Chapter 1

Introduction

This thesis is concerned mainly with instability studies on electromagnetic waves in space dusty plasmas described by a generalised distribution function namely, the Kappa or bi-Lorenztian distribution function.

In the last few years the field of Plasma Physics in general and plasma waves, instabilities and radiations, in particular, have grown tremendously. Two reasons can be put forward for this continuous growth. The first has been the active program of research pursued towards the achievement of controlled thermonuclear fusion. This has led to an enhanced understanding of plasmas under normal laboratory and near-reactor conditions. The second has been a large number of experiments launched with satellites to provide *in situ* data on the properties and nature of plasmas in the Earth's and other planetary magnetospheres and the solar wind. Both these areas of research have yielded abundant evidence showing new types and characteristics of waves and instabilities and their interactions with plasmas.

In this introduction section, we first give a brief discussion about dusty plasmas and its occurrence in space plasmas. We then report some properties/characteristics of dusty plasmas such as dust charging and dust dynamics and review the basic theory of waves, instabilities in dusty plasmas. Finally we touch upon the recent wave instability studies in dusty plasmas.

1.1 Dusty plasmas

A *dusty plasma is a plasma containing particles* large enough compared to the plasma ions, yet small enough that the electromagnetic forces on the dust have a significant effect on their motion, compared to the gravitational attraction of a planet. In other words, a dusty plasma *is a three component plasma system consisting of electrons,* ions and charged dust grains. When the dust becomes molecular ion in size, it is called a muti-component plasma not a dusty plasma.

In 1930s different types of photometric observations clearly showed that the dark 'holes' in the milky way, observed by William Herschal almost 150 years earlier, were infact regions of heavy obscuration by cosmic dust. Continuing observations since then have established that dust is an almost ubiquitous component of the cosmic environment (Mendis and Rosenberg, 1994). In recent years renewed interest in dusty plasmas has arisen because of the observations, *interalia*, of dust in the vicinity of comet Halley by the Vega and Giotto probes; in the vicinity of comet Giacobini-Zinner by the ICE satellite; and in the vicinities of Jupiter, Saturn and Uranus by Voyager Spacecraft (Mace and Hellberg, 1993). The inference of the existence of very small grains in the interstellar medium as well as their *insitu* detection in the environment of comet P/Halley reinforces the reasonable expectations that the transition from gas to large dust particles in the cosmic environment is a continuous one through macromolecules, clusters and very small grains (Mendis and

Rosenberg, 1994). The most typical applications in the solar system include planetary rings, different asteroid zones, cometary comae and tails and closer home to certain regions of the Earth's lower magnetosphere. Dusty plasmas are also the subject of current interest due to their occurrence in various laboratory devices and industrial processes: for example, plasmas in plasma processing, plasma etching, plasma furnace systems, edge plasmas in some magnetohydrodynamics power generators, rocket exhaust, fusion devices, etc (Jana et al., 1993).

1.2 Characteristics and Properties of Dusty Plasmas

For a dusty plasma there are three characteristic length scales. They are

(1).dust grain size, a

(2).the plasma Debye length, λ_D

(3).average intergrain distance, d, roughly related to the dust density $\approx n_D^{-1/3}$.

In any case the size of the dust 'a' is the smallest of the three lengths (Verheest, 1996).

Based upon these length scales, i.e.,depending on the concentration of the dust grains, there are two regions in a dusty plasma. *In the first region,* $a << \lambda_D << d$, *the* grains may be considered to be a collection of individual, screened grains, in which each grain is shielded by a Debye sphere of electrons. In the second regime, $a << d << \lambda_D$, charged dust may be considered to be massive charged point particles, similar to multiply charged negative or positive ions. This regime may characterize various cosmic dusty plasma environments such as interstellar clouds, the Earth's ionosphere (at $\sim$ 80 km) and Planetary rings (Rosenberg, 1993).

1.2.1 Charge of dust particles in a plasma

Isolated grains ($a << \lambda_D << d$)

Central to all studies that are discussed in a dusty plasma is the charge Q acquired by the dust grains. There are several processes which cause the charge on a dust grain to be non-zero, such as electron and ion collection, photo-emission, secondary electron emission due to energetic electron impact, secondary electron emission due energetic ion impact, electric field emission, thermionic emission, triboelectric emission and radiative emission of electrons and α particles. Of these, the most important processes in the cosmic environment are in general, electron and ion collection, photo-emission, secondary electron emission due to energetic electron impact and electric field emission (Mendis and Rosenberg, 1994). For a grain in a plasma with temperature T_e for electrons (mass m_e) and T_i for ions (mass m_i), the fact that the flux of electrons having thermal velocity C_e ($= \frac{k_BT_e}{m_e}^{1/2}$) is larger than that of the heavier ions which have smaller thermal velocity C_i ($\frac{k_BT_i}{m_i}^{1/2}$) will make the grain charge Q and its surface potential ϕ_s usually negative.

The current carried by the particle species α (electron or ion) for $\phi_s = 0$ is given by

$$J_{o\alpha} = n_\alpha q_\alpha \frac{k_B T_\alpha}{m_\alpha}^{1/2} \pi a^2 f_\alpha(w) \tag{1.1}$$

where n_α is the number density of the species, w is the relative velocity between the plasma and the grain and f_α is a rather complicated function of w. In general the ion-current intercepted by the grains increases with w. Thus the charge on a moving grain tends to be more positive than on a grain at rest with respect to the plasma. However, this is not necessarily always the case. The electron current is not affected by the slow relative drift between the dust and the plasmas because $w << C_e$, where C_e is the thermal speed of the electrons. Because the ions are much heavier than the electrons ($m_i >> m_e$) the ion current is, for ϕ_s=0, much smaller than the electron current density, and the grain becomes negatively charged. This reduces the electron current and increases the ion current.

The absorption of the solar UV radiation releases photo-electrons and hence constitutes a positive charging current. Its magnitude depends on the material properties of the grain, ie, its photo-emission efficiency, on the grain surface potential and grain size.

There are several other charging currents, in most solar system applications these are usually neglected (Goertz, 1989).

For a given dust grain, at a given time, the charge Q changes because of these currents according to the equation

$$\frac{dQ}{dt} = \frac{d}{dt}C(\phi_s - \bar{\phi}) = \sum_\alpha J_\alpha \tag{1.2}$$

where $\sum_\alpha J_\alpha = I$ is the total current to the grain, C is the capacitance, ϕ_s is the grain surface potential, and $\bar{\phi}$ is the average potential of the ambient plasma with a dust grain distribution (Mendis and Rosenberg, 1994). In a plasma the capacitance C of a spherical grain is given by

$$C = 4\pi\epsilon_o a e^{-a/\lambda_D} \tag{1.3}$$

The exponential factor in (3) reflects the Debye screening of the grain's charge by the charge density in the plasma surrounding the charge (Goertz, 1989).

In a steady state, the grains may reach an equilibrium surface potential, ϕ_s, with respect to the plasma. The equilibrium surface potential is given by the requirement that $\sum J_\alpha = 0$. Then $\frac{dQ}{dt} = 0$ and $Q = C(\phi_s - \bar{\phi})$. The values of both C and $\bar{\phi}$ depend on how closely the grains are packed together (Mendis and Rosenberg, 1994).

For an initially cold plasma all the grains are then negative. As the temperature increases, the equilibrium charge of all the grains should become positive. However, the charge will not change instantaneously but will evolve according to $\frac{dQ}{dt} = \sum_\alpha J_\alpha$. Large grains will respond rapidly and acquire a positive charge quickly. Small grains collect smaller current and thus take a longer to reach the new equilibrium value. From observations it is clear that the fluctuations in the surface potential (and hence charge) are larger for bigger particles. The bigger grains' charge fluctuates greatly but has a positive time average. The small particles retain an average negative value. The possibility that different size particles have opposite charges may be very important for the coagulation of dust grains into bigger particles. The charge on very small grains ($a < 0.1\mu m$) is limited by field emission and electrostatic disruption which should occur if the surface field exceeds a critical value (Goertz, 1989).

Grain ensemble ($a << d << \lambda_D$)

The values of both the capacitance C and the ambient plasma potential $\bar{\phi}$ depend on how closely the grains are packed together. In the high grain density case, the grain charge may be lower than the 'isolated' value. There are two competing effects that lead to this result: one is that the capacitance of the grain increases, which tends to increase the charge; the other is that the magnitude of the grain surface potential, relative to the plasma potential decreases, which decreases the charge. The capacitance of a grain increases from its value in vacuum (where the capacitance is proportional to the grain radius) as the grain spacing becomes comparable to or less than Debye length. In this case, the positive sheath (for a negatively charged grain) moves closer to the grain surface, thus essentially decreasing the capacitor gap, or the distance between the edge of the sheath and the grain surface, and thereby increasing the capacitance.

The more important effect at high dust density arises from electron depletion, when the dust grains carry a significant fraction of the (negative) charge density in the plasma, so that much of the electron charge resides on the grain surfaces. In this case, the surface potential of a grain does not have to be as negative, with respect to the plasma potential, as in the isolated grain case to balance the electron and ion currents to the grain. This leads to a decrease in the magnitude of the grain charge, since the charge is proportional to $(\phi_s - \bar{\phi})$ (Mendis and Rosenberg, 1994).

Goertz (1989) investigated how the grain potential $\phi(r)$ changes when dust grains are placed closer and closer to each other. The one dimensional Poisson's equation for an ensemble of grains' each carrying a charge Q_i is given by

$$\frac{\partial^2}{\partial x^2}\phi = (\frac{e}{\epsilon_o})\Big[n_e(\phi) - n_i(\phi)\Big] + \sum Q_i f_i(r) \tag{1.4}$$

For a Boltzmann distribution of the plasma electrons and singly charged ions we have

$$n_e(\phi) = n_o exp(\frac{e\phi}{k_B T})$$
$$n_i(\phi) = n_o exp(-\frac{e\phi}{k_B T}).$$

where n_o is the electron density far away from the dust where the plasma potential is zero and the plasma is charge neutral; $f(r)$ is zero outside the grain and $f(r) = \frac{3}{4}\pi a^3$ inside the grain assuming that the charge Q is uniformly distributed throughout the grain.

If the distance between the grains is larger than the Debye length, the maximum potential between the grains is almost zero. When the sheets are placed close to each other, the potential between the grains is smaller, and the average charge density on each sheet is reduced. The same effect occurs for grains in the three dimensional case. When the inter-grain distance d is smaller than the Debye length, the average charge on each grain is reduced, and the maximum potential between the grains is negative compared to the potential at infinity which we assume to be zero. Now, the charge on each grain is given by

$$Q = (\phi_s - V_p)4\pi\epsilon_o a \tag{1.5}$$

where V_p is the maximum plasma potential between the grains, i.e. where $\frac{\partial^2}{\partial x^2}\phi = 0$. Thus the average charge on the grains is smaller than that of an isolated grain at the same surface potential.

Havens et.al. (1987) studied the variation of the grain charge with dust density in a dust cloud embedded in a plasma, with the cloud at an average potential V_p, using coupled equations for current balance to the grain and overall charge neutrality in the cloud. They have shown that Q and V_p depend only on the parameter $P = \frac{aNT}{n_o}$, where "a" is the grain radius in meters, T is the plasma temperature and N is the dust density. From the observations it is clear that when P is small, $(\phi_s - V_p)$ approaches the classical single-grain value and the plasma potential is zero. If the density N and consequently P are increased, the magnitude of average charge is reduced, and the plasma potential becomes negative. This collective effect is most important when $P \approx P_c = 10^{-9}$ if T is the thermal energy of the plasma electrons expressed in electron volts. At this value of P the charge density carried by the grains (i.e., NQ) is comparable to the charge density of the electrons $(n_o e)$, and hence most of the electrons are trapped on the grains. If P becomes larger than 10^{-8}, the average charge on a grain is very small, and collective electrostatic effects are negligible. If P is less than 10^{-10}, the grains are treated as isolated grains and collective effects are also small (Goertz, 1989).

1.2.2 The motion of charged dust grains

The basic nature of the trajectories of interplanetary dust grains entering planetary magnetospheres, getting charged to significant negative potentials within the plasmaspheres, and moving under the combined influence of planetary gravity and Lorentz force was discussed many years ago. Since then there has been a growing interest on the dynamics of charged dust in planetary magnetospheres and cometary environments.

The basic equation governing the dynamics of a charged dust grain of mass m_D, velocity v_D, in a planeto-centric inertial frame is

$$m_D \frac{d\vec{v}_D}{dt} = Q(t)\left[\vec{E} + \frac{\vec{v}_D \times \vec{B}}{C}\right] + \vec{F}_G + \vec{F}_c + \vec{F}_r + \vec{F}_d \quad (1.6)$$

where F_G is the gravitational force and F_c, F_r and F_d are forces associated with collisions of the grain with plasma, radiations and other grains respectively. In the region of the magnetosphere, that is co-rotating with the planet of mass M_p with angular velocity Ω_p, $F_G = -\frac{GM_p m_D}{r^2}$ is the gravitational force (Mendis and Rosenberg, 1994). The force F_c, which arises from the relative motion between the grain and the plasma, has contributions both from direct impact with ions as well as from Coulomb interactions between the grain charge and the ions. However, it was shown to be of negligible importance to the dynamics of charged dust in the magnetospheres of Jupiter and Saturn and plays only a marginal role in orbital evolution. The force F_r due to radiation pressure is also negligible in the Jovian and Saturnian magnetospheres, but is of crucial importance in the terrestrial magnetospheres and is given by $F_r = \pi a^2 q$. The radiation pressure q is directed away from the sun and is given by

$$q = \frac{f_{pr} S_{sun}}{cD^2} \quad (1.7)$$

where f_{pr} is the scattering efficiency for radiation related to the albedo of dust particle, S_{sun} is the solar constant, D is the distance from the sun (in AU) and c is the speed of light. Finally F_d is negligible in all cases (Goretz, 1989).

Dynamics of charged grains in planetary magnetospheres

Charged grains are subject to azimuthal (about the planet) as well as radial electromagnetic forces in planetary magnetospheres, so their angular momentum is not constant. This will produce a radial transport and distribute grains throughout the magnetosphere. Consider the case of the Earth's magnetosphere. In this case the dust grains of various sizes at geosynchronous orbit are uniformly distributed in longitude and move subject to the gravity, co-rotation, and solar wind induced convection, electric field and radiation pressure. Radiation pressure causes the grain orbits to become elliptical and accounts for the shifts of the orbits. The eccentricity of the orbits increases with time, and once they become large enough, the grains can intersect the Earth and be lost. Once the grains exit the magnetosphere into the solar wind, they are carried away and lost from the system. Plasma drag also leads to an orbital decay inside the synchronous orbit and an outward radial drift outside of synchronous orbit. This is strictly true only for a co-rotating plasma, which is not the case outside the Earth's plasmapause.

The fluctuations of the grain charge can lead to a radial diffusion of grains. If the grain acquires its equilibrium charge instantaneously, the average electromagnetic force integrated over one gyro-orbit about the guiding centre, would have only a radial component and hence no torque. However, a grain will not change its charge instantaneously, and hence there will be phase lag in the charge with respect to the orbital position. The average electromagnetic force then has an azimuthal (longitudinal) component which does exert a torque on the grain leading to radial transport. This 'gyrofrequency' can be very large for small grains in Jupiter's magnetosphere (Goretz, 1989).

Dynamics of grains near comets

Grain motions near comets are influenced by radiation pressure, plasma drag and the electromagnetic force. Here the effects of gravity are negligible. Electromagnetic forces effects grains of submicron size but does not influence the larger grains. It is clear that the shaping of the dust tail by electric force depends on the grains' size (Goretz, 1989).

1.3 Waves and Instabilities in Dusty plasmas

In this section we first present a general introduction about waves and instabilities in a conventional plasma and then give an overview of the waves and instabilities in dusty plasmas.

Any periodic motion can be considered as a wave; so too a variation in the distribution of energy (both kinetic and potential) in a medium. So any disturbance in the distribution of energies creates waves. A rough sub-division of the stable wave motions in a homogeneous plasma is possible in terms of four characteristic frequencies of processes within the plasma, assumed immersed in a magnetic field. In many typical cases these frequencies occur in the following order:

(i)inter-particle collision frequencies (lowest),

(ii)ion cyclotron frequency,ω_{ci},

(iii)electron cyclotron frequency, ω_{ce}, and

(iv)electron plasma frequency, ω_{pe} (highest).

At frequencies below (i) a plasma would behave as an ordinary gas and propagate a simple sound wave. Such waves are of importance only at high densities or at low plasma temperatures, where the collision cross sections are large. At frequencies between (i) and (ii) one finds the lowest frequency wave characteristic of the plasma state. This wave is the hydromagnetic or Alfven wave and depends on the electrical conductivity of the plasma state.

As the wave frequency is increased toward (ii), the ion cyclotron frequency, the Alfven wave splits into two circularly polarised waves, one rotating in the same sense as the ions and the other in the opposite sense, i.e.,in the sense of rotation of the electrons. The first of these, called *the ion cyclotron* wave, propagates at frequencies below the ion cyclotron frequency. This wave becomes highly dispersive, its group velocity (energy propagation velocity) approaching zero as the driving frequency approaches the ion frequency. The second of the two waves, called the electron cyclotron wave, is of special interest, since it provides an explanation for the whistler phenomenon observed in ionospheric research.

An instability is any disturbance or variation in the quasi-equilibrium state of the system that reduces the free energy and brings the system to a true thermodynamic state.

Plasma instabilities are normal modes of a system that grow in space or time. Thus the word 'instability' in a plasma implies a well-defined relationship between the wave vector $\vec{k}$ and frequency ω; thus plasma fluctuations relate the free energies of the system.

By 'free energy' we mean particle kinetic energy which can be transferred to fluctuating fields (that is, the inverse Landau damping). The two forms of distributional free energy are:

1. A non-Maxwellian energy distribution with an excess of high energy particles.

2. A velocity distribution that is anisotropic in space; for example, with the temperature parallel to the field lines $T_{\parallel}$ not equal to the temperature perpendicular to the field lines $T_{\perp}$. These free energy sources are not always separable. For example, the loss - cone distribution (occurring in magnetic mirror machines) is a combination of both non-Maxwellian energy distribution with an excess of high - energy particles and a velocity distribution that is anisotropic in space.

During an instability this free energy of the distribution is converted to copious radiation and changes in the distribution lead to enhanced particle losses.

Not all the deviations from a Maxwellian distribution lead to an instability. Consider an infinite, homogeneous plasma with an isotropic velocity distribution in a uniform magnetic field. If the distribution function $f(E_k)$ decreases monotonically with energy E_k, that is if $\frac{\partial f(E_k)}{\partial E_k} < 0$ for all E_k, then the plasma is stable (Gardner; 1963), even if the distribution is non-Maxwellian (for a Maxwellian distribution $\frac{\partial f(E_k)}{\partial E_k} < 0$ in general). Therefore a necessary requirement for instability in a plasma with an anisotropic velocity distribution is $\frac{\partial f(E_k)}{\partial E_k} > 0$, for some value of E_k.

If the fluctuations are relatively weak the linear theory is appropriate to describe the physics of the instability. The traditional development of the linear theory of instabilities in collisionless plasmas follows a well-established procedure; the linear Vlasov equation is subjected to a Fourier/Laplace analysis in space/time, yielding fluctuating particle densities and particle flux densities that are inserted into Maxwell's equations to yield a dispersion equation. The solution of this dispersion equation relates ω and k and thereby determines the normal modes of the plasma.

The dispersion equation may be solved either as a boundary value problem (ω is given as real, and one solves for a complex component of $\boldsymbol{k}$) or as an initial value problem (k is given as real, and one solves for a complex ω). The second approach is subject to fewer mathematical ambiguities and it is the approach more often followed in the literature.

For the complex wave vector $\boldsymbol{k} = \boldsymbol{k}_r + i\boldsymbol{k}_i$, $\boldsymbol{k}_r$ and $\boldsymbol{k}_i$ are the real and imaginary parts of the wave vector. For the complex frequency $\omega = \omega_r + i\gamma$, ω_r is the real frequency and γ is the growth or damping rate. For a heavily damped oscillation any solution of the linear dispersion equation satisfies the condition $\gamma < -|\omega_r| < 2\pi$. We use the term "waves" to describe those weakly damped solutions that satisfy $\frac{-|\omega_r|}{2\pi} \leq \gamma \leq 0$ and describe as "instabilities" growing solutions with $\gamma > 0$. All fluctuations will denote both stable waves and instabilities. The phase speed of a fluctuation, the speed at which a point of constant phase of a single mode propagates through the plasma, is $\frac{\omega_r}{k}$; the relative motion between the observer and the medium bearing the wave , the damping or the growth rate γ calculated from homogeneous plasma theory are all independent of the frame in which the calculations are performed.

If the distribution function of each plasma species is Maxwellian and no external electric fields are present, the dispersion relation typically yields non-growing roots. In order to yield one or more plasma instabilities, the dispersion relation must be based on distribution functions involving free energy; that is, having a non-Maxwellian property corresponding, for example, to an anisotropy or an inhomogenity.

1.4 Waves in Dusty plasmas

During the past few years there has been a substantial increase in the theoretical studies of the collective behaviour of dusty plasmas that explain how the presence of charged dust grains in a plasma can effect wave dispersion, instabilities and wave scattering.

Some basic properties of various waves in a dusty plasma have been obtained from multi-fluid analysis, which treat the dust grains as a component of a three component plasma comprising electrons, ions and (negatively or positively) charged dust of uniform mass and charge (and therefore uniform size). The fluid equations for each species α are the equations of continuity and momentum given by

$$\frac{\partial n_\alpha}{\partial t} = - \nabla \cdot (n_\alpha \overrightarrow{v_\alpha}) \tag{1.8}$$

$$n_\alpha m_\alpha (\frac{\partial}{\partial t} + \vec{v}_\alpha \cdot \nabla) \vec{v}_\alpha = - \nabla P_\alpha + q_\alpha n_\alpha \left(\vec{E} + \frac{\vec{v}_\alpha \times \vec{B}}{c} \right) \tag{1.9}$$

coupled with Maxwell's equations. The overall charge neutrality in the plasma is given by

$$Z_i n_i + \epsilon_D n_D Z_D = n_e \tag{1.10}$$

where $\epsilon_d = 1, -1$ respectively for positively, negatively charged grains. Here q_α, Z_α are the charge, charged state of each species α, $\bar{E}$ and $\bar{B}$ are the electric and magnetic fields, and n_α, $\bar{v}_\alpha$, m_α and P_α are the density, fluid velocity, mass and pressure of each species α. To obtain dispersion relations for linear waves, the fluid equations are solved for small perturbations about an equilibrium steady state [Mendis and Rosenberg, 1994].

The presence of charged dust has been shown to both modify the usual linear modes known in an electron - ion plasma and also lead to the presence of new modes associated with the dust grains in low frequency and low phase velocity regimes (Shukla 1992). New low-frequency modes associated with the response of the dust grains can arise when the dust grain dynamics are included via the momentum and continuity equations for the dust species.

In the case of unmagnetised plasmas, dust can modify the linear dispersion relation for ion-acoustic waves. The dispersion relation for dust acoustic waves in a dusty plasma in the phase velocity regime where the electron inertia is negligible $V_{tD}, V_{ti} << V_{ph} << V_{te}$ (where $V_{t\alpha}$ is the thermal speed of species α and $V_{ph} = \frac{\omega}{k}$) and in the very large dust mass limit, is given by (Shukla and Silin, 1992)

$$\omega^2 = \delta \frac{k^2 C_s^2}{1 + k^2 \lambda_{De}^2} \tag{1.11}$$

where $\delta = \frac{n_{io}}{n_{eo}} > 1$ for negatively charged dust, and $C_s = (\frac{k_B T_e}{m_i})^{1/2}$ is the usual ion sound speed. For long wavelengths the phase velocity of this mode is given as $V_{ph} = (\frac{\delta k_B T_e}{m_i})^{1/2}$, the dust ion acoustic mode can exit as a normal mode of the system even for $T_e = T_i$ as long as dust grains carry most of the negative charge in the plasma, i.e, $\delta >> 1$, because in this case ion Landau damping is small. This is in contrast to the electron - ion plasma, where $T_e >> T_i$ is required for propagation of ion-sound waves (Krall and Trivelpiece, 1973). This mode may be relevant to astrophysical situations such as in the F-ring of Saturn; it may also be relevant to the possible existence of an electrostatic shock just inside the ionopause of comet Halley (Shukla and Silin, 1992).

For the lower phase velocity regime $V_{tD} << V_{ph} << V_{ti}, V_{te}$ the presence of dust can lead to a new dust acoustic wave. Excitation of the dust acoustic mode by streaming electrons and ions may have relevance to planetary rings (Rao et.al., 1990).

In a magnetised, homogeneous dusty plasma the presence of charged dust can similarly affect electrostatic waves such as acoustic waves, electrostatic ion cyclotron (EIC) waves and lower hybrid waves. A three component magnetised dusty plasma by multi-fluid analysis showed that there are two ion-acoustic waves and two electrostatic ion cyclotron waves associated with the positive ions and the negative (or positive) dust grains. For negatively charged dust, frequencies of both acoustic waves increase with dust density. For positively charged grains, frequency of the ion-acoustic mode decreases with increasing dust density, while the frequency of the EIC mode approaches the ion gyrofrequency as n_D decreases (d'Angelo, 1990). The dispersion relation of the lower hybrid mode in the frequency regime $\Omega_D, \Omega_i << \omega << \Omega_e$, is also modified by the presence of charged dust (Shukla, 1992).

The multi-fluid analysis was also used to study the effects of negatively charged dust grains on electrostatic drift waves in inhomogenous magnetised low-β plasmas. The analysis showed that, the dynamics of negatively charged dust grains can modify the dispersion properties of the usual electrostatic drift waves and lead to the appearance of new low frequency dust drift waves in the regime $\omega << \Omega_D$ (Shukla et.al., 1991).

The dispersion properties of low frequency electromagnetic waves, including Alfven waves and magnetosonic waves can be modified by the presence of dust. For example, consider the case of the Alfven wave spectrum in a cold plasma in the very low frequency regime $\omega << \Omega_D$; the dispersion relation is

$$\omega^2 = \frac{k^2 V_A^2}{\left[1 + (\frac{V_A}{c})^2 + \frac{n_{Do} m_D}{n_{io} m_i}\right]} \tag{1.12}$$

where V_A=Alfven speed=$(\frac{B^2}{4\pi n_{io} m_i})^{1/2}$. For many astrophysical and space dusty plasmas, the last term in the denominator may be greater than one owing to the large ratio of dust to ion mass, so that the dust dynamics decreases the phase speed in this regime (Mendis and Rosenberg, 1994).

Nonlinear acoustic waves in dusty plasmas have also been investigated using multi-fluid analysis. The formation of large amplitude ion-acoustic solitons in a dusty, unmagnetised plasma with negatively charged grains, cold ions and Boltzmann distributed electrons has been investigated. The presence of dust particles was found to lead to the appearance of rarefactive (negative potential) solitons as well as compressional (positive potential) solitons, which do not exist in the absence of dust (Bharutharam and Shukla, 1992). It was also found that the dust-acoustic waves could also propagate nonlinearly as solitons of either negative or positive potential in a three component plasma of electrons, ions and negatively charged, cold dust grains (Rao et.al., 1990).

In the regime $d \geq \lambda_D$ charged dust grains affect waves in dusty plasmas. Kinetic analysis has shown that the dust can significantly affect wave propagation, even when the charge density carried by the grains is small compared to the electron or ion charge density, due to inhomogenities arising from the dust grains and their screening clouds which modify the plasma equilibrium (de Angelis et.al. 1988,1989).

1.4.1 Instabilities in a plasma

Fluid and Kinetic Instabilities:

As the free energy (say the relative drift speed between two components) is increased, the imaginary part of the frequency, γ, of a damped mode becomes less negative until $\gamma = 0$ is reached at some wave vector. We term this condition the threshold of the associated instability because any further increase of the free energy leads, at some wave vector, to $\gamma > 0$, or wave growth. And some where above the threshold, it is often true that at least one component (j) is resonant with the instability; that is, $|\zeta_j| \leq 1$ where ζ_j is the argument of the dispersion function $Z(\zeta_j)$ used in the linear dispersion relation. In this regime, wave growth depends on velocity-space details of the j^{th} component distribution function and the instability is termed "kinetic".

If the free energy is further increased (for example if the relative drift speeds of the components become much greater than the component thermal speeds), the maximum growth rate also continues to increase; all plasma components then become non-resonant ($|\zeta| >> 1$), and the dispersion equation can be reduced to a cold plasma form. In this regime, the growing mode is usually termed a "fluid" instability.

Given a particular source of free energy, a plasma may be unstable to several different modes. So the classification of any micro-instability requires identification of both the free energy and the dispersion properties.

Longitudinal and Transverse Instabilities

When discussing plasma wave and instabilities, it is convenient to separate the fluctuating electric fields into two types: longitudinal ($\vec{k} \times \vec{E}^{(1)} = 0$) and transverse ($\vec{k}.\vec{E}^{(1)} = 0$). The complete solution of the general dispersion relation will typically have contributions from both types of fields: We define these as $\vec{E}_L^{(1)} = \vec{k}\vec{k}.\frac{\vec{E}^{(1)}}{k^2}$ and $\vec{E}_T^{(1)} = \frac{\vec{k}\times\vec{E}^{(1)}}{k}$, respectively.

Plasma fluctuations that have only a longitudinal electric field may be derived through the use of a kinetic equation and a single Maxwell equation, the Poisson's equation. Such waves and instabilities have $B^{(1)} = 0$ and are termed "electrostatic". In contrast, waves and instabilities with fluctuating electric and magnetic fields perpendicular to the wave vector and with no longitudinal electric field can be described through the use of an appropriate kinetic equation and Faraday's equation and Ampere-Maxwell equation. These fluctuations are called "electromagnetic".

Most fluctuations in space plasmas of non-zero β have both the transverse and longitudinal components. If

$$0 < |E_T^{(1)}|^2 + |B^{(1)}|^2 < |E_L^{(1)}|^2$$

we will term the wave primarily "electrostatic" and if

$$0 < |E_L^{(1)}|^2 < |E_T^{(1)}|^2 + |B^{(1)}|^2$$

the mode is primarily "electromagnetic". Finally, the term "electromagnetic" will encompass fluctuations with arbitrary ratios of longitudinal and transverse fluctuating fields.

In addition to the above classification, instabilities may also be classified on the basis of their frequency, the growing mode and the driving mechanism. Thus we have

1.Classification on the basis of frequency:

i)Micro instabilities

ii) Macro instabilities

2.Classification on the basis of the growing mode:

i) Convective instability

ii)Absolute instability

and

3.Classification on the basis of the driving mechanism:

i) Streaming instability

ii) Rayleigh-Taylor instabilities

iii)Universal instabilities and

iv) Kinetic instabilities

Micro vs Macro : The most general classification of growing modes in a plasma divides them into two broad categories:

Macro instabilities occur at relatively long wavelengths and micro instabilities at shorter wavelengths.

Macro instabilities depend on the configuration-space properties of the plasma and are well described by the fluid equations.

Micro instabilities are driven by the departure from thermodynamic equilibrium of the plasma velocity distribution and therefore must be described by the Vlasov equation or other kinetic equations.

In a magnetised plasma with the gyro-radius r_L of a characteristic ion, macro instabilities generally grow most rapidly at $kr_L << 1$, whereas the micro instabilities generally have maximum growth rates at $kr_L \geq 1$.

Distinction between the two categories is not clear cut; a macro mode may have appreciable growths at short wavelengths and a micro mode may persist even at small wavenumbers. The distinction is further blurred by the fact that the wavenumber at maximum growth rate of some instabilities depend on the plasma parameters and may slide from the micro- to the macro - regime as the parameters change. Nevertheless, the macro vs micro distinction is a convenient one to begin any general discussion of unstable plasma modes.

Further, high frequency (or short wavelength) instabilities tend to have a more "fine-grained" nature than the low frequency instabilities. This difference is sometimes expressed by designating the high frequency instabilities as micro instabilities in contrast with the low frequency "macro instabilities" but again there is no sharp division between the two types. High frequency instabilities manifest themselves through enhanced emission of electromagnetic radiation, increased particle losses and changes in the particle distribution function in the direction of thermodynamic equilibrium.

The main driving mechanism for the high frequency instabilities is a departure of the ion or the electron distribution from a Maxwellian velocity distribution.

With a Maxwellian distribution, the waves are damped (Landau damping); but a wave can grow in some particle distributions that depart from Maxwellian distributions.

Landau or cyclotron damping occurs because of the transfer of energy from waves to a group of particles whose velocities satisfy some resonance condition. The rate of damping depends on the distribution of particles in this special region of velocity space. If the distribution is not Maxwellian there is the possibility that the energy transfer may be modified and goes the other way, so that the wave grows at the expense of the particle's kinetic energy. Thus micro instabilities depend on the microscopic details of the velocity distribution.

Micro instabilities also result in turbulence and the rapid diffusion of the plasma across the confining magnetic field. These instabilities involve fluctuating electric or magnetic fields inside the plasma; compared with magnetohydrodynamic instabilities they are often slow growing and not associated with any large scale motion which makes them more difficult to detect. They however produce an enhanced level of fluctuation. Any anomalous particle loss which may result is fairly readily determined from density measurements, but an identification of the instability is usually much more complicated. The diffusion in velocity space resulting from micro instabilities is much slower than the speed of sound but it can nevertheless be too fast to allow confinement for thermonuclear times. Experimentally fast anomalous diffusion, sometimes called Bohm diffusion, has been observed in many toroidal experiments.

Other contributing factors for high frequency instabilities are :

1. Density gradient
2. Temperature gradient and
3. Magnetic field gradient.

Low frequency instabilities :

Instabilities with frequencies less than the ion cyclotron frequency have been investigated extensively because of the possible link between the instabilities and the diffusion of plasma across the magnetic field. Experiments by Hoh and Lehnert (1960) showed the first unambiguous correlation between diffusion and instabilities (fluctuation).

Quite apart from the relation between plasma loss and instabilities, low frequency oscillations have their own interest as manifestation of characteristics of plasmas such as Landau damping, anisotropy introduced by magnetic field, etc.

Absolute and Convective Instabilities : Although the criterion discussed above can determine if an instability can occur, it does not determine if the instability is a convective instability or an absolute instability.

For a convective instability the wave propagates along the system so that the disturbance at a fixed point in space may amplify or decay with time. On the other hand an absolute instability increases with time, at every point in space. A convective instability can be likened to a traveling (evanescent) wave while an absolute instability should be compared with a standing (amplifying) wave.

Whenever we have a dispersion relation

$$D(k, \omega) = 0$$

which has either complex k for real ω, or complex ω for real k, then the wave may be described as either stable or unstable depending on whether the wave grows or decays in space or time. Unfortunately, however, the distinction is not always that simple, for there exist classes where a wave may grow in space but decay in time at a fixed point. We shall use the nomenclature that a wave is unstable if for some real k, with $\omega = \omega_r + i\gamma$, ω, has positive real imaginary part, or $\gamma > 0$. We shall call a wave with complex $k = k_r + ik_i$, for real ω, an amplifying wave if the wave grows in space in the direction of energy flow and evanescent if the wave decays in space in the direction of energy flow. It is not sufficient to find only the sign of the imaginary part of k, since growth in the direction of the phase velocity may lead to a decay in the direction of the group velocity, as for a backward wave. A further distinction is that if a finite source (in space and time) leads to growth in time at every point in space, we call this as absolute instability. However, whenever a growing disturbance propagates in space (convects) such that, at a fixed point in space, the wave eventually decays in time, we call this a convective instability. This distinction is not observer independent; clearly, since an observer moving along with the growing disturbance would see it growing everywhere, so it would appear to him to be an absolute instability.

Classification on the basis of Free energy : On the basis of the type of free energy available to drive the instabilities, they are classified as follows:

1.Streaming instabilities

In this case, either a beam of energetic particles travels through the plasma, or a current is driven through the plasma so that the different species have a drift relative to one another; the drift energy is used to excite waves and oscillation energy is gained at the expense of drift energy in the unperturbed state.

2.Rayleigh-Taylor instabilities

In this case the plasma has a density gradient or a sharp boundary, so that it is not uniform. In addition an external, non-electromagnetic force is applied to the plasma. It is this force which drives the instability.

3.Universal instabilities

Even when there is no obvious driving force such as an electric or a gravitational field, a plasma is not in perfect thermodynamic equilibrium as long as it is confined. The plasma pressure tends to make the plasma expand and the expansion energy can drive an instability. This type of free energy is always present in any finite plasma and the resulting instabilities are called universal instabilities.

4.Kinetic instabilities

In fluid theory the velocity distributions are assumed to be Maxwellian. If the distributions are, in fact, not Maxwellian there is a deviation from thermodynamic equilibrium; instabilities can be driven by this anisotropy of the velocity distribution. Such instabilities are called kinetic instabilities.

1.4.2 Instabilities in a Dusty plasma

The charged grains present in dusty plasmas can modify the behaviour of the usual plasma instabilities and develop new types of instabilities. Since dust grains are subject to non-electromagnetic forces such as gravity, friction or radiation pressure, there can be new sources of free energy to drive the instabilities. In dusty space plasmas, a source of free energy to drive instabilities is the relative drift between the charged dust and lighter plasma particles such as electrons and ions. A number of hydromagnetic and kinetic instabilities in dusty plasmas have been investigated in recent years.

Streaming instabilities in dusty plasmas can be studied using kinetic analysis. The conditions for the onset of the two stream instability in a plasma model is in which two charged dust distributions stream relative to each other. Small grains (below micrometer) are brought to rest with respect to the surrounding gas in very short distances, while the larger grains are practically unaffected. This breaking mechanisms is applied to interstellar gas clouds, for which one observes a large deletion of several elements at low cloud velocities, a depletion which decreases with cloud velocity. Hence this two stream instability may be important for grain destruction in high velocity clouds, as it effectively breaks the small grains but leaves larger ones intact, thereby creating two populations of grains which stream relative to each other with cloud velocity (Verheest, 1996).

Kelvin - Helmholtz instability occurs when adjacent plasma layers are in relative motion, but the dust is stationary. In other words when there is a gradient in the fluid flow speed between adjacent fluid layers. Multi-fluid analysis is used to examine the effect of either negatively or positively charged dust on the Kelvin-Helmholtz instability in a magnetised, low-β plasma. The dust is assumed to be immobile and of uniform mass and charge. The charged dust alters the critical shears for the onset of instability from that in an electron-ion plasma, where a relative speed between adjacent flows of the order of the ion-sound speed is required for instability. The critical shear increases with dust charge density in a plasma with negatively charged grains and decreases with dust charge density in a plasma with positively charged grains.

Ion acoustic and dust instabilities were investigated using a standard Vlasov analysis for a dusty unmagnetised plasma with electrons, ions and dust of uniform mass and charge. When the electrons have a weak drift 'u' in a range $V_{ti} < u < V_{te}$, dust ion-acoustic waves can be excited if $\delta\frac{T_e}{T_i} >> 1$ (in which case ion Landau damping is small), when 'u' is greater than the phase velocity of the mode $\delta^{1/2}C_s$. This instability may be relevant to cosmic plasmas, where generally it is assumed that $T_e \sim T_i$, in environments where dust carries much of the negative charge.

The dust acoustic mode may be excited under certain conditions when the plasma electrons and ions are drifting together with speed 'u' relative to the charged dust component. The dust-acoustic instability is the analog of the ion-acoustic instability in the frequency range associated with the dust dynamics. In planetary rings, there may a relative drift between the plasma electrons/ions and the charged dust grains. Hence the dust acoustic instability occurs in planetary rings.

If there is a localised region of enhanced negatively charged dust density in a plasma, there can be a corresponding depression of the electron density in that region to satisfy the condition of overall charge neutrality. At the boundary of the region where the dust density increases, the electron density would decrease, and assuming uniform n_i,

$$\Delta n_e = -Z_D \Delta n_D \tag{1.13}$$

as long as the dust density is low enough so that Z_D does not depend on n_D. In a dusty plasma in an external magnetic field, the associated diamagnetic drifts can lead to the drift instabilities. Saturn's ring observations indicates relatively sharp radial gradients in the optical depth, which is proportional to the dust density. The charge fluctuations can drive the drift wave unstable, under conditions that might prevail in the tail of comet 21P/Giacobini-Zinner.

The presence of negatively charged dust considerably reduces the range of unstable wavenumbers, while the opposite is true for dust grains. The dust charges were assumed constant, an assumption which is valid for wave frequencies much smaller or larger than the charging frequency of the dust. Observations show that self consistent charge fluctuations coupled to dust dynamics influences the Rayleigh-Taylor instability, leading to a rapid decrease of the unstable regime (Verheest, 1996).

1.5 Review of work on instabilities in dusty plasmas

In this section we give a brief review of the most recent research on wave instabilities in dusty plasmas. Only those works, that are in tune with the rest of this review have been selected and have been arranged, as far as possible, in chronological order.

Havnes (1980) examined the conditions for the onset of instability in a plasma model in which two charged dust distributions stream relative to each other.

Electrostatic waves in Saturn's rings were also discussed by Bliokh and Yaroshenko (1985)

Ershkovich and Mendis (1986) investigated the Kelvin - Helmholtz instability that can occur in a plasma when there is a gradient in the fluid flow speed between adjacent fluid layers.

Pilipp et.al.(1987) investigated the effect of charged dust grains on the propagation and dissipation of Alfven waves in interstellar clouds, as Alfven waves are the slowest decaying, showing no nonlinear steepening.

Havnes (1988) considered streaming between the solar wind and cometary dust grains. At high densities which may be found in cometary comae, the dust grains can be important charge carriers, leading to an electron depletion. The resulting instability drastically enhances the coupling between the solar wind and the dust, which favour small dust grains to be swept along with the solar wind plasma.

Goertz (1989) briefly touched upon electrostatic modes in the presence of drifting dust grains in planetary environments, leading to the familiar two-stream instability.

d'Angelo and Song (1990) found that when adjacent plasma layers are in relative motion, but the dust is stationary leads to the Kelvin-Helmholtz instability. For negative dust grains, the critical ion shear increases without upper bound, where as for the positively charged grains it is reduced, so that excitation of the instability becomes easier. This could be important for wavelike motions in cometary tails.

Tsytovich et.al. (1990) found that since dust grains are subject to non-electromagnetic forces such as gravity, friction, or radiation pressure, there can be new sources of free energy to drive instabilities, including relative drifts between the charged dust and lighter plasma particles (electrons and ions) in cosmic dusty environments.

Rao et.al. (1990) who pioneered research on the dust acoustic mode by including the dynamics of a tenuous dust fluid used a Boltzmann distribution for the electrons and ions.

They coined the name "dust-acoustic mode" to describe the novel mode at low enough frequencies and with a phase velocity far below the ion-acoustic velocity.

d'Angelo (1990) then studied the electrostatic ion and dust cyclotron and ion-acoustic modes. d'Angelo and Song (1990) considered the effect of either negatively or positively charged dust on the Kelvin-Helmholtz instability in a magnetised, low-β plasma with shear in the ion field aligned flow, using a multi-fluid analysis. The dust was assumed to be immobile and of uniform mass and charge.

Shukla (1992) reviewed linear low-frequency electrostatic and electromagnetic modes; the possible relevance of these results to astrophysical and cometary plasmas was pointed out, without going into further details.

Shukla and Silin (1992) described yet another new wave, due to electron depletion and high dust charges, in a model where the dust grains form an immobile background.

Forlani et.al. (1992), by averaging over a random distribution of dust particles, have shown how plasma fluctuations are modified and point to the possibility of wave damping due a to beating of the wave with the dust density fluctuations.

Bharutharam et.al. (1992, a & b) investigated whether the dust grains influence two-stream instabilities between electrons and ions, or else can themselves form a drifting beam. This could occur in planetary rings. In all cases the presence of dust grains enhances the growth of the instabilities, as well as the velocity ranges over which the instability can occur.

Salimullah and Sen (1992) examined the dielectric properties of a plasma studded with charged dust. The resulting inhomogeneous electric field significantly influences the dispersion properties of the plasma, even when the plasma Debye length is much smaller than the average grain separation.

Salimullah et.al. (1992) found that the combined presence of dust and static magnetic field has a significant effect for perpendicular wave propagation; leading to an electrostatic ion Bernstein mode in a dusty plasma.

de Angelis et.al. (1992) analysed the scattering of electromagnetic waves by a distribution of fixed charged dust.

Bharuthram and Shukla (1992) studied two-stream instabilities driven either by ion or dust beams in an unmagnetised dusty plasma and found that the dust affects both growth rates and ranges of drift speeds for which instability occurs.

Rao (1993) discovered a class of dust-magneto-acoustic waves, of both the fast and slow types. The fast branch generalises electrostatic dust- acoustic modes to magnetised plasmas. The wave frequencies for oblique modes are between the dust gyrofrequency and the ion and electron gyrofrequencies.

Rosenberg (1993), using the standard Valsov approach to ion and dust acoustic instabilities, considered some weighting of the dust at different sizes and charges.

Varma et.al. (1993) studied electrostatic oscillations and instabilities, by treating the dust charge as an additional dynamical variable.

Jana et.al. (1993) discussed charge fluctuations in response to oscillations in the plasma currents flowing to the grains, but not in a fully self consistent manner. Dissipative and instability mechanisms for ion and dust waves in the plasma should lead to their interesting applications in laboratory and astrophysical situations.

Melandso et.al. (1993a) were the first to include variations in the dust grain charge due to collective modes in the plasma and also deal with dust acoustic waves.

Melandso et.al. (1993b) gave a kinetic model for dust acoustic waves applying it to planetary rings, which can have a thickness up to 100 km. They included both Landau and Tromso damping or growth, in addition to velocity differences between the dust and the plasma, as dealt with by Rosenberg (1993) who used constant dust charges.

Rosenberg and Krall (1994) discussed drift instabilities, when there was a local electron density gradient opposite in sign to a dust density gradient.

d'Angelo (1994) included a new mechanism, that of creation damping due to the continuous injections of fresh ions in the plasma, to replace those that are lost on the dust grains. Creation damping had been considered much earlier when discussing recombination instabilities in ordinary plasmas. Creation damping is usually not dominant, except for such low-frequency motion that the grain dynamics becomes important.

Li et.al. (1994) gave attention to longitudinal waves in a plasma where the dust forms an immobile background of variable charges. There is a damping for ion-acoustic and electrostatic ion cyclotron waves, whereas the high-frequency Langmuir waves grow. The damping or growth rates are proportional to the dust charging frequency.

Aslaksen and Havnes (1994), assume the dust grains to be of one size but with a discrete distribution of electric charges. Hence the dust charge becomes an additional phase space variable.

Vladimirov (1994) investigated the propagation of electromagnetic and Langmuir waves, taking the effect of capture of plasma electrons and ions into account. He found that the resultant damping leads to a lowering of the frequencies.

Verheest (1994) looked into the charge fluctuation instabilities for electromagnetic waves, by taking into account the momentum changes due to capture or release of plasma electrons and ions by the dust.

Chhajlani and Parihar (1994) observed that the inclusion of charged dust decreases the region of instability and the critical Jean's wave number, rendering star formation more difficult.

Kulkarni et al (1994) have derived the dispersion relation for acoustic waves in a homogenous, unmagnetised and uniform plasma consisting of charged streaming dust particles and streaming electrons. The results were used to interpret the interaction between the solar wind plasma and cometary dust particles.

Chow and Rosenberg (1995) investigated the electrostatic ion cyclotron instability, and showed that the critical drift, needed to excite the instability, decreased as the negative dust charge density increased.

Winske et. al. (1995) considered an extensive numerical treatment of a dust-acoustic instability, caused by a drift of plasma ions with respect to the charged dust. The instability saturated by trapping some of the ions, and was slightly weaker when the dust grains had a range of sizes, charges and masses.

Rao (1995) observed that when a static magnetic field was included, two new higher frequency types of dust-magnetosonic waves, which were generalisations of dust acoustic modes, occured.

Jana et.al. (1995) observed that self consistent charge fluctuations coupled to dust dynamics influenced the Rayleigh-Taylor instability, leading to a rapid decrease of the unstable regime.

Varma and Shukla (1995a) showed that the dust grains directly respond to gravity, not really hindered by magnetic fields, where as electrons and ions, which were magnetised, could do so only through the Rayliegh-Taylor instability.

Varma and Shukla (1995b) studied a novel flute-like instability that was different from the usual Rayleigh-Taylor instability. It comes about in a non-uniform plasma held in equilibrium by a magnetic field against gravity, there is a polarization electric field in the direction of gravity for negatively charged dust grains.

Benkadda and Tsytovich (1995) discussed self-consistent equations for ion density, envelope electric fields and charge variations for a dusty plasma. A new type of modulational instability of Langmuir waves, related to dust charging process, was found.

Shukla and Vladimirov (1995) investigated modulational instability of high-frequency electromagnetic waves in collisional dusty plasmas, taking into account the effects of dust charge fluctuations in the dynamics of quasi-stationary plasma slow motions.

Jovanovic and Horton (1995) studied linear and nonlinear stages in the development of ion-temperature-gradient-driven drift wave instability analytically in the presence of shear flows, magnetic shear, inhomogeneity and curvature.

Barken et.al. (1995) reported laboratory observations of the dust acoustic instability and the results were compared with available theories.

Pandey and Dwivedi (1995) studied the effect of the mass and charge dynamics on the collective behaviour of a dusty plasma. It was shown that the finite non-zero streaming velocity of the dust grains led to a novel coupling of the dust mass fluctuations with other dynamic variables of the plasma and the grains. The mass fluctuations caused a collisionless dissipation and provided an alternate channel for the beam mode instability to occur. It was concluded that the higher value of the ion mass density to dust mass density ratio reduced the threshold value for the onset of the instability.

Rosenberg and Krall (1996) investigated low frequency drift instabilities in a dusty magnetised plasma with negatively charged grains in which locally there was an electron density gradient which was opposite in sign to a dust density gradient. Frequencies less than the ion gyrofrequency but much larger than the dust gyrofrequency were considered. Instabilities analogous to the universal instability and lower hybrid drift instability were investigated.

Tripathi and Sharma (1996) studied dispersion properties of some low-frequency electrostatic and electromagnetic modes in magnetised dusty plasmas, taking into account the dust size distribution. It was seen that in the very low frequency regime, a new kind of damping existed for an electrostatic dust-cyclotron and right-hand circularly polarised electromagnetic Alfven mode; where as the left-handed circularly polarised Alfven mode remained undamped. In the low frequency regime the dispersion relations for all modes were modified.

Avinash and Shukla (1996) showed that adiabatic dust charge fluctuations caused an instability of the dust-acoustic waves. The results may be useful in understanding the origin of non-thermal electrostatic noise that arise in astrophysical and laboratory plasmas.

Pandey and Dwivedi (1996) discussed the gravitational instability of a dusty plasma with ion dynamics taken into account.

Bharuthram (1997) investigated low frequency instabilities using the full kinetic dispersion relation. Both the dust-acoustic and dust modified two stream instabilities were found to be excited, their existence depending on the wave propagation angle.

Bharutharm and Singh (1997), using kinetic theory, investigated the lower hybrid drift instability in a dusty plasma. For the length and time scales of the fluctuations, the electrons were treated as magnetized, and the ions and the dust species as unmagnetized. The instability was driven by the equilibrium diamagnetic current associated with the electrons and ions. The dependence of real frequency and growth rate of the lower hybrid drift instability on plasma parameters such as particle drift speeds, densities and temperatures, dust to ion mass ratio and dust charge, was studied.

Amin et.al. (1997) discussed analytically the modulational instability of an electron plasma wave in a homogeneous, unmagnetized, hot collisionless dusty plasma. It was noticed that the growth rate of the modulational instability of the electron plasma wave through a ultra-low-frequency dust mode is more efficient than that through the usual ion-acoustic mode in a dusty plasma.

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