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# EFFECT OF A CONVERGING MAGNETIC FIELD IN PLASMA CONTAINING DUST PARTICLES

**Dr. Ramesh Kumar Gupta**
Guru Kashi University, Talwandi Sabo

***Abstract***

*An important area of research has been the plasma characteristics and evolution of dust charge in plasma with dust particles. Particles are confined within a volume in most astrophysical and laboratory-based plasmas by a magnetic field whose strength increases towards the edge of the plasma system under discussion. Given the importance of dust in most plasma, research into the effect of magnetic field changes with field lines converging outward will shed light on how particle dynamics affect the dust charging mechanism. We used hydrogen plasma with $H^+$ ions, electrons, and 1 µm dust particles. An axisymmetric magnetic mirror field with converging field lines is used to develop a kinetic-fluid hybrid model. The effect of a magnetic field that gets stronger as it gets closer to the wall on the properties of plasma containing micron-sized dust particles is investigated. The mirror force caused by the magnetic field gradient is discovered to have a considerable effect on the sheath structure and particle distribution across the system length. Due to the converging nature of the magnetic field, the mirror force restricts ion migration towards the wall, lowering electron flux in the sheath and resulting in a decrease in negative dust charge. As a result, the coulomb drag force peak moves closer to the wall and becomes smaller. The collecting drag force, on the other hand, tends to rise near the wall due to the high density of the ions.*

***Keywords: Effect, converging, magnetic, plasma, dust particle, etc***

## 1. INTRODUCTION

An important area of research has been the plasma characteristics and evolution of dust charge in plasma with dust particles. Particles are confined within a volume in most astrophysical and laboratory-based plasmas by a magnetic field whose strength increases towards the edge of the plasma system under discussion. Given the importance of dust in most plasma, research into the effect of magnetic field changes with field lines converging outward will shed light on how particle dynamics affect the dust charging mechanism. Furthermore, the evolution of various forces acting on dust particles is influenced by the particle's local ion and electron distribution. We investigated the effect of a converging magnetic field on several plasma properties when the plasma contains additional micron-sized dust particles in this chapter. Dusty plasma is an example of an open system with extraordinarily high dissipation processes. Damping of dust particle translational, rotational, and oscillatory motions happens quickly and on tiny spatial scales. Dusty plasma as an oscillatory system, for example, has a figure of merit of only a few units. Any movement of dust particles is impossible without significant energy feeding. The interaction with ions and electrons of the plasma results in an input of energy and momentum, which is coupled with a large charge of the dust particle–up to $10^3$–$10^5$ elementary charges. Because of the higher electron mobility, this charge is usually negative. A high charge amplifies the effects of all external forces, including conservative (electrostatic), dissipative (ion drag), and gyroscopic forces (Lorentz forces acting on a dust particle either directly or indirectly through the light components of the plasma). Dust particles must be made more controlled and mobile for numerous purposes. Active particles, in particular, are generated for this purpose by

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coating their surfaces with specific coatings that absorb a lot of energy and momentum and convert it into directional motion and drift. External fields, such as a magnetic field, are also utilized. Fields with longitudinal gradients can be utilized to explore bulk dusty structures experimentally; forces of varying magnitudes will then act on different horizontal regions of the structure. Dusty plasma under a magnetic field has been of interest for the past 20 years, first and foremost from the standpoint of dynamics, particularly the creation of rotation mechanisms under varied conditions. Methods of managing dusty structures with a magnetic field were studied, including the control of the shape and size of dusty structures as well as the arrangement of particles within them. The results of examining the appropriate rotation of dust particles are particularly interesting, since they reveal that the magnetic properties of dusty plasmas are caused by a change in the flow of plasma particles onto their surface. Precessional motions are discovered, and dusty plasma is proven to have paramagnetic characteristics.

### 1.1 Charged dust expansion in a magnetic field model

When dust cloud particulates are spatially confined in a plasma backdrop, background plasma accumulates and charges the dust particles. A plasma density depletion area may result from the charging process. At the edge of the dust cloud boundary layer, where an ambipolar electric field occurs, a gradient in the density of charged plasma species emerges. The dust cloud boundary layer's ambipolar electric field provides an energy source for generating plasma waves. By affecting the connection between plasma dynamics and charged dust particulates, the presence of a background magnetic field can affect plasma fluctuation formation. Dust acoustic waves have been studied and reported in unmagnetized dusty plasmas. Rosenberg was the first to discover the conditions for exciting dust acoustic waves in collisionless dusty plasmas, demonstrating that ion and electron drifts higher than the dust acoustic phase speed can make the dust acoustic wave unstable. In space applications, the dust acoustic wave in unmagnetized boundary layer plasma could be generated by electron flow above the dust acoustic phase speed across the boundary.

Large amplitude self-excited dust acoustic waves were thought to be generated by streaming ions and electrons with velocity on the order of the ion acoustic speed along the magnetic field in laboratory dusty plasma investigations. Nonetheless, the electric field has been blamed for self-excited dust acoustic wave generation. The charged particles cannot freely flow perpendicular to the magnetic field because there is a background magnetic field. Aside from EIC modes in magnetized dusty plasmas, the cross-field dust acoustic instability in an inhomogeneous dust boundary layer can behave very differently than unmagnetized dusty plasmas, especially when electrons are strongly magnetized. Dust acoustic turbulence may cause diffusion over the boundary layer on the order of the ion thermal speed. Through a shear-driven instability and the lower-hybrid drift instability, dust cloud expansion over the magnetic field may provide circumstances for generating waves along the boundary layer in the lower hybrid frequency range. Computational simulations with massless fluid electrons and fluid ions on ions timeframes have previously been used to investigate shear-driven instability in growing dust clouds. On longer dust durations, the new model will study plasma variations in the lower hybrid frequency/dust lower hybrid frequency region due to E B flow and diamagnetic drifts.

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**2. REVIEW OF THE LITERATURE**

**Elena Dzlieva, L. D'yachkov, Leontiy Novikov, Sergey Pavlov, and Vladimir Karasev (2021)** in inhomogeneous magnetic fields, we investigate the behavior of dust particles in a layered glow discharge. Standing striations produce dust structures, which act as dust particle traps. These structures begin to revolve when a magnetic field is applied. The experiments were conducted out at striations near the solenoid's end, when an inhomogeneous magnetic field begins. The dusty structure can be distorted by increasing the magnetic field. The rotation of a dusty structure in an inhomogeneous magnetic field has been thoroughly researched; it exhibits distinct characteristics when compared to rotation in a uniform field. We looked into the mechanisms of such rotation and calculated its speed.

**Hu Li, Jian Wu, and Chengxun Yuan (2016)** in dusty plasma, the effect of charged dust particles and their size distribution on electromagnetic wave propagation is examined. It is demonstrated that the additional collision mechanism given by charged dust particles can drastically affect plasma's electromagnetic characteristics, resulting in the appearance of electromagnetic wave attenuation through dusty plasma. The dust density, radius, and charge numbers on the dust surface all influence the attenuation coefficient. The findings will be utilized to improve our understanding of how electromagnetic waves propagate in space and in laboratory dusty plasma.

**H. Shourkaei, H. Shourkaei, H. Shourkaei (2015)** in the presence of an external magnetic field and neutral collision forces, the properties of dust in a plasma sheath are examined. The continuity and momentum equations of ions and dusts are numerically solved with varying magnitudes of impact force using the fluid model. The electron and ion density distributions, ion flow velocity, and electron potential have all been estimated for various magnetic field magnitudes and directions. The effect of the magnetic field on the plasma sheath is demonstrated, and the collision force reduces the dust kinetic energy.

**Wayne Scales and Haiyang Fu (2013)** the boundary zone between charged dust clouds and background plasmas causes plasma variations. The expansion of a charged dust cloud through a magnetic field, the formation of the inhomogeneous boundary layer, and associated processes are studied using a self-consistent computer model. The charging of dust grains results in the formation of a boundary layer and an ambipolar electric field. In unmagnetized plasmas, this ambipolar field serves as a source for low frequency dust acoustic waves. Due to EB and diamagnetic current generation, a sufficiently strong background magnetic field may have an impact on dust acoustic wave evolution and dust density structures. When compared to unmagnified dusty plasma, the creation of dust acoustic density fluctuation over a strong magnetic field (pe/ce1) may be minimized. In the lower hybrid and dust lower hybrid frequency ranges, fluctuations generated at longer timescales travelling along the dust boundary layer will be examined. The use of plasmas in space and in laboratories is considered.

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## 3. OBJECTIVES

- To study charged dust expansion in a magnetic field model.
- To investigate scaling and dynamics of the ions and electrons in plasma affected by the presence of a converging magnetic field.

## 4. RESEARCH METHODOLOGY

We used hydrogen plasma with $H^+$ ions, electrons, and 1 µm dust particles. An axisymmetric magnetic mirror field with converging field lines is used to develop a kinetic-fluid hybrid model. The problem is one-dimensional (1D), with ions treated kinetically and dust particles treated fluidically, assuming massive dust species exhibit collective behavior in plasma. Electrons are simply Maxwellian in nature.

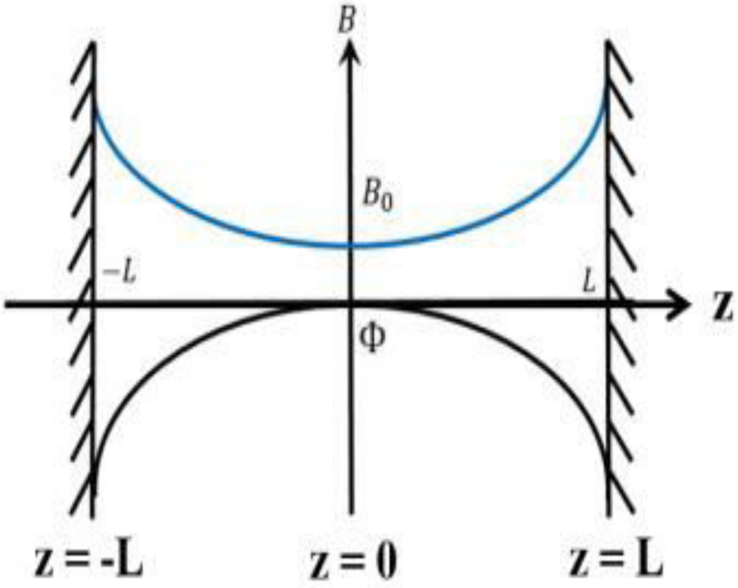


**Figure 1: Geometry of the model**

### 4.1 Modelling and theoretical formulation

Fig. 1 shows the model's geometry. In this case, the electric potential φ (z) and the magnetic field B(z) are symmetric. The magnetic field has a minimum value of $B_0$ at the centre. The hydrogen plasma is made up of $H^+$ ions, electrons, and dust. An ion's constant energy is given by

$$\varepsilon = 1/2\ m_i v_{\parallel}^2\ k + \mu B(z) + q\varphi(z)\ (1)$$

Here, mi is the mass, $v_{\parallel}$ is the angular velocity parallel to the magnetic field, B(z) is the magnetic field, and q is the charge of both ions. The magnetic moment

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$$\mu = miv^{2}_{\perp}/2B(z)$$

The ion's kinetic equation in phase space (z, ε, μ) is given by

$$\sigma v_{\parallel}(z,\varepsilon,\mu)\frac{\partial f(z,\varepsilon,\mu,\sigma)}{\partial z} = S(z,\varepsilon,\mu) \tag{2}$$

Where f(z, ε, μ, σ) and S(z, ε, μ) are the positive ion's distribution function and source function, respectively. The particle's orientation is indicated by the symbol σ. The walls are assumed to be non-reflecting and symmetric about z = 0, with the distribution function's boundary requirements as follows: f(−L, ε,μ,+1) = f(L, ε,μ,−1) = 0.

Depending on the ion's energy, the phase space can be separated into a passing and reflecting zone, with the requirement that v‖ must be real. Based on the dependency of effective potential, the distribution function of a positive ion in a magnetic field whose intensity increases towards the wall can be determined for two different instances $\varepsilon_{eff} = -\mu B(z) - q\varphi(z)$ with the aid of distance If the energy of the ions generated with a finite temperature is more than the effective potential at each point, they are accelerated towards the wall. Otherwise, between the turning points, it repeats its motion $\varepsilon = \varepsilon_{eff}$.

***For Case (i), μ[B(z)−B0] > −qφ(z)***

$$\sum_{\sigma} f(z,\varepsilon,\mu,\sigma) = \begin{cases} 2\int_{0}^{L}\frac{S(z',\varepsilon,\mu)}{v_{\parallel}(z',\varepsilon,\mu)}dz', & \varepsilon > \varepsilon_{eff}(\pm L) \\ 2\int_{0}^{z_t}\frac{S(z',\varepsilon,\mu)}{v_{\parallel}(z',\varepsilon,\mu)}dz', & \varepsilon_{eff}(z) < \varepsilon < \varepsilon_{eff}(\pm L) \end{cases} \tag{3}$$

***For Case (ii), μ[B(z)−B0] < −qφ(z)***

$$\sum_{\sigma} f(z,\varepsilon,\mu,\sigma) = \begin{cases} 2\int_{0}^{L}\frac{S(z',\varepsilon,\mu)}{v_{\parallel}(z',\varepsilon,\mu)}dz', & \varepsilon > \mu B_0 \\ 2\int_{z_t}^{L}\frac{S(z',\varepsilon,\mu)}{v_{\parallel}(z',\varepsilon,\mu)}dz', & \varepsilon_{eff}(z) < \varepsilon < \mu B_0 \end{cases} \tag{4}$$

Where z ′ is the ion generation point

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## 5. RESULT AND DISCUSSION

### 5.1 Normalization and scaling

To numerically solve the Poisson equation and the current balance equation of a dust particle, we normalize the variables with appropriate scaling settings. The following are the normalized parameters:

$$\eta = \frac{-e\phi}{T_e}, \quad s = \frac{z}{L}, \quad \tau = \frac{T_e}{T_i}, \quad Z_s = \frac{q_s}{e}$$

$$M = \frac{m_i}{m_e}, \quad N_s = \frac{n_s}{n_0}, \quad u_s = \frac{v_s}{c_s}, \quad \delta_d = \frac{n_{d0}}{n_0}$$

Where s = i, e, and d denote ion, electron, and dust, while $c_s$ denotes the ion sound speed. The converging magnetic field's mirror ratio is,

$$R = \frac{B(z)}{B_0} = exp(\alpha\eta) \quad (5)$$

Where α is a constant that is positive the ion source's spatial variation is provided by

$$h(z) = \exp(-\gamma\eta) \quad (6)$$

Where $\gamma = 1$ is a constant.

### 5.2 The dynamics of the ions and electrons in plasma affected by the presence of a converging magnetic field

The dynamics of ions and electrons in plasma are greatly influenced by the presence of a converging magnetic field. This, in turn, has an impact on the dust particles' charge characteristics. $\alpha= 0$ indicates a uniform magnetic field, while higher values of indicate a more converging magnetic field structure for the specified model field. When a result, as the value of grows, the mirror force $F_z = -\mu\nabla_{\|}B$ owing to the magnetic field gradient in the converging field increases towards the bulk of the plasma α. We've assumed that the mirror force impacts just positive ions, and that this causes changes in the plasma potential, which alters the electron and dust density distribution in space. For varied magnetic field profiles, Fig. 2 shows the fluctuation of normalized dust surface potential (Φd) with respect to normalized plasma potential. With a rise in the floating potential at the wall, the dust surface becomes less negative for higher values of. Although the electrostatic force attracts the ions, the mirror force in this situation prevents them from moving towards the wall. As the velocity of the sheath is insufficient to reach the wall, this effect grows stronger, resulting in the accumulation of additional ions in the sheath. The electron current declines at the sheath in order to balance the positive ion current. Because

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the dust particles are largely charged by electrons, a decrease in the dust charge at the sheath region in the event of a more converging magnetic field, as illustrated in Fig. 3, is caused by a drop in the current.

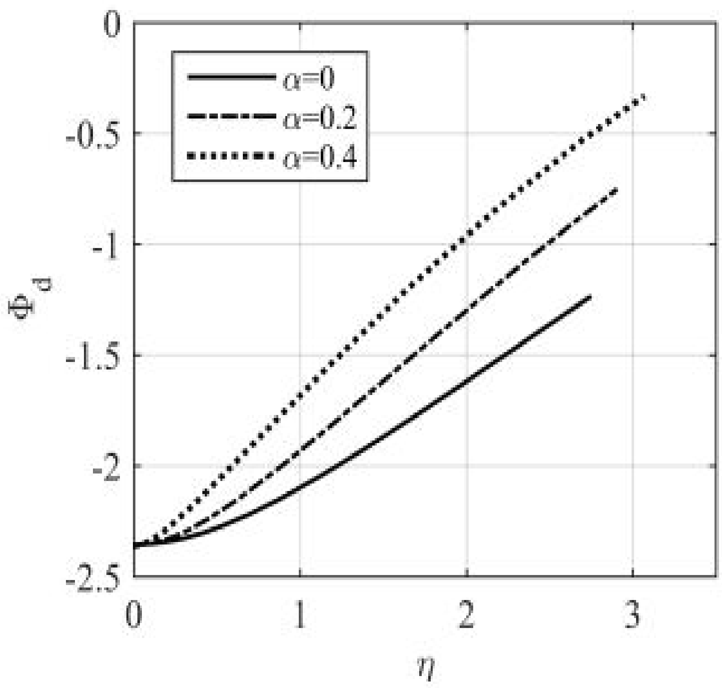

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**Figure 2: Normalized dust surface potential variation with normalized plasma potential for various magnetic field profiles (α)**

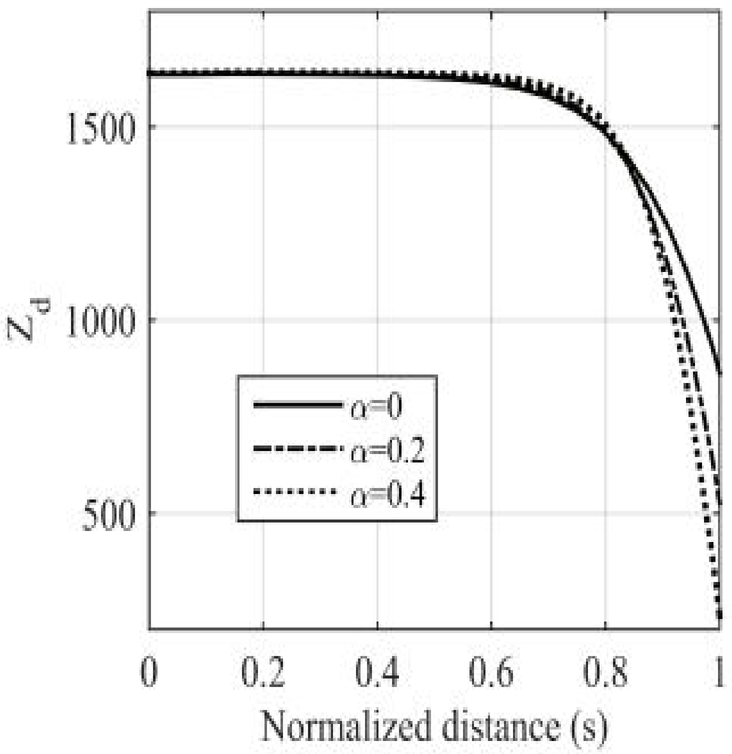


**Figure 3: Dust charge variation with distance for various magnetic field profiles (α)**

Starting from the bulk to the wall, Fig.4 depicts the variation in total particle density and ion velocity for various magnetic field profiles. These figures can be used to approximate the sheath edge. The sheath edge is defined as the point at which quasineutrality breaks and the ions reach their sound velocity. The sheath edge is highly visible from the density and ion velocity profile in the event of a homogeneous magnetic field (α= 0). After the quasineutrality breaking point, the ions acquire the Bohm velocity when a magnetic field gradient is introduced into the plasma. With rising value of, this point moves closer to the wall. When the magnetic field gradient is increased, the deposition of space charge towards the sheath edge steadily increases.

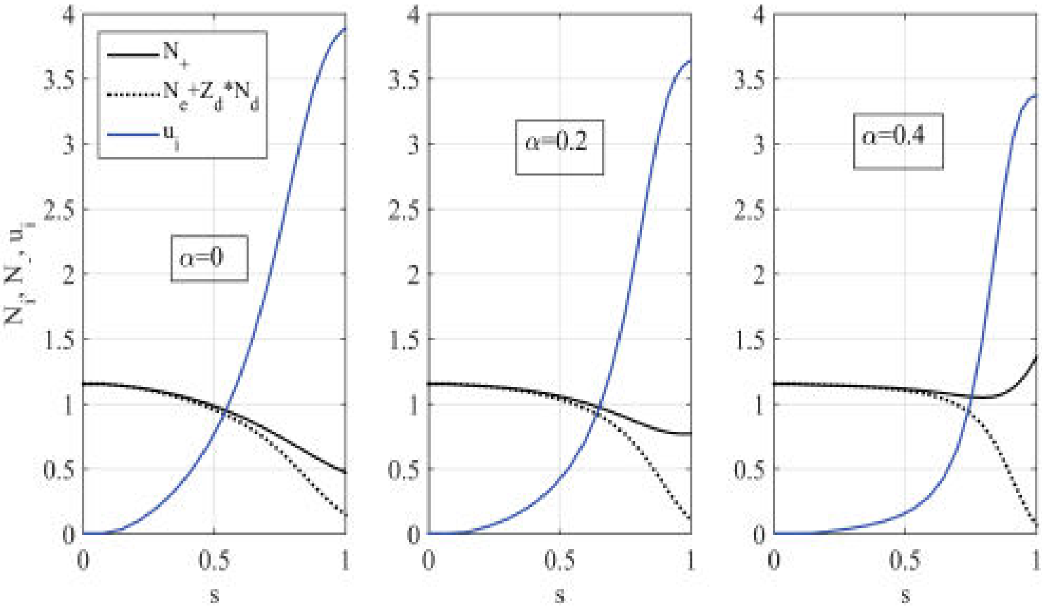


**Figure 4: Spatial variations of normalized positive and negative charge density and ion velocity for different magnetic field profiles**

## 6. CONCLUSION

The effect of a magnetic field that gets stronger as it gets closer to the wall on the properties of plasma containing micron-sized dust particles is investigated. The mirror force caused by the magnetic field gradient is discovered to have a considerable effect on the sheath structure and particle distribution across the system length. Due to the converging nature of the magnetic field, the mirror force restricts ion migration towards the wall, lowering electron flux in the sheath and resulting in a decrease in negative dust charge. Due to the drop in velocity caused by the mirror force, the ions achieve the Bohm velocity at a position beyond the quasineutrality breaking point. As a result, the coulomb drag force peak moves closer to the wall and becomes smaller. The collecting drag force, on the other hand, tends to rise near the wall due to the high density of the ions. When the magnetic field gradient is high, the bulk region extends out more than when the gradient is low. Furthermore, the effect of gravitational force on dust grains can be felt across a considerably longer distance, which is the bulk region for larger magnetic field gradients. This field could be useful in the study of dust physics in the lab or astrophysical plasmas confined by magnetic fields with converging field lines.

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