EFFECT OF AN ELECTRON BEAM ON THE CURRENT CONVECTIVE INSTABILITY—ETC(U)

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**Title:** Effect of an Electron Beam on the Current Convective Instability

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**Abstract:**
We consider the possible effects of an electron beam on the current convective instability in a weakly ionized plasma, with application to the diffuse aurora-like situation. A linear instability analysis including these effects is presented.
EFFECT OF AN ELECTRON BEAM ON THE CURRENT CONVECTIVE INSTABILITY

The current convective instability (CCI) has recently been cited as playing a role in the generation of scintillation causing large scale size plasma irregularities in the diffuse aurora [Ossakow and Chaturvedi, 1979; Chaturvedi and Ossakow, 1979; Keskinen et al., 1980; Vickrey et al., 1980; Chaturvedi and Ossakow, 1981; Keskinen and Ossakow, 1982; Rino and Vickrey, 1982]. This instability is caused by a field-aligned current in the presence of a transverse plasma density gradient in a collisional plasma [Kadomtsev and Nedospasov, 1960]. In the diffuse auroral situation, it is generally recognized that a significant part of the observed field-aligned current is carried by the cold ionospheric electron component, drifting relative to ions. It is this electron drift that causes a variety of current driven plasma instabilities in the system, such as the current convective instability. However, a precipitating flux of soft energetic electrons are also present alongside the cold drifting electrons in the medium. In our previous work (Ossakow and Chaturvedi, 1979) only the cold electron drift component was considered. In this note, we have examined the effects of an electron beam (in addition to the cold drifting electron component) along the magnetic field on the current convective instability. It is found that, though the presence of an electron beam modifies the current convective instability growth rate, in the diffuse auroral application, such effects are practically negligible.

We follow the approach outlined in Ossakow and Chaturvedi [1979] in the linear stability analysis. The coordinate system has the magnetic field aligned with the z-axis, as does the cold electron drift $v_o$. A density gradient along the y-axis and an electron beam of density $n_b$ and velocity $v_b$ are also present. In the following the beam and the cold plasma quantities will be denoted by subscripts $b$ and $c$ respectively. Further, the temperature effects for the cold plasma component are neglected. Our basic equations are

$$\frac{3n_o}{\partial t} + \nabla \cdot (n_o v_o) = 0$$  \hspace{1cm} (1)

$$v_1 = \frac{c}{B_0} E_\perp \times \hat{z} + \frac{v_{1n}}{n_1} \frac{c}{B_0} E_\perp + \frac{e}{m_1} \hat{v}_1 \times E$$  \hspace{1cm} (2)
Most of the symbols have their standard meaning, \( \sigma \) denotes the particle species (\( i \equiv \) ions, \( e \equiv \) electrons), \( n \) is the density, \( \nu_{\text{on}} \) denotes the collision frequency of the species \( \sigma \) with neutrals, \( T_{\text{eb}} \) is the beam electron temperature in energy units and subscripts \( \perp \) and \( z \) represent perpendicular and parallel to the magnetic field respectively, etc. In equations (2)-(4), inertial effects were neglected, Pedersen mobility effects for electrons were also neglected in comparison to the ion Pedersen drift. In the stability analysis, quantities are split into equilibrium and perturbed components, \( f = f_0 + \tilde{f} \) with the perturbed quantities varying as \( \exp(ikr-i\omega t) \). An assumption of quasi-neutrality is made, i.e.,

\[
\tilde{n}_i = \tilde{n}_{eb} + \tilde{n}_{ec}
\]

Following Ossakow and Chaturvedi [1979], one writes for the perturbed electron and ion densities,

\[
\tilde{n}_{ec} = n_{oc} \hat{\phi} \frac{(k^2 \frac{e}{z m v} + i \frac{c}{B_o} k_{xz} \nu_{\perp} \ln n_{oc})}{(-i\omega + ik_{z} v_{o})} \]

\[
\tilde{n}_{eb} = n_{b} \hat{\phi} \frac{(k^2 \frac{e}{z m v} + i \frac{c}{B_o} k_{xz} \nu_{\perp} \ln n_{b})}{(-i\omega + ik_{z} v_{b} + \frac{T_{eb}}{m v ebn})} \]

\[
\tilde{v}_{eb} = \frac{c}{B_o} E_{\perp} x z + \frac{cT_{eb}}{eB_o} \nu_{\perp} n_{b} x z - \frac{T_{eb}}{m v ebn} \frac{\partial n_{b}}{\partial z} z - \frac{e}{m v ebn} E_{z} + \nu_{b} \tilde{v}_{z}
\]

\[
\tilde{v}_{ec} = \frac{c}{B_o} E_{\perp} x z - \frac{e}{m v ecn} E_{z} + \nu_{o} \tilde{v}_{z}
\]
and

\[ \frac{[i \frac{k}{B} - k_1 v^* v_1 \ln n_{oc} - \frac{e k^2}{m_i v_{in}^2} - \frac{v_{in} c}{m_i v_{in} + \frac{B}{v_{in}^2}}]}{[-i\omega + i k v^\omega_{zi}]} \]

\[ \tilde{n}_1 = n_{oc} \Phi \]

(8)

In the above, we have made the electrostatic assumption for the perturbed electric fields, \( \overline{\tilde{E}} = -\tilde{\phi} \). From the set (6)-(8), one readily obtains

\[ \omega[B \omega_{z v} - \frac{v_{in} v_{en}}{\Omega e_1} - k z v_0 \omega[-1 - \frac{v_{en} k}{k_1^2} \frac{k}{k_1 v^* v_1 \ln n_{oc}} + \frac{m_e v_{en}}{v_{en} k^2} + \frac{v_{en} v_{in}}{\Omega e_1}]] \]

\[ \approx -\frac{n_b}{n_{oc}} \frac{v_{en} k^2}{(\omega - k z v_0)} \frac{v_{en} k}{k_1 v^* v_1 \ln n_{oc}} + \frac{m_e v_{en}}{v_{en} k^2} + \frac{v_{en} v_{in}}{\Omega e_1} \]

(9)

where \( \beta = [1 + (v_{en} m_e/v_{en} m_i)] \). The right hand side of equation (9) contains the effects of an electron beam on the mode driven unstable by the current convective instability, which is described by the left hand side of eq. (9) (i.e., setting \( n_b/n_{oc} = 0 \) one regains the dispersion relation obtained by Ossakow and Chaturvedi, 1979).

As an illustrative example and a special case of interest, we assume the electron beam to be cold \( (T_{eb} = 0) \) and uniform \( (v^* v_1 \ln n_b = 0) \), One then obtains, from eq. (9),

\[ \omega = k z v_0 \frac{[v_{en} k \frac{k}{k_1 v^* v_1 \ln n_{oc}} + m_e v_{en} k^2 + v_{en} v_{in}]}{[k^2 (1 - \frac{n_b}{n_{oc}} v_{en} v_b v_{en}) + \frac{v_{en} v_{in}}{\Omega e_1}]} \]

(10)

so that \( (\omega = \omega_R + i\gamma) \)
In deriving equation (10), we further assumed that $\frac{m_e v_{ecn}}{m_i v_{in}} << 1$, $\omega << k_z v_o$, $k_z v_b$. The latter assumption is reasonable, since we are interested in the effects of the beam on the mode which grows due to an absolute instability (without the above assumptions, (9) has two roots, one given by (10) and the other yielding $\omega = k_z v_b$). In the absence of the beam ($n_b = 0$), this relation leads to the one obtained in Ossakow and Chaturvedi [1979]. For a beam such that $n_b/n_{oc} = 10^{-2}$ and $v_b = 3.5 \times 10^8$ cm s$^{-1}$ (corresponding to electron fluxes of energy ~100 eV), one finds that the beam induced contribution in the denominator of eq. (10) is down by ~0(10$^{-5}$) compared to the leading term (where we have used $v_o \sim 1$ km s$^{-1}$). However, one notes that the beam contribution would decrease (enhance) the growth rate somewhat if the electron beam velocity and the electron drift were parallel (anti-parallel).

Allowing for a non-uniform beam one gets

\[
\omega = k_z v_o \frac{\left[ -i \frac{v_{ecn} k_z v_{x,z} v_{ln n_{oc}}}{\Omega_e} k_l^2 + m_e v_{ecn} k_z^2 + \frac{v_{ecn} v_{in}}{\Omega_i} \right]}{k_z \sigma + \frac{v_{in} v_{ecn}}{\Omega_i} + 1 \left( \frac{n_b}{n_{oc}} \frac{v_o v_{ecn}}{v_b v_{bn}} \frac{v_{bn}}{\Omega_e} \frac{k_z v_{x,z} v_{ln n_{oc}}}{k_l^2 n_b} \right)}
\]

where $\sigma \equiv 1 + (n_b v_o v_{ecn}/n_{oc} v_b v_{bn})$.

One gets for the growth rate of the current convective instability ($\omega = \omega_R + i \gamma$),

\[
\gamma = k_z v_o \frac{\left[ -i \frac{v_{ecn} k_z v_{x,z} v_{ln n_{oc}}}{\Omega_e} k_l^2 + \frac{v_{in} v_{ecn}}{\Omega_i} - \delta^2 \left( m_e k_z^2 v_{ecn} + v_{ecn} v_{in} \right) \right]}{\left[ \left( k_z^2 + \frac{v_{in} v_{ecn}}{\Omega_i} \right)^2 + \delta^2 \right]^2}
\]

(11a)
where \( \delta = n_b v_b \left( n_{\text{oc}} v_{\text{oc}} n_b \right) \) denotes the effects of beam non-uniformity. We now see that the beam effects are more complex than before on the growth rate of the CCI, and their contributions to reduce or increase the growth rate would depend on, in addition to the relative sense between beam velocity and the drift direction, the direction of the beam density gradient. However, for diffuse aurora situations, a beam with parameters, \( n_b/n_{\text{oc}} \sim 10^{-2} \), and \( v_b \sim 3 \times 10^8 \text{ cm s}^{-1} \), these contributions are down by a factor of \( \sim 0(10^{-5}) \) for equal beam density and cold background density gradients (where we have used \( v_o \sim 1 \text{ km s}^{-1} \)). Therefore, beam effects appear to be much too small to have any practical implications on the growth rate of the CCI.

In conclusion, we find that the soft precipitating fluxes of electrons (\( \sim 100 \text{ eV} \)) may have little effect on the large scale size (\( \sim 1 \text{ km} \)) slow processes like the current convective instability induced structures for the diffuse auroral situation. However, in calculating growth rates or stability thresholds from say (10a) with even \( n_b = 0 \) one must notice that it is \( v_o \) (i.e., the cold current velocity) that enters the growth rate. Since magnetometers infer total parallel (to \( \mathbf{B}_o \)) current from their measurements (T. Potemra, private communication, 1981), one must be able to separate (or assess) the warm parallel current contribution from (to) the total current. Letting the total parallel current be proportional to \( v_o \) (\( J_z = n v_o z \)) can lead to an underestimate of \( v_o \) when \( v_o \) and \( v_b \) are anti-parallel.
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