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THE STRONG ION-ACOUSTIC TURBULENCE AND THE ELECTRON SPECTRUM IN AN ELECTRIC FIELDS

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The problem of the ion-acoustic turbulence-plasma interaction has long been known. We shall consider the case of strong ion-acoustic turbulence.

$$\frac{m_e}{m_i} \ll \frac{W^s}{nT_e} \ll 1 \qquad (1)$$

In this case the wave-particle collision integral changes significantly, that is physically related to the effect of the turbulent resonance broadening, which is determinated by the effective frequency of turbulent collisions ν_{eff} [1]. The problem we consider is not self-consistent in the sense that the wave - particle interactions do not effect the spectrum and the wave energy density W^s / nT_e, the waves being generated by external sources.

The equation for the distribution function of electrons in the electric field with the known ion-acoustic turbulence takes the form:

$$\frac{\partial f}{\partial t} + \frac{eE}{m}\left(\cos\theta \frac{\partial f}{\partial v} - \frac{\sin\theta}{v}\frac{\partial f}{\partial \theta}\right) = \frac{1}{v^2 \sin\theta}\frac{\partial}{\partial\theta}\sin\theta\, \tilde{A}\frac{\partial f}{\partial\theta} + I(f(v,\theta,t)) \qquad (2)$$

$$\tilde{A}(v,\theta) = \pi\left(\frac{e}{m}\right)^2 \int k_z^2 |\varphi_k|^2 \delta(\omega - \vec{k}\vec{v})\, v\, d\vec{k} \qquad (3)$$

The first term in the right-hand side in (2) describes the process of the elastic scattering of electrons. The term $I(f(v,\theta,t))$ describes the weak inelastic interactions of electrons with a strong ion-acoustic turbulence. This process depends on the ion-acoustic wave spectrum I_k. When ion-acoustic waves are generated in a narrow region of wave numbers near $k = k_*$ and when $k < k_*$ I_k is determinated by the nonlinear scattering of waves on ions then [2]

$$I_k = \frac{W_0}{k} \ln\frac{k}{k_0} \begin{cases} 0 & k > k_* \\ 1 & k < k_* \end{cases} \qquad (4)$$

If $v > v_* = v_{Te}(W^s/nT_e)^{1/4}$ the collision integral $I(f(v,\theta,t))$ can be obtained via the expansion into a series of exact expressions with the parameter

$$\nu_{eff} / k v_{Te} \ll 1 \qquad [3].$$

If E = 0, the stationary solutions of (2) are isotropic and have a power character [3]

$$\Phi = \Phi_0 v^{-\gamma} \qquad (5)$$

γ being a function of the turbulent spectrum width

Table

$\ln\frac{k_*}{k_0}$	3	4	5	6	7	8	9	10	11
γ	1,7	2,1	2,5	2,9	3,1	3,3	3,6	3,9	4,1

If E≠0, in the strict sense the exact stationary solutions of (2) over the whole velocity space in an infinite plasma do not exist; when v is high there is a stream of runaway electrons. How-

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ever, we can assume that in the weak field E and if the velocities V are not very high (the appropriate criterion is given below) the electron distribution function can be written in the form

$$f(v,\theta,t) = \Phi(v,t) + f_1(v,\theta,t) \qquad (6)$$

where an anisotropic addition $f_1(\ ,\theta,t) \ll \Phi(v,t)$ is caused by the electric field.

If the ion-acoustic turbulence is isotropic the equation for the isotropic part of the distribution function $\Phi(v,t)$ is

$$\frac{\partial\Phi}{\partial t} = M\frac{1}{v^2}\frac{\partial}{\partial v}v^5\frac{\partial\Phi}{\partial v} + I(\Phi) \qquad (7)$$

$$M = -\frac{1}{4}\left(\frac{eE}{m}\right)^2\int\sin\theta\cos\theta\,d\theta\int^{\theta}\frac{\sin\theta'}{\tilde{A}(v,\theta')}d\theta' \qquad (8)$$

The anisotropic addition $f_1(v,\theta,t)$ is

$$f_1(v,\theta,t) = \int\left[\frac{e}{2m}\frac{E}{\tilde{A}}v^3\sin\theta\frac{\partial\Phi}{\partial v} + \frac{v^3}{\tilde{A}}I(\Phi)\frac{\cos\theta}{\sin\theta}\right]d\theta \qquad (9)$$

The solution of (7) can be found by the perturbation method. If $V \ll V_{**}$ or the electric field E is weak, the solution takes the form

$$\Phi(v) = Pv^{-\gamma}(1 + Lv^8)$$

$$L = \frac{M\gamma(4-\gamma)}{(\gamma-8)\left[a_4(\gamma-7)(\gamma-6)(\gamma-5) - a_3(\gamma-7)(\gamma-6) + a_2(\gamma-7) - a_1\right]} \qquad (10)$$

The main part of (10) coincides with (5) and describes the stationary function of the electron distribution in the absence of an electric field. γ is taken from Table. The addition Lv^8 corresponds to the influence of the electric field. a_k are the coefficients with $\Phi^{(k)}$ in $I(\Phi)$[3]. The condition $Lv^8 \ll 1$ is fulfilled if the electric field is rather weak

$$\frac{E^2}{W^5} \ll \frac{1}{3}\left(\frac{V_{Te}}{2V}\right)^8\left(\frac{K_* V_{Te}}{\omega_{pe}}\right)^2\left(\frac{W^5}{nT_e}\right)^2\begin{cases}\ln^{-5}\frac{K_*}{K_0} & K_* \gg K_0\\ 1/4 & K_* \gtrsim K_0\end{cases} \qquad (11)$$

Writing (11) in another form, we obtain, that the solution (10) takes place if V is 'small' $V_* \ll V \ll V_{**}$

$$V_{**} = V_*\left(\frac{W^5}{E^2}\right)^{1/8}\left(\frac{K_* V_{Te}}{\omega_{pe}}\right)^{1/4}\frac{1}{2\cdot 3^{1/8}}\begin{cases}\ln^{-5/8}\frac{K_*}{K_0} & K_* \gg K_0\\ 4^{-1/8} & K_* \gtrsim K_0\end{cases} \qquad (12)$$

In the opposite case (the conditions (11) and (12) are not fulfilled) the solution takes the form

$$\Phi(v) = \frac{P_1}{v^4}\left[1 - \frac{1}{24Mv^8}\left(210a_4 - 30a_3 + 5a_2 - a_1\right)\right] \qquad (13)$$

The main term in (13) coincides with the 'stationary' spectrum of [4].

The condition of validity of solutions (10) and (13) $f_1(v,\theta) \ll \Phi(v)$ is broken down at high velocities, when the first term under the integral in (9) has a predominant role. Comparison with $\Phi(v)$ results in

$$V \ll V_{***} = V_{**}\left(\frac{W^5}{E^2}\right)^{1/8}\left(\frac{K_0 V_{Te}}{\omega_{pe}}\right)^{1/4}(3\pi^2)^{1/8}\begin{cases}\ln^{1/8}\frac{K_*}{K_0} & K_* \gg K_0\\ 2^{-1/4} & K_* \gtrsim K_0\end{cases} \qquad (14)$$

These results can be used for the estimation of the current density in the turbulized plasma and are important for the anomalous resistance problem.

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