered of two-level type. We assume that the plasma is cold and collision-free and use a system of equations

$$\begin{gathered}\frac{\partial \mathbf{v}}{\partial t}+(\mathbf{v},\nabla)\mathbf{v}=-\frac{e}{m}\left(\mathbf{E}+\frac{1}{c}[\mathbf{v},\mathbf{B}]\right),\\ \frac{\partial \mathbf{u}}{\partial t}+(\mathbf{u},\nabla)\mathbf{u}+\Omega^2\boldsymbol{\xi}=-\frac{e}{m}\left(\mathbf{E}+\frac{1}{c}[\mathbf{u},\mathbf{B}]\right),\\ \frac{\partial \boldsymbol{\xi}}{\partial t}+(\mathbf{u},\nabla)\boldsymbol{\xi}=\mathbf{u},\quad \frac{\partial n}{\partial t}+\operatorname{div}(n\mathbf{v})=0,\quad \frac{\partial N}{\partial t}+\operatorname{div}(g_mN\mathbf{u})=0,\\ \operatorname{rot}\mathbf{B}=-\frac{4\pi e}{c}n\mathbf{v}-\frac{4\pi e}{c}g_mN\mathbf{u}+\frac{1}{c}\frac{\partial \mathbf{E}}{\partial t},\quad \operatorname{rot}\mathbf{E}=-\frac{1}{c}\frac{\partial \mathbf{B}}{\partial t},\end{gathered}\tag{1}$$

where **v** and **u** are the velocities of the free and bound electrons, respectively; ξ, displacement of the bound electrons; n, electron density; $N = N_1 - N_2 < 0$, difference in level population; and g_m, oscillator strength. The other symbols are those commonly used.

We act in the spirit of the theory of nonpotential plasma oscillations in an external field and consider the case $\mathbf{k}|\mathbf{E}_0$, where **k** is the wave vector for the inherent oscillation of the plasma and $\mathbf{E}_0(t) = \mathbf{E}_0 \sin\omega_0 t$ is the external hf field. In this particular case the external field has only a minor effect on the corresponding potential oscillations [6].

We linearize (1) in the field of the external wave for perpendicularity between the field perturbation $\delta\mathbf{E}$ and the plane formed by **k** and $\mathbf{E}_0$, which leads to a dispersion equation previously examined in [3-5] and which describes the behavior of the AMP in the absence of an external field:

$$1-\frac{\omega_p^2+k^2c^2}{\omega^2}-\frac{\omega_m^2}{\omega^2-\Omega^2}=0,\tag{2}$$

where

$$\omega_p^2=\frac{4\pi ne^2}{m};\quad \omega_m^2=\frac{4\pi g_mNe^2}{m}.$$

Equation (2) does not contain new singularities, and therefore we consider the case where $\delta\mathbf{E}$ lies in the plane of **k** and $\mathbf{E}_0$.

Here we use the fact that the velocities of the free and bound electrons in the external field are small by comparison with the velocity of light, which gives us the dispersion equation

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$$1 - F_1(\omega)\{\beta^2(B_2^{(e)} + B_0^{(e)}) + \alpha^2(B_2^{(m)} + B_0^{(m)}) + \alpha\beta(D_2 + D_0)\} -$$
$$- F_{-1}(\omega)\{\beta^2(B_{-2}^{(e)} + B_0^{(e)}) + \alpha^2(B_{-2}^{(m)} + B_0^{(m)}) + \alpha\beta(D_{-2} + D_0)\} = 0, \tag{3}$$

where the symbols are as follows:

$$F_n(\omega) = \frac{k^2c^2}{(\omega + n\omega_0)^2 \varepsilon_{tr}^{(n)} - k^2c^2}; \quad \varepsilon_{tr}^{(n)} = 1 + \delta\varepsilon_e^{(n)} + \delta\varepsilon_m^{(n)};$$

$$\delta\varepsilon_e^{(n)} = -\frac{\omega_p^2}{(\omega + n\omega_0)^2}; \quad \delta\varepsilon_m^{(n)} = -\frac{\omega_m^2}{(\omega + n\omega_0)^2 - \Omega^2};$$

$$B_n^{(e)} = -\frac{\delta\varepsilon_e^{(n)}}{\varepsilon_{tr}^{(n)}}[1 + \delta\varepsilon_m^{(n)}]; \quad B_n^{(m)} = -g_m\frac{\delta\varepsilon_m^{(n)}}{\varepsilon_{tr}^{(n)}}[1 + \delta\varepsilon_e^{(n)}];$$

$$D_n = \frac{\delta\varepsilon_e^{(n)}\delta\varepsilon_m^{(n)}}{\varepsilon_{tr}^{(n)}}(1 + g_m); \quad \beta^2 = \left(\frac{eE_0}{mc}\right)^2 \frac{1}{\omega_0^2}; \quad \alpha^2 = \left(\frac{eE_0}{mc}\right)^2 \frac{\omega_0^2}{(\omega_0^2 - \Omega^2)^2}.$$

We envisage the low-frequency case, where ω is less than all the characteristic frequencies appearing in (3). We will assume that $\omega_0 \sim \omega_+$, where ω_+ are the solutions to (2) on the assumption that $\omega_p^2 + k^2c^2$, $|\omega_m^2| \ll \Omega^2$ (long wave case).

Then from (3) we get for $\omega_0 \sim \omega_+$ that

$$\omega^2 = (\Delta\omega)^2 + \frac{2}{3}\beta^2\frac{k^2c^2}{\Omega}\Delta\omega, \tag{4}$$

where

$$\Delta\omega = \omega_0 - \omega_+.$$

Instability occurs for $-\frac{2}{3}\beta^2\frac{k^2c^2}{\Omega} < \Delta\omega < 0$, and the instability increment is maximal in this range:

$$\gamma = \pm\frac{1}{3}\beta^2\frac{k^2c^2}{\Omega}. \tag{5}$$

For $\omega_0 \sim \omega_-$ we get similarly

$$\gamma = \pm\beta^2\frac{k^2c^2}{\omega_-}. \tag{6}$$

Analysis of (3) for the resonance cases $\omega - \omega_0 = -\omega$, where $\omega \sim \omega_\pm$, indicates that there is no instability in these frequency ranges.

We now consider the shortwave ($kc \gg \Omega$) solutions to (3); for $\omega_0 \sim \omega_+$ the low-frequency solution to (3) leads to an instability increment analogous to that given by (5) and (6).

For $\omega_0 \sim \omega_-$ and $|\omega_0 - \Omega| \ll |\omega_m|$ the low-frequency solution to (3) takes the form

$$\omega^2 = (\Delta\omega)^2 - \frac{1}{3}\beta\frac{\omega_m^2}{\omega_0 - \Omega}\Delta\omega. \tag{7}$$

From (7) we have an instability with a maximum increment

$$\gamma = \pm\frac{1}{6}\beta\frac{\omega_m^2}{\omega_0 - \Omega}. \tag{8}$$

Analysis of the resonant cases $\omega - \omega_0 = -\omega$, where $\omega \sim \omega_+$, indicates that there is no instability in these frequency ranges.

Therefore, an external hf field in resonance with the natural frequencies of the AMP leads to instabilities of the form of (5), (6), and (8) in certain cases. In the case of (8), an external field in resonance with the frequency of the transitions Ω in the inverted two-level system stimulates transfer of energy from the latter to free electrons.

In the hf limit, viz., frequencies much larger than the natural frequencies of the system, (3) becomes

$$1 + 2\beta^2\frac{k^2c^2}{\omega_0^2}\frac{\delta\varepsilon_e^{(0)} + g_m\delta\varepsilon_m^{(0)}}{\varepsilon_{tr}^{(0)}} = 0,$$

whose solutions that usually satisfy the conditions ω_p^2, $|\omega_m^2| \ll \Omega^2$ take the form

$$\omega_1^2 = \omega_p^2 + 2\beta^2 \frac{k^2c^2}{\omega_0^2}\omega_p^2, \quad \omega_2^2 = \Omega^2 + \omega_m^2. \tag{9}$$

It follows from (9) that the oscillations of the AMP in these cases are stable. This is of interest as an occurrence of suppression of instability in an AMP by an external field, where the increment was

$$\gamma = |\omega_m|/2,$$

as follows from (2) for $\omega_p^2 + k^2c^2 \sim \Omega$, where this increment occurs in the absence of an external field [5]. However, the conclusion is not general and applies only for the above conditions.

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LITERATURE CITED

1. N. G. Basov, É. M. Belenov, V. A. Danilychev, and A. F. Suchkov, "Electrical-ionization lasers with compressed carbon dioxide," Usp. Fiz. Nauk, 114, 213 (1974).
2. S. I. Krasheninnikov and V. V. Starykh, "A feature of the beam instability in a weakly ionized plasma of high density," Fiz. Plazmy, No. 3 (1977).
3. N. L. Tsintsadze and H. Wilhelmsson, "Instabilities in active molecular plasma," Phys. Scripta II, 11, No. 3 (1975).
4. O. E. H. Rydbeck and Å. Hjalmarsson, "Wave propagation properties of the molecular electronic plasma," Pennsylvania State Univ. Scientific Report No. 359 (1970).
5. V. P. Kovtun and N. L. Tsintsadze, "Electromagnetic-wave instability in an active molecular medium," Soobshch. Akad. Nauk Gruz. SSR, 86, No. 2 (1977).
6. V. P. Silin, Parametric Action of High-Power Radiation on Plasma [in Russian], Nauka, Moscow (1973).

RELAXATION OF MOLECULE VIBRATIONAL ENERGY IN HETEROGENEOUS MIXTURES

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In connection with the problem of producing low-temperature gasdynamic lasers (GDL) and proposals on the use of aerosol particles in the active media of GDL [1-3], investigations of the relaxation processes in vibrational nonequilibrium disperse systems are of great interest. The fundamental regularities of molecule vibrational relaxation in such systems were clarified in [3]. However, the singularities in the progress of the V—T and V—V' processes with the participation of adsorbed molecules were not considered here. The purpose of this paper is a more complete description of the kinetics of these processes and of heterogeneous vibrational relaxation of molecules as a whole [4].

Let a disperse system be a mixture of monomers of two species A_1, A_2 and complexes of identical magnitude (A_L) consisting of m_L molecules of the same species as A_2. The composition and other governing parameters of the heterogeneous mixture will be considered constant. We shall neglect the mutual interaction between the complexes. This is allowable if the mutual collision frequency of the complexes Z_{LL} in a two-phase system is much less than their collision frequencies with the monomers Z_{Ln} ($n = 1, 2$), i.e.,

$$\frac{Z_{LL}}{Z_{Ln}} \sim 4\sqrt{2}\, m_L^{-3/2} \frac{\varkappa_L}{\varkappa_n} \ll 1, \tag{1}$$

where $\varkappa_m$ is the relative molecule concentration of the m-component in the mixture. We shall consider monomer interaction with complexes under the assumption that the particle size and the mean spacing between them are small compared to the monomer mean free path in a gas.

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