DISPERSION RELATION OF A NEW DUST ACOUSTIC MODE IN QUANTUM PLASMA IN PRESENCE OF DUST POLARIZATION FORCE

Physics

Dr. Monika Malik — Government College Kharkhara (Rewari) affiliated to Maharishi Dyanand University Rohtak-, Haryana (India)

ABSTRACT

In the present work , dispersion relation of new mode of Dust Acoustic (DA) wave has been derived by incorporating the quantum correction for all the three species viz electrons, ions and negatively charged dust particles. The effect of dust polarization on the dispersion relation has also been studied. For the purpose of analysis the quantum hydrodynamical model has been used. It is observed that with the inclusion of quantum correction term for all the species and the dust polarization force the dispersion relation of DA wave has significantly modified.

KEYWORDS:

INTRODUCTION

A dusty plasma is basically a three component plasma which contains electrons, ions and charged dust grains. Dust grains are billions times heavier than the protons and their size range from nanometre to millimetre. A plasma with dust particle will be termed as dusty plasma when dust particles takes part in collective behaviour. Condition to term plasma as dusty plasma in term of characteristics length viz dust grain radius r_d, the inter grain distance a, and plasma Debye radius (λ_D) is $r_d \ll a \ll \lambda_D$ [1]. The presence of charged dust grains does not only modify the exiting low-frequency waves but also introduce new types of low-frequency dust related waves such as dust acoustic wave (DAW), Dust ion acoustic wave (DIAW), DIA solitons/shocks and DA solitons /shocks and associated instabilities [2-5].

Recently a great deal of attention has been paid to quantum effects in dusty plasmas[6-12]. The important role of quantum mechanical effects in plasmas has been recognized in microelectronic devices, dense astrophysical systems, metallic nanostructures, and laser plasmas [11].

In present case dispersion relation of new dust acoustic mode proposed by Stenflo et al . [4] have been derived by considering quantum correction term for electrons , ions and dust particle in presence of dust polarization force.

BASIC EQUATION AND DISPERSION RELATION

Classical plasma is characterised by low density and high temperature whereas quantum plasmas have high density and/or low temperature. Quantum effect starts playing a significant role when de Broglie wavelength is comparable to or larger than inter-particle distance $n^{-1/3}$ i. e when

$$n \lambda^3 \gg 1$$

In such a situation, ultracold dusty plasma behaves like a Fermi gas and quantum mechanical effects are expected to play a central role in the behaviour of charged particles.

Assuming dynamics of plasma particles is governed by equation of state given by

$$p_j = \frac{m_j V_{FJ}^2}{3 n_{j0}^3} \quad {}^3 \quad n_j$$

where j equals e for electrons, i for ions, and d for dust grains, m_j is the mass, $V_{Fj} = \left(\frac{2 k_B T_{Fj}}{m_j} \right)^{1/2}$ is the Fermi speed, k_B is the Boltzmann constant, and T_{Fj} is the Fermi temperature. Furthermore, n_j is the number density with its equilibrium value n_{j0}.

Dust Acoustic mode arises due to the collective motion of (negatively) charged dust particles in the background of electron and ions in thermodynamic equlibirrium. In the present case, for the propagation of low frequency dust acoustic wave , one dimensional quantum hydrodynamic model has been taken. Further in the present analysis the quantum statistical and diffraction effect of all the three species have been taken in to account.

In the presence of electrostatic field E $=-\nabla \varphi$ (where φ is the electrostatic potential), the perturbed momentum equations for massless electron and ion in a quantum plasma are given by

$$0 = e \frac{\partial \varphi_1}{\partial x} - \frac{2 k_B T_{Fe}}{n_{e0}} \frac{\partial n_d}{\partial x} + \frac{{}^2}{4 m_e n_{e0}} \frac{\partial^3 n_{e1}}{\partial x^3} \tag{1}$$

$$0 = -e\frac{\partial \varphi}{\partial x} - \frac{2k_B T_{Fi}}{n_{i0}}\frac{\partial \eta_1}{\partial x} + \frac{{}^2}{4 m_i n_0}\frac{\partial^3 \eta_1}{\partial x^3} \qquad (2)$$

where e is the magnitude of the electron charge, φ is the DAW potential,   is the Planck constant divided by 2π, and n_{e1} and n_{i1} is a small electron and ion number density perturbation in its equilibrium value. The quantum corrections in the above equations appears through the Fermi temperatures and through the third terms in (1) and (2)

The dynamics of dust particles is governed by

$$\frac{\partial n_{d1}}{\partial t} + n_{d0}\frac{\partial \vartheta_d}{\partial x} = 0 \qquad (3)$$

$$m_d\left(\frac{\partial}{\partial t} + \nu\right)\vartheta = Z_d\,e\frac{\partial(1-\Gamma)\varphi}{\partial x} - \frac{2k_B T_{Fd}}{n_{d0}}\frac{\partial n_{d1}}{\partial x} + \frac{{}^2}{4 m_d n_{d0}}\frac{\partial^3 n_{d1}}{\partial x^3} \qquad (4)$$

Where ν is the dust collision frequency and Γ is the dust polarization interaction parameter.
The entire system of equation is then closed by Poisson equation

$$\nabla^2 \varphi = 4\pi\left(e n_{e1} + Z e n_{d1} - e n_{i1}\right) \qquad (5)$$

Assuming perturbed quantities and φ proportional to as $e^{j(kx-\omega t)}$, where k and ω are wave vector and frequency respectively, Eq (1)and Eq (2) gives perturbed electron and ion density as

$$n_{e1} = \frac{n_{e0}\,e\varphi}{2k_B T_{Fe}(1+\gamma_e)} \qquad (6)$$

$$n_{i1} = -\frac{n_{i0}\,e\varphi}{2k_B T_{Fi}(1+\gamma_i)} \qquad (7)$$

Where $\gamma_e = -\frac{{}^2 k^2}{8 m_e k_B T_{Fe}}$ and $\gamma_i = \frac{{}^2 k^2}{8 m_i k_B T_{Fi}}$

Combining Eq (3) and Eq (4)

$$\left[\omega(\omega + i\nu_d) - k^2 V_{Fd}^2(1+\gamma_d)\right]n_{d1} = -\frac{Z_d\, n_{d0}\, e k^2(1-\Gamma)\varphi}{m_d} \qquad (8)$$

Where $V_{Fd} = \left(\frac{2k_B T_{Fd}}{m_d}\right)^{1/2}$ and $\gamma_d = ({}^2 k^2)/(8 m_i k_B T_{Fi})$.

Inserting n_{ji} from (6)-(8),in Poisson we get

$$\omega(\omega + i\nu_d) - k^2 V_{Fd}^2(1+\gamma_d) = \frac{Z^2 e^2\, n_{d0}\, k^2(1-\Gamma)}{m_d\left(k^2 + \frac{4\pi e^2 n_0(1+\sigma)}{2k_B T_{Fi}(1+\gamma_i)}\right)} \qquad (9)$$

Where $\sigma = \frac{n_{e0} T_{Fi}(1+\gamma_i)}{n_{i0} T_{Fe}(1+\gamma_e)}$ and using $C_{Dq} = Z_d\left(2k_B T_{Fi} n_{d0}/m_d n_{i0}\right)^{1/2}$ solution of (9) can be written as

$$\omega = -\frac{i\nu_d}{2} \pm \left[-\frac{\nu_d^2}{4} + k^2 V_{Fd}^2(1+\gamma_d) + \frac{C_{Dq}^2 k^2\, (1-\Gamma)(1+\gamma_i)}{\left(k^2\frac{2k_B T_{Fi}(1+\gamma_i)}{4\pi e^2 n_0} + (1+\sigma)\right)}\right]^{1/2} \qquad (10)$$

For $\nu_d = 0$

$$\omega = \left(k^2 V_{Fd}^2 \left(1+\gamma_d\right) + \frac{C_{Dq}^2 k^2 \grave{o} \left(1-\Gamma\right)\left(1+\gamma_i\right)}{\left(k^2 \frac{2k_B T_{Fi}\left(1+\gamma_i\right)}{4\pi e^2 n_{i0}} + \left(1+\sigma\right) \right)} \right)^{1/2} \quad (11)$$

Also when $\Gamma = 0$ **$\Gamma = 0$** and instead of poission Equation Quasi-neutrality is considered , above solution will reduced to

$$\omega = k\left(V_{Fd}^2 \left(1+\gamma_d\right) + \frac{C_{Dq}^2 \grave{o} \left(1+\gamma_i\right)}{\left(1+\sigma\right)} \right)^{1/2} \quad (12)$$

CONCLUSION

To summarize, In this paper the dispersion relation for a new Dust Acoustic mode is obtained using Quantum hydrodynamic model for plasma. It is found that dust polarization force modify the dispersion properties of this new dust acoustic mode proposed in quantum plasma.

REFERENCES
[1] SHUKLA P. K and MAMUN A. A., Introduction to Dusty Plasma Physics Institute of Physics, Bristol, 2002.
[2] MERLINO R. L, HEINRICH J. R.,. HYUN S.-H, and MEYER J. K., Nonlinear dust acoustic waves and shocks, Physics of Plasmas 19 (2012) 057301.
[3] MERLINO R. L , 25 years of dust acoustic waves, J. Plasma Physics (2014) 1. doi:10.1017/S0022377814000312
[4] HAAS F., GARCIA L. G., GOEDERT J., and MANFREDI G, Phys. Plasmas 10 (2003) 3858.
[5] RAO N. N., SHUKLA P. K., and YU M. Y., Dust-Acoustic Waves in Dusty Plasma , Planet. Space Sci. 38 (1990) 543
[6] HOSSAIN M. M., HASAN M, ASADUZZAMAN M. and HAQUE M. M, Ion-Acoustic Higher Order Non-Linear Structures in Quantum Dusty Plasma, Journal of Modern Physics 4 (2013) 1530-1535.
[7] SHUKLA P. K and ALI S., Dust acoustic waves in quantum plasmas, Physics of Plasmas 12 (2005) 114502,
[8] STENFLO L., SHUKLA P. K., and MARKLUND M., New low frequency oscillations in quantum dusty plasmas, EPL 74 (2006) 844 .
[9] GHEBACHE S. and TRIBECHE M. Weakly Nonlinear Quantum Dust Ion-Acoustic Waves, Open Journal of Acoustics 3 (2013) 40-44. http://dx.doi.org/10.4236/oja.2013.32007
[10] MAHMOOD S. and MUSHTAQ A. Quantum ion acoustic solitary waves in electron–ion plasmas: A Sagdeev potential approach, Physics Letters A 372 (2008) 3467–3470.
[11] Xiu-Feng Y., Shan-Jin W., Jian-Min C.,.Yu-Ren S, MaiMai L., and Wen-Shan D., Effect of multicomponent dust grains in a cold quantum dusty plasma, Chin. Phys. B 21(5), (2012) 055202.
[12] SHARMA P. and JAIN S. , Effect of polarization force on low-frequency dust modes with quantum correction, EPL, 113 (2016) 65001. doi: 10.1209/0295-5075/113/65001