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Kinetic Alfvén wave in three-component dusty plasmas

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Kinetic Alfvén waves in three-component dusty plasmas are investigated. A dispersion relation for a low-frequency Alfvén wave in a dusty plasma is obtained. A damped (or growth) mode of a kinetic Alfvén wave having velocity $v_A = B_0/\sqrt{m_d n_{d0}\mu_0}$ dominated by the dust particle collective dynamics is shown to exist in a dusty plasma. The damping effect is provided by the dust charge fluctuation dynamics.

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A large fraction of the matter in the universe is in the plasma state. On the other hand, a considerable amount of solid matter in the universe is found in dust particulate form, which is often embedded in plasmas as an impurity. This type of plasma naturally (or artificially) doped with dust grains may be called dusty plasma. Recently, the physical processes in dusty plasmas [1,2] have been studied intensively because of their importance for a number of applications in space plasmas [1–3], the earth's environment, and in laboratory and several technologies [4–7]. The interesting features of a dust particle are its variable mass, size, and shape and mainly its fluctuating charge. Generally dust particles are highly charged ($Q_{d0} \sim 10^3 e - 10^4 e$) with variable sizes (10 nm–100 μm) and masses. Though the assumption that dust particles are spherical point masses of equal size (i.e., equal radius) will not introduce much error, the charge acquired by them must be taken into account. Generally, dust particles in a plasma are charged by plasma current, photoemission, secondary emission, and field emission, etc. [8]. The amount of charge acquired by a dust particle is determined by its capacity and the electron and ion thermal current balance to the grain [9]. When an equilibrium charge has been attained by the dust grains, the plasma with charged dust grains may be regarded as simply a multispecies plasma for processes with a time scale shorter than the characteristic grain charging time. Many of the interesting investigations pertaining to the dusty plasma fall in this category.

The study of collective effects in dusty plasmas is of significant interest. Previously plasmas with constant (on characteristic time scales of the processes under consideration) charges on the dust particles had been studied extensively. However, recently [10–13] the effect of variable charges on dust particles has been investigated and the influence is found to be strong, especially for low frequency waves.

Here, in this paper, we study the kinetic Alfvén wave in a dusty plasma, taking into account the charge fluctuation and finite Larmor radius effect of the dust grains. To illustrate these effects we use the Vlasov equations. The parallel electric field which is generated by the finite Larmor radius effect of the dust grains is expected to let the Alfvén wave couple with the dust acoustic wave (DAW). A new type of damped or growth mode is expected from dust charge fluctuation considerations.

All the plasma particles (electron, ion, and dust) will be described by the Vlasov equation or collisionless Boltzmann equation,

$$\frac{\partial f_j}{\partial t} + \vec{\nabla}\cdot(\vec{v} f_j) + \vec{\nabla}_v \cdot \left[\frac{q_j}{m_j} (\vec{E} + \vec{v}\times\vec{B}) f_j \right] = \vec{0} , \qquad (1)$$

where $j = e$, i and d and gradients in configuration and velocity space are denoted by ∇ and ∇_v, and all other symbols have their usual meaning. The density of dust particles in the plasma is supposed to be high enough so that a fluid description can be used for the dust particles in the phase space. An electromagnetic force with electric field $\vec{E}$ and magnetic field $\vec{B}$ is acting on the plasma particles.

Moreover, the equilibrium magnetic field $\vec{B}_0$ is along the z direction and the electric counterpart $\vec{E}_0 = 0$. Though the finite Larmor radius effect generated parallel electric field is expected to couple Alfvén wave with DAW, for the limiting case ($k_\perp \rho_d \to 0$), the frequency of the fast (compressional) mode becomes of the order of the dust cyclotron frequency; hence, we can consider that the fast mode is decoupled. Then the compressional component of the magnetic field perturbation, $\vec{B}_{z1}$, can be assumed to be much smaller than the transverse components. This allows us to use a scalar potential ϕ to represent the transverse components of the electric field, $\vec{E}_\perp$ [14],

$$\vec{E}_\perp = -\vec{\nabla}_\perp \phi , \qquad (2)$$

because then B_z becomes zero. To represent the z component of the electric field, we must use a different potential, ψ,

$$E_z\hat{z} = -\hat{z}\frac{\partial\psi}{\partial z} , \tag{3}$$

so that transverse components of $\vec{\nabla}\times\vec{E}$ are not zero.

The appropriate field equations are Poisson's equation,

$$\nabla_\perp^2\phi + \frac{\partial^2\psi}{\partial z^2} = \frac{e}{\epsilon_0}\left[n_i - n_e + \frac{Q_d}{e}n_d\right] , \tag{4}$$

and the z component of Ampere's law,

$$\frac{\partial}{\partial z}\nabla_\perp^2(\phi-\psi) = \mu_0\frac{\partial}{\partial t}[J_{ze}+J_{zi}+J_{zd}] , \tag{5}$$

along with Maxwell's equation,

$$\vec{\nabla}\times\vec{E} = -\frac{\partial\vec{B}}{\partial t} , \tag{6}$$

where n_j and J_{zj} represent number and current densities for the jth species of the plasma particles and $Q_d = z_d e$ (z_d is the dust charge number) is the mean charge of the dust particles. Note than in Eq. (4), Q_d is positive for positively charged dust, and vice versa.

For the present study we shall assume that all the dust particles are spherical with equal mass m_d and radius a_d. The surface potential U_d of the dust particles relative to the plasma potential V is related to the dust charge by $Q_d = 4\pi\epsilon_0 a_d U_d$ [15]. We look at a situation where the dust particles are mainly charged by plasma currents. This is probably most often the case in, for example, planetary rings where other charging mechanisms (e.g., secondary emission, photoelectric effect, spittering) will be of minor importance. The dust charging equation is given by

$$\frac{dQ_d}{dt} = \sum I_j , \tag{7}$$

where $I_j (j = i,e)$ is the plasma current flowing to the dust. These currents are found from the integral

$$I_j = \int \sigma_j(v,U) q_j v F_j(\vec{r},\vec{v},t)dv \tag{8}$$

over the velocity space. Here q_j and f_j are the charge and the distribution functions while $\sigma_j = \pi a_d^2(1-2q_jU_d/m_jv^2)$ is the collision cross section [15], m_j stands for the mass of the plasma particles, and $dv = 2\pi v_\perp dv_\perp dv_\parallel$. Expressing different physical variables as a sum of equilibrium and perturbed part (denoted by 0 and 1, respectively) and linearizing Eqs. (1)–(7), we have

$$\frac{\partial f_{j1}}{\partial t} + \vec{\nabla}\cdot(\vec{v}f_{j1}) + \vec{\nabla}_v\cdot\left[\frac{q_j}{m_j}(\vec{v}\times\vec{B}_0)f_{j1}\right] = -\vec{\nabla}_v\cdot\left[\frac{q_j}{m_j}(\vec{E}_1+\vec{v}\times\vec{B}_1)f_{j0}\right] , \tag{9}$$

$$\vec{E}_{\perp 1} = -\vec{\nabla}_\perp\phi_1 , \tag{10}$$

$$E_{z1} = -\frac{\partial\psi}{\partial z} , \tag{11}$$

$$\nabla_\perp^2\phi_1 + \frac{\partial^2\psi_1}{\partial z^2} = \frac{e}{\epsilon_0}\left[n_{i1} - n_{e1} + \frac{Q_{d0}}{e}n_{d1} + \frac{Q_{d1}}{e}n_{d0}\right] , \tag{12}$$

$$\frac{\partial}{\partial z}\nabla_\perp^2(\phi_1-\psi_1) = \mu_0\frac{\partial}{\partial t}[J_{ze1}+J_{zi1}+J_{zd1}] , \tag{13}$$

$$\vec{\nabla}\times\vec{E}_1 = -\frac{\partial\vec{B}_1}{\partial t} , \tag{14}$$

$$\frac{\partial Q_{d1}}{\partial t} + \vec{v}\cdot\vec{\nabla}Q_{d1} + \left[\frac{Q_{d0}}{m_d}(\vec{v}\times\vec{B}_0)\right]\cdot\vec{\nabla}_v Q_{d1} = \sum I_{j1} . \tag{15}$$

For electrons, the linearized distribution function f_{1e} becomes, assuming $k_\perp\rho_e \approx 0$ and $\omega \ll \omega_{ce}$ [$k_\perp,\rho_e = \sqrt{(T_e/m_e)}/\omega_{ce}$ and $\omega_{ce} = eB_0/m_e$ being the perpendicular component of wave vector, electron Larmor radius, and cyclotron frequency, respectively],

$$f_{e1}(v) = -\frac{e}{m_e}\frac{k_\parallel\psi_1}{(k_\parallel v_\parallel - \omega)}\frac{\partial f_{e0}}{\partial v_\parallel} . \tag{16}$$

Similarly for ions, the linearized distribution function f_{i1} becomes, assuming $k_\perp\rho_i \approx 0$ and $\omega \ll \omega_{ci}$ ($\rho_i = \sqrt{(T_e/m_i)}/\omega_{ci}$ and $\omega_{ci} = eB_0/m_i$ being the ion Larmor radius at the electron temperature and cyclotron frequency, respectively),

$$f_{i1} = \frac{e}{m_i}\frac{k_\parallel\psi_1}{(k_\parallel v_\parallel - \omega)}\frac{\partial f_{i0}}{\partial v_\parallel} . \tag{17}$$

For dust particles, by retaining the finite Larmor radius effect,

$$f_{d1} = -\frac{Q_{d0}}{m_d}\sum\sum\frac{e^{i(n-m)\theta}}{(\omega - k_\parallel v_\parallel - n\omega_{cd})} \times J_n\left[\frac{k_\perp v_\perp}{\omega_{cd}}\right]J_m\left[\frac{k_\perp v_\perp}{\omega_{cd}}\right][A+B] , \tag{18}$$

where

$$A = k_\perp\phi_1\left[-\frac{k_\parallel v_\parallel}{\omega}\right]\frac{n\omega_{cd}}{k_\perp v_\perp}\frac{\partial f_{d0}}{\partial v_\perp} + k_\perp\phi_1\frac{k_\parallel}{k_\perp}\frac{n\omega_{cd}}{\omega}\frac{\partial f_{d0}}{\partial v_\parallel} ,$$

$$B = k_\parallel\psi_1\left[\frac{v_\parallel}{v_\perp}\frac{n\omega_{ci}}{\omega}\frac{\partial f_{d0}}{\partial v_\perp} + \left[1 - \frac{n\omega_{cd}}{\omega}\right]\frac{\partial f_{d0}}{\partial v_\parallel}\right] ,$$

and θ is the phase angle of the Larmor motion and $\omega_{cd} = Q_{d0}B_0/m_d$ is the dust particle cyclotron frequency. $J_n(k_\perp v_\perp/\omega_{cd})$ and $J_m(k_\perp v_\perp/\omega_{cd})$ are the nth and mth order Bessel function of the first kind. In deriving Eq. (18) use is made of the identity

$$\exp(iz\sin\theta) = \sum J_n(z)\exp(in\theta) . \tag{19}$$

For low frequency waves we can neglect the velocity dependence in Q_d [15], which reduces the linearized dust charging equation (15) to

$$\frac{\partial Q_{d1}}{\partial t}+\vec{v}\cdot\vec{\nabla}Q_{d1}=\sum I_{j1} . \quad (20)$$

The Fourier amplitudes of the charge density and current density perturbation are obtained from

$$q_j n_{j1}=q_j n_{j0}\int f_{j1}dV , \quad (21)$$

$$J_{j1}=q_j n_{j0}\int v f_{j1}dV . \quad (22)$$

The typical phase velocity of the Alfvén wave is smaller than the ion and electron thermal velocities. The distribution functions will therefore be very close to a Maxwellian distribution and the error we make by the calculating the perturbed quantities from a Maxwellian distribution will be small. Thus the unperturbed distribution function may be assumed to be an isotropic Maxwellian.

$$f_{j0}(v)=\left[\frac{1}{2\pi v_{Tj}}\right]^{3/2}\exp\left[-\frac{v_\perp^2+v_\parallel^2}{2v_{Tj}^2}\right] . \quad (23)$$

The drifting velocity between the plasma and the dust is supposed to be small, if any. If β is larger than m_e/m_d, the ion and electron thermal speed will become larger than the Alfvén speed and the resultant charge and current density as well as plasma current perturbations may be reduced to [using Eqs. (21), (22), and (8)]

$$\frac{Q_{d0}n_{d1}}{\epsilon_0}=-\frac{\omega_{pd}^2}{v_{Td}^2}[1-I_0(\lambda_d)e^{-\lambda_d}]\phi_1 + \frac{\omega_{pd}^2 k_\parallel^2}{\omega^2}I_0(\lambda_d)e^{-\lambda_d}(1-i\delta_d)\psi_1 , \quad (24)$$

$$\frac{en_{i1}}{\epsilon_0}=-\frac{\omega_{pi}^2}{v_{Ti}^2}(1+i\delta_i)\psi_1 , \quad (25)$$

$$\frac{en_{e1}}{\epsilon_0}=\frac{\omega_{pe}^2}{v_{Te}^2}(1+i\delta_e)\psi_1 , \quad (26)$$

$$\mu_0 J_{zd1}=\frac{\omega_{pd}^2}{c^2}\frac{k_\parallel}{\omega}I_0(\lambda_d)e^{-\lambda_d}(1-i\delta_d)\psi_1 , \quad (27)$$

$$\mu_0 J_{zi1}=-\frac{\omega_{pi}^2}{c^2 v_{Ti}^2}\omega_k(1+i\delta_i)\psi_1 , \quad (28)$$

$$\mu_0 J_{ze1}=-\frac{\omega_{pe}^2}{c^2 v_{Te}^2}\frac{\omega}{k_\parallel}(1+i\delta_e)\psi_1 , \quad (29)$$

$$I_{i1}=-\frac{\omega_{pi}^2\pi a_d^2\epsilon_0\omega}{v_{Ti}^2 k_\parallel}\left[1+i\delta_i\left[1-\frac{2eU_{d0}k_\parallel^2}{m_i\omega^2}\right]\right]\psi_1 , \quad (30)$$

$$I_{e1}=-\frac{\omega_{pe}^2\pi a_d^2\epsilon_0\omega}{v_{Te}^2 k_\parallel}\left[1+i\delta_e\left[1+\frac{2eU_{d0}k_\parallel^2}{m_e\omega^2}\right]\right]\psi_1 , \quad (31)$$

where velocity of light $c=1/\sqrt{\epsilon_0\mu_0}$, dust Larmor radius at the electron temperature $\rho_d=(T_e/m_d)^{1/2}/\omega_{cd}$, dust cyclotron frequency $\omega_{cd}=Q_{d0}B_0/m_d$, plasma frequency of the jth species $\omega_{pj}^2=q_{j0}^2 n_{j0}/\epsilon_0 m_j$, and $I_0(\lambda_d)$ is the modified Bessel function of the first kind with $\lambda_d=k_\perp^2\rho_d^2$. In deriving the above equations we use the plasma dispersion function $z(\xi)$ defined as

$$z(\xi)=\frac{1}{\sqrt{\pi}}\int\frac{e^{-x^2}}{(x-\xi)}dx . \quad (32)$$

Fractional Landau rates for different species are defined as follows:

$$\delta_d=2(\pi)^{1/2}\beta_d^{-3/2}\exp(-\beta_d^{-1}) , \quad (33)$$

$$\delta_i=(\pi)^{1/2}\beta_d^{-1/2}\left[\frac{T_d}{T_i}\right]^{1/2}\left[\frac{m_i}{m_d}\right]^{1/2} , \quad (34)$$

$$\delta_e=(\pi)^{1/2}\beta_d^{-1/2}\left[\frac{T_d}{T_e}\right]^{1/2}\left[\frac{m_e}{m_d}\right]^{1/2} , \quad (35)$$

where

$$\beta_d=2\frac{v_{Td}^2}{v_A^2} , \quad (36)$$

and $v_{Tj}^2=(T_j/m_j)$ stands for the thermal speed of different $(j=e,i,d)$ species. It may be noted that in deriving different Landau damping rates we have approximated $\omega/k_\parallel\approx v_A$. Using Eqs. (30) and (31) in Eq. (21) we have for the perturbed dust charge

$$Q_{d1}=\frac{\pi\epsilon_0\omega\psi_1}{k_\parallel(\omega-k_\parallel v_\parallel)}\left[\frac{a_d^2}{\lambda_{Di0}^2}\delta_i X+\frac{a_d^2}{\lambda_{De0}^2}\delta_e Y - i\left[\frac{a_d^2}{\lambda_{Di0}^2}+\frac{a_d^2}{\lambda_{De0}^2}\right]\right] , \quad (37)$$

where $X=1-2eU_{d0}k_\parallel^2/m_i\omega^2$ and $Y=1+2eU_{d0}k_\parallel^2/m_e\omega^2$, and $\lambda_{Dj0}^2=\epsilon_0 T_j/n_{j0}q_j^2$ are the Debye screening lengths for different species. It is interesting to note the role of fractional Landau damping rates as well as the ratio of dust radius and Debye screening length of ion and electron on dust charge perturbation.

The dispersion relation can be obtained by substituting Eqs. (24)–(31) and (37) into (12) and (13). If we ignore the fractional Landau damping, we get

$$\left[\pm I_0(\lambda_d)e^{-\lambda_d}-\frac{\omega^2}{k_\parallel^2 c_{ds}^2}\right]\left[1-\frac{\omega^2}{v_A^2\lambda_d k_\parallel^2}[1-I_0(\lambda_d)e^{-\lambda_d}]\right] = \frac{\omega^2}{k_\parallel^2 v_{Td}^2}[1-I_0(\lambda_d)e^{-\lambda_d}]\pm\frac{i\pi n_{d0}\omega^3}{(\omega-k_\parallel v_\parallel)k_\parallel^3\omega_{pd}^2} \times\left[\frac{a_d^2}{\lambda_{Di0}^2}+\frac{a_d^2}{\lambda_{De0}^2}\right] , \quad (38)$$

where $c_{ds}=\sqrt{(T_e/m_d)}$ is the dust sound speed with electron temperature and $v_A=c\omega_{cd}/\omega_{pd}$ is the dust Alfvén speed. This dispersion relation shows the coupling of the Alfvén wave and the DAW, along with an additional imaginary term which may lead to damping (or growth) of the normal mode. In a low β plasma, since $c_{ds}^2\ll v_A^2$, the two waves are decoupled and the dispersion relation of the Alfvén wave becomes

$$\frac{\omega^2}{k_\parallel v_A^2}=\frac{\lambda_d}{1-I_0 e^{-\lambda_d}}+\frac{T_e}{T_d}\lambda_d \pm i\frac{\pi n_{d0}\omega\lambda_{ds}^2\left[\frac{a_d^2}{\lambda_{Di0}^2}+\frac{a_d^2}{\lambda_{De0}^2}\right]}{\omega_{pd}^2 k_\parallel[1-I_0(\lambda_d)e^{-\lambda}](\omega-k_\parallel v_\parallel)} . \tag{39}$$

Here we call the wave represented by the dispersion relation the "kinetic Alfvén wave in a dusty plasma" because of its kinetic property. If $\lambda_d \ll 1$, the dispersion relation of the kinetic Alfvén wave reduces to

$$\omega^2=k_\parallel^2 v_A^2\left[1+k_\perp^2\rho_d^2\left[\frac{3}{4}+\frac{T_e}{T_d}\right]\pm\frac{i\pi n_{d0}\omega c_{ds}^2\left[\frac{a_d^2}{\lambda_{Di0}^2}+\frac{a_d^2}{\lambda_{Dde0}^2}\right](1+\frac{3}{4}k_\perp^2\rho_d^2)}{\omega_{pd}^2 k_\parallel(\omega-k_\parallel v_\parallel)}\right] . \tag{40}$$

Here it can be noted that unlike the magnetohydrodynamics (MHD) Alfvén wave, the kinetic Alfvén wave can propagate across the magnetic field and will undergo Landau damping for each species because of its coupling to the electrostatic mode. It is also important to note that the wave has an electric field component in the direction of the ambient magnetic field.

Expressing ω as the sum of real and imaginary parts $\omega=\omega_r+i\gamma$ with $\omega_r \gg \gamma$ we have from Eq. (40)

$$\omega_r=k_\parallel v_A\left[1+k_\perp^2\rho_d^2\left[\frac{3}{4}+\frac{T_e}{2T_d}\right]\right] , \tag{41}$$

and

$$\gamma\approx\pm\omega_r\frac{\pi n_{d0}\omega c_{ds}^2}{\omega_{pd}^2 k_\parallel(\omega-k_\parallel v_\parallel)}\left[\frac{a_d^2}{\lambda_{Di0}^2}+\frac{a_d^2}{\lambda_{De0}^2}\right] . \tag{42}$$

We may qualitatively assess the importance of this new type of Alfvén wave by determining the damping factor (or growth) for typical laboratory as well as space plasmas. We also note that for $T_d=T_i=0$ but $T_e\neq 0$ the above dispersion relation may be obtained from the MHD equations if one uses the modified Ohm's law,

$$\vec{E}+\vec{v}\times\vec{B}=\frac{m_j}{q_j}\frac{d\vec{v}_j}{dt}+\frac{\vec{\nabla}p_j}{q_j n_j}-\frac{\vec{J}\times\vec{B}}{q_j n_j} , \tag{43}$$

where p_j is the pressure of the jth species plasma particle.

From Eq. (42) it is clear that in a dusty plasma the kinetic Alfvén wave will either grow or damp for wave phase velocities satisfying the condition $\omega/k_\parallel \approx v_A \leq v_\parallel$ via wave particle resonant interaction. For a positively charged dust particle the wave will grow, whereas for negatively charged dust it will be damped. As the electron and ion thermal speed are much larger than the Alfvén speed (v_A), they interact with the Alfvén wave primarily through their linear wave particle resonance, i.e., linear Landau damping. But the highly charged massive dust particles move much more slowly than the Alfvén speed and they interact with the Alfven wave through linear Landau damping and cross-field-correlated electrostatic and magnetic perturbation induced charge fluctuation (Eq. 37). However, linear Landau damping in the case of dust species is almost negligible.

Equation (42) gives the growth rate (or damping factor) of kinetic Alfvén waves in dusty plasmas. Dependence of the growth rate on a_d^2/λ_{Dj0}^2 has a profound implication regarding the importance of dusty plasmas in the laboratory.

For typical dusty plasma parameters $B_0=5$ T, $T_e\approx T_i=15$ keV, $n_{d0}\approx 10^{10}$ m^{-3}, $Q_{d0}\approx 100e$, $m_d\approx 10^{-15}$ kg, and $10^{-3}\leq a_d/\lambda_{Dd0}\leq 10^2$, which may be close to laboratory conditions, we get $v_A\approx 200$ s^{-1} and $\gamma\approx 10^5$ s^{-1} (for $v_A \gg v_\parallel$).

Similarly for parameters $B_0=4.74\times 10^{-7}$ T, $T_e\approx T_i\approx 17.25\times 10^{-4}$ eV, $n_{d0}\approx 10^2$ m^{-3}, $Q_{d0}\approx 7e$, $m_d\approx 10^{-13}$ kg, and $a_d/\lambda_{Dd0}\approx 10^{-8}$, which may be close to dusty plasma environments in interstellar clouds, we have $v_A\approx 0.2$ km s and $\gamma=10^{-10}$ s.

The damping effects of the kinetic Alfvén waves in dusty plasmas introduced by charged fluctuation of the negatively charged dust particles allow the localized energy to propagate away from the Alfvén wave itself and thus deposit th surface wave energy into the plasma. The resonant absorption of Alfvén waves in an inhomogeneous medium may find applications for the heating of fusion plasma in laboratorylike α-particle-driven kinetic Alfvén waves and the heating of solar-corona-like sheared Alfvén waves coupled with surface waves, reminding us of the presence of dust particles in every environment of the universe. Our present study may also help us to understand the filamentary structures existing within the diffuse aurora if the plasma is taken to be inhomogeneous. The aurora is a part of the overall interactions of the solar wind, the earth's magnetosphere, and the earth's atomspheric particles, viz., oxygen and nitrogen particles. When these spectacular displays of luminous radiation (auroras) in the arctic skies are examined carefully, some clear microscopic patterns, such as the discrete arcs having certain shapes with spacings of a few tens of kilometers, are observed. The earth's magnetosphere is abundant with dust particles originating from collisional fragmentation of debris from comets, industrial contaminations, etc., creating an environment for dusty plasmas. Typical parameters are $n_d\approx 10$ m^{-3}, $m_d\approx 10^{-15}$ kg, $n_i\approx 10^9$ m^{-3}, and $a_d\approx 1$ μm. If the formation of kinetic Alfvén waves is possible (collision effects like conductivity may prevent the formation of kinetic Alfvén waves) in the earth's magnetosphere, then the acceleration of the electrons or protons by the kinetic Alfvén waves along the line of force will convincingly explain the observed discrete arcs or filamentary structure of the aurora.

Many regions in dark interstellar clouds are turbulent and because kinetic Alfvén waves in dusty plasmas are low frequency waves and decay very slowly for negatively charged dust, the turbulence is probably composed of kinetic Alfvén waves. The effect of charged dust particles on the damping of kinetic Alfvén waves may be important to drive mass loss from evolved stars.

At this juncture we can compare the kinetic Alfvén mode in dusty plasmas with energetic α particles driven by Alfvén waves in normal electron ion plasmas extensively investigated by several workers. α particles produced in a deuterium-tritium fusion reaction can be confined by the strong magnetic field of a tokamak and transfer their energy to the bulk plasma and may trigger a self-heating or plasma ignition process under appropriate conditions. However, the energetic α particles can also introduce new types of plasma instabilities. In this type of kinetic Alfvén wave, electron and ion species interact with Alfvén waves through linear electron Landau damping and ion Compton scattering, respectively. The α particles have thermal speed comparable with the Alfvén speed and they interact with the Alfvén waves through both linear and nonlinear Landau resonance (α Compton scattering). This is simplified since we can distinguish between kinetic Alfvén waves in dusty plasmas and α particles driven by kinetic Alfvén waves by their mode of interactions with the different species of plasma particles.

In α particles driven by kinetic Alfvén waves, linear α Landau resonance provides the instability, whereas in dusty plasmas, dust charge fluctuations will provide the instability when the dust particles are positively charged, since negatively charged dust charge fluctuations lead to wave damping. Due to the preferential capture of electrons, dust particles are generally negatively charged and hence kinetic Alfvén waves in dusty plasmas are normally damped. On the other hand, α particles driven by kinetic Alfvén waves generally grow (unstable). Here we note that α particles driven by kinetic Alfvén waves are the phenomenon related to laboratory plasmas (tokamak) with much more complicated situations like diamagnetic drift, particle and magnetic field (having radial and polodial components) gradient, etc., whereas the kinetic Alfvén waves in dusty plasmas proposed by us may be relevant to space as well as laboratory plasmas.

In this paper we have investigated theoretically the occurrence of kinetic Alfvén waves in dusty plasmas dominated by the dust particle collective dynamics. From the dispersion relation obtained it is clear that a damped (or growth) mode of kinetic Alfvén wave may propagate through low-β dusty plasmas with velocity $v_A = B_0/\sqrt{m_d n_{d0} \mu_0}$.

Although Alfvén waves have been the subject of study in astrophysical and space plasmas for a long time, little experimental attention was paid to it because of difficulties in exciting it in the laboratory. Presently plasma dimensions and β's have reached sufficiently high values to make it possible to study Alfvén waves in the laboratory. Auxiliary heating by means of Alfvén waves has been tried in some laboratories. Because of the linearized nature of wave conversion, Alfvén waves have the potential of providing plasma profile control. Alfvén waves have recently been proposed for space resolved measurement of magnetic fields in tokamaks and may become important as a diagnostic tool in the future. This wave is a potential candidate for radio-frequency heating of a fusion plasma because low cost power sources in the appropriate frequency range are readily available and its absorption rate is high.

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