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A note on the drift waves in the presence of electrons added by meteors by ablation phenomena or by thermionic emissions

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Abstract. The role of added electrons on the drift dissipative instability in a nonuniform collisional plasma is analysed. We observe the presence of a drift wave that depends entirely on the added electrons through the collision frequency coupling and there is an additional damping. The present study is applied to the density irregularities caused by meteor ionization in the ionosphere.

Keywords. Drift dissipative instability; a new mode of drift wave; anomalous collision frequency; ionosphere irregularity.

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1. Introduction

The orbit theory says that the density gradients in a nonuniform magnetized plasma create drift of charged particles across the magnetic field lines [1]. These charge-dependent drifts establish currents in the medium and excite waves and oscillations. In the E region of the ionosphere, these waves manifest as type-II irregularities [2].

In the ionosphere plasma, meteors create additional electrons in significant numbers by the ablation phenomena, the thermionic emissions and the secondary emissions [3–5]. In a magnetized plasma, an ionized matter can flow in the form of currents and bring in additional charged particles. Therefore, in this short note, we analyse the effects of these added electrons on the drift dissipative instability.

In §2, we derive the dispersion relation and analyse the wave characteristics. In §3, these analyses are discussed in relation to the generation of density irregularities in the E region of the ionosphere and their possible observable effects. Here we consider the drift velocity of the background electrons due to the density gradient and neglect the drift velocities of the charged dust grains, the ions and added electrons. The background electrons and the added electrons by any of the mentioned processes are hot.

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2. Dispersion relation

We consider a plasma medium having a uniform, homogeneous magnetic field. The magnetic field lines are in the direction of z-axis of the right-hand coordinate system. Singly ionized, collisional, nonuniform background plasma (subscript b) has a density gradient along the positive x-axis. All the collisions of the constituent charged particles are with the neutrals in the background plasma. The collisions among the charged species are neglected. The positive ions have the same mass. The multiply charged dusts which create Z_{D} electrons ($Z_{\mathrm{D}} > 1$) have the same mass. The added electrons and ions are denoted by the subscript d. The temperature of the background electrons and the added electrons are T_{eb} and T_{ed} respectively. In equations, we use the common subscript j where $j = \mathrm{e}$ denotes the electrons and $j = \mathrm{i}$ denotes the positive ions. The equilibrium values are denoted by an additional subscript '0'. The linearized first-order perturbations are written without 1 either as the superscript or as the subscript.

The medium is such that the electron gyrofrequency Ω_{e} is greater than the electron neutral collision frequency υ_{e} ($\Omega_{\mathrm{e}} > \upsilon_{\mathrm{e}}$) and the ion gyrofrequency Ω_{i} and the gyrofrequency of the charged dusts Ω_{D} are respectively less than the ion collision frequency υ_{i} and the dust collision frequency υ_{D} with the neutrals ($\Omega_{\mathrm{i}} < \upsilon_{\mathrm{i}}$; $\Omega_{\mathrm{D}} < \upsilon_{\mathrm{D}}$). In this system, the ions and the dusts are unmagnetized and they do not acquire the drift velocities. The background electrons will have a dominant drift velocity $\vec{V}_0$ along the negative y-axis and interact strongly with the wave perturbations in the form $\mathrm{e}^{\iota(\omega t - ky)}$ ($\iota = \sqrt{-1}$). Here ω is the frequency in radians and k is the wave number.

The continuity equation

$$\frac{\partial n_j}{\partial t} + \vec{\nabla} \cdot n_j \vec{V}_j = 0, \tag{1}$$

the equation of motion

$$n_j m_j \frac{\mathrm{d}\vec{V}_j}{\mathrm{d}t} - \vec{\nabla} P_j + n_j q_j \left(\vec{E} + \frac{\vec{V}_j \times \vec{B}}{c} \right) - n_j m_j \upsilon_j \vec{V}_j \tag{2}$$

and Gauss divergence equation

$$\vec{\nabla} \cdot \vec{E} = 4\pi e (n_{\mathrm{ib}} + n_{\mathrm{id}} - n_{\mathrm{eb}} - n_{\mathrm{ed}}) \tag{3}$$

are linearized and Fourier transformed to obtain the dispersion relation. In eqs (1)–(3), n_j is the number density, m_j is the mass, $P_j = n_j T_j$ is the pressure, T_j is the temperature in energy units, $\vec{V}_j$ is the velocity, c is the velocity of light in vacuum. The charge q_j is $-e$ for electrons, e for the ions (for the ions $Z_{\mathrm{D}} = 1$) and $Z_{\mathrm{D}} e$ for the dusts. E is the perturbed electric field and B is the perturbed magnetic field. The equilibrium magnetic field is B_0. To avoid the confusion that may arise between the Boltzmann constant k_{B} and the wave number k, we use T in the energy units.

We see from eq. (2) that the electrons, in equilibrium, acquire a drift velocity $\vec{V}_0$

$$V_0 = -c \, \frac{T_{\mathrm{eb}}}{e B_0 L} \tag{4}$$

along the negative y-axis. Here $L = n_{\mathrm{b0}}(\mathrm{d}x/\mathrm{d}n_{\mathrm{b0}})$ is the scale length of the equilibrium density gradient. From eq. (3) we assume that the quasineutrality condition

$$4\pi e(n_{\mathrm{ib}} + n_{\mathrm{id}}) = 4\pi e(n_{\mathrm{eb}} + n_{\mathrm{ed}})$$

is valid for all orders of perturbations.

From eqs (1) and (2), we get the density perturbation for the background ions to be

$$\frac{n_{\mathrm{ib}}}{n_{\mathrm{ib0}}} = \frac{keE}{m_{\mathrm{ib}}\omega(\iota\omega + v_{\mathrm{ib}})} \approx -\frac{keE}{m_{\mathrm{ib}}\omega^2} \tag{5}$$

and for ions added to the medium to be

$$\frac{n_{\mathrm{id}}}{n_{\mathrm{id0}}} = \frac{keE}{m_{\mathrm{id}}\omega(\iota\omega + v_{\mathrm{id}})} \approx -\frac{keE}{m_{\mathrm{id}}\omega^2}. \tag{6}$$

The perturbed density for the background electrons is

$$\frac{n_{\mathrm{eb}}}{n_{\mathrm{eb0}}} = -\frac{keE}{m_{\mathrm{e}}} \frac{v_{\mathrm{eb}}}{(\omega - kV_0)(\Omega_{\mathrm{e}}^2 + v_{\mathrm{eb}}^2) - \iota k^2 v_{\mathrm{eb}} C_{\mathrm{sb}}^2} \tag{7}$$

and for the electrons added to the medium is

$$\frac{n_{\mathrm{ed}}}{n_{\mathrm{ed0}}} = -\frac{keE}{m_{\mathrm{e}}} \frac{v_{\mathrm{ed}}}{\omega(\Omega_{\mathrm{e}}^2 + v_{\mathrm{ed}}^2) - \iota k^2 v_{\mathrm{ed}} C_{\mathrm{sd}}^2}. \tag{8}$$

Here E is parallel to k and C_{s} is the thermal velocity of electrons shown by the additional subscript. When the dust with the charge number Z_{D} is considered, to get the perturbed density of the dust, we replace n_{id} by n_{D}; n_{id0} by n_{D0}; m_{id} by m_{D}; v_{id} by v_{D}; e by $Z_{\mathrm{D}}e$. In eq. (3) replace n_{id} by $Z_{\mathrm{D}}n_{\mathrm{D}}$.

We select the frequency region where $\omega_{\mathrm{pb0}}^2/\omega\Omega_{\mathrm{e}}$ and $\omega_{\mathrm{pd0}}^2/\omega\Omega_{\mathrm{e}} \gg 1$ and $m_{\mathrm{e}}\Omega_{\mathrm{e}}^2/m_{\mathrm{d}}\omega v_{\mathrm{eb}} \ll 1$. Here ω_{pb0} and ω_{pd0} are the electron plasma frequencies shown by the subscript b and d. To get the dispersion relation we set

$$4\pi(n_{\mathrm{eb}} + n_{\mathrm{ed}}) = D(\omega, k) = 0 \tag{9}$$

in the form

$$D(\omega, k) = R(\omega, k) + \iota I(\omega, k), \tag{10}$$

where $R(\omega, k)$ is the real part and $I(\omega, k)$ is the imaginary part. Using eqs (7), (8) and (9), simplifying and comparing the resulting terms with eq. (10), we get

$$R(\omega, k) = n_{\mathrm{eb0}} v_{\mathrm{eb}} \omega(\Omega_{\mathrm{e}}^2 + v_{\mathrm{ed}}^2) + n_{\mathrm{ed0}} v_{\mathrm{ed}}(\omega - kV_0)(\Omega_{\mathrm{e}}^2 + v_{\mathrm{eb}}^2)$$

and

$$I(\omega, k) = -k^2 v_{\mathrm{eb}} v_{\mathrm{ed}} n_{\mathrm{eb0}}[C_{\mathrm{sd}}^2 + \beta_{\mathrm{e}} C_{\mathrm{sb}}^2],$$

where

$$\beta_{\mathrm{e}} = \frac{n_{\mathrm{ed0}}}{n_{\mathrm{eb0}}}.$$

We study the propagation properties and the damping rates when v_{eb} and v_{ed} are less than Ω_{e}. We assume $\omega = \omega_{\mathrm{r}} + \iota\Gamma$ to be such that $\omega_{\mathrm{r}} \gg \Gamma$ and expand in the Taylor series $D(\omega, k)$ around $\omega = \omega_{\mathrm{r}}$. The first two terms in this expansion are

$$D(\omega, k) = D(\omega_{\mathrm{r}}, k) + \iota\Gamma \left.\frac{\partial D(\omega, k)}{\partial \omega}\right|_{\omega_{\mathrm{r}}=\omega}. \tag{11}$$

When we equate eq. (10) with eq. (11) and set $D(\omega_r = \omega, k) = R(\omega, k) = 0$, then we get the wave propagation characteristics by the relation

$$\omega = \frac{\upsilon_{ed}\beta_e k V_0}{\upsilon_{eb} + \beta_e \upsilon_{ed}}. \tag{12}$$

The damping rate Γ is now

$$\Gamma = \frac{k^2 \upsilon_{eb}\upsilon_{ed}(C_{sd}^2 + \beta_e C_{sb}^2)}{\Omega_e^2(\upsilon_{eb} + \beta_e \upsilon_{ed})}. \tag{13}$$

3. Discussion

We see from eq. (12) that the additional electrons either created or added to the medium generate drift waves which are absent when such electrons are absent, i.e., $\upsilon_{ed} = 0$. Since these waves depend on the collision frequencies of the generated electrons which in turn depend on their T values, it will be interesting to discuss this aspect in relation to the Earth's ionosphere.

In the lower part of the atmosphere, meteors are good sources of electrons. Maximum deposition of meteor dusts is seen in 70–90 km height [6,7]. The electrons formed by meteors in the E region of the ionosphere are responsible for radiometeors and visual meteors [3,8]. The line density of electrons formed by the meteors can be in the range of 10^{11} and 10^{13} [9–11]. The ablation phenomena and the thermionic emission phenomena are responsible for the formation of additional electrons. The rate of ablation ionization depends on the velocity of the meteor dusts and their masses. Meteors in the velocity range 30–70 km s^{-1} form sufficient additional electrons in the region of the electro-jet, especially during meteor showers. Even at lower velocities, due to the atmospheric friction, meteors acquire temperatures high enough to emit a significant number of electrons [4,5]. Visual observations show the persistence of ionizations for a longer period [8].

As seen here, the additional electrons can generate drift waves (eq. (12)) and they undergo collisional damping (eq. (13)) leading to an additional decay of the drift velocity $\vec{V}_0$. This damping will then change the intensity of low-frequency ionospheric irregularities and reduce the anomalous collision frequencies. The anomalous collision frequency is larger than υ_e and is used to explain the height difference between the observed conductivity maxima and calculated conductivity maxima [12]. A reduction in the anomalous collision frequency by 10% will increase the time needed for the cross-field diffusion of the ionization by 10%. This may be important to explain the persistence of meteor ionization [8].

4. Conclusions

We see that added electrons by external sources excite drift waves. The nature of these waves depends on the collision frequencies of the added electrons. In the absence of the added electrons, these waves are absent. Due to their damping, these waves are likely to reduce the drift velocity V_0. We expect that the strength of the density irregularities is lower. The anomalous collision frequencies are reduced. This will increase the diffusion time scale of meteor ionization.

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References

[1] F F Chen, *Introduction to plasma physics* (Plenum Press, New York and London, 1979) pp. 59–66

[2] M C Kelley, *The Earth's ionosphere* (Academic Press, San Diego, California, USA, 1989) pp. 154–175

[3] P Colestock, S Close and J Zinn, Theoretical and observational studies of meteor ionization with the atmosphere in characterizing the ionosphere, published in *Meeting Proceedings RTO*. M.P. IST-056 Neuilly-sun-Seire, France, 12-1 to 12-12 (http://www.rto.nato.int/abstract.asp) (2006)

[4] A M Furman, Translated from Astronomicheskii Zhurnal, Provided by the NASA astrophysics data system, **37**, 746 (1960)

[5] D A Mendis, Wai-Ho Wonga, M Rosenberg and G Sorasio, *J. Atmos. Solar-Terrestrial Phys.* **67**, 1178 (2005)

[6] D M Hunten, *Geophys. Res. Lett.* **8**, 369 (1981)

[7] D M Hunten, R P Turco and O B Toon, *J. Atmos. Sci.* **37**, 1342 (1980)

[8] J D Drummond, B W Grime, C S Gardner, A Z Liu, X Chug and T L Kane, *J. Geophys. Res.* **106**, 21517 (2001)

[9] Girija Rajaram, Harish Chandra, *Proc. Indian Acad. Sci., (Earth Planet Sci.)* **100**, 255 (1991)

[10] S M Hunt, M Oppenheim, S Close, B G Brown, F McKeen and M Minardi, *Icarus Rev.* **168**, 34 (2004)

[11] A D Taylor and W G Elford, *Earth Planet Space* **50**, 569 (1998)

[12] C Ronchi, R N Sudan and P L Similon, *J. Geophys. Res.* **95**, 189 (1990)