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Zakharov Kuznetsov equation for four component dust magnetoplasma using the multi-fluid concept

Zulfiqar Ahmad [a,b], A. Mushtaq [c,*], S. Neelam [b]

[a] Department of Physics, University of Peshawar, 25000 Peshawar, Pakistan
[b] Department of Physics, Abdul Wali Khan University Mardan, 23200, Pakistan
[c] Department of Physics, FBAS, International Islamic University (IIUI), Islamabad 44000, Pakistan

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Abstract

The present article aims to put forward a theoretical and numerical investigation of linear and nonlinear dust ion acoustic (DIA) waves in a four component magnetized dusty plasma by using the multi-fluid concept. In particular the dynamics of low amplitude DIA solitons is investigated via the Zakharov Kuznetsov type nonlinear evolution equation derived by employing the reductive perturbation technique. We consider two cases. The first one considers the existence and propagation of DIA waves in a four component dusty plasma when the ions are inertial while the dust particulates are assumed to be stationary, while in the second case the ions and both positively and negatively charged dust grains are assumed as inertial species. Electrons in both cases are considered to be isothermal. It is observed that both the positive and negative solitons are coexisted in the present plasma model. The characteristics of DIA solitons in both cases are investigated with effect of the both positive and negative dust concentrations, magnetic field and different temperature ratios. By using the small-k expansion method the soliton stability analysis is carried out for both cases. It appears timely to add that the theoretical results presented herein are supported by the numerical analysis and illustrations. The relevance of the study carried out to the laboratory and cosmic plasmas is also pointed out.

Keywords: Dust ion acoustic waves; Magnetized four component dusty plasma; Zakharov Kuznetsov equation; Laboratory and cosmic plasmas

1. Introduction

The presence of massive and charged dust grains in laboratory and space plasmas introduces new dimensions to collective linear and nonlinear plasma behaviors. The charged dust grain modifies the plasma properties in two ways. First, at static level it modifies the equilibrium quasi-neutrality condition, second produces new modes at kinetic level when dust is considered dynamically (Rao et al., 1990). In dusty plasmas when dust grains are assumed stationary, the dust ion-acoustic wave (DIAW) (Piel and Melzer, 2002; Shukla and Silin, 1992) and some new low frequency electromagnetic modes (Shukla, 1992; Birk et al., 1996) are found, while the inclusion of dust charge dynamics features in new eigen modes such as dust acoustic waves (DAWs) (Rao et al., 1990; Barkan et al., 1995) and dust lattice waves (DLWs) (Piel and Melzer, 2002; Melnadsø, 1996). The propagation of linear and nonlinear excitations in such plasmas have received a considerable interest due to some space observations (Shukla and Mamun, 2002; Goertz, 1989; Mendis and Rosenberg, 1994) as well as experimental confirmation (Merlino and Goree, 2004). The discovery of DAWs (Rao et al., 1990; Barkan et al., 1995), and DIAWs give a fresh impetus to the study of waves in dusty plasmas. The linear properties

* Corresponding author.
E-mail address: msherpao@gmail.com (A. Mushtaq).

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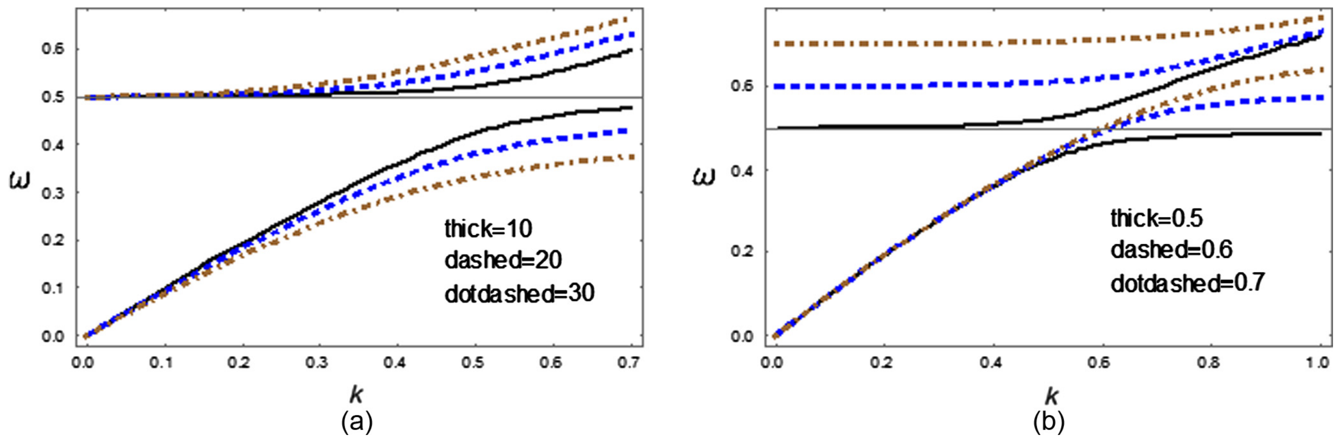

Fig. 1. The plot of dispersion relation based on Eq. (14) shows ω versus k for two modes using laboratory plasma for different values of obliqueness and magnetic field i.e. (a) $\theta = 10$ (thick curve), $\theta = 20$ (dashed curve) and $\theta = 30$ (dotted dashed curve) where $\Omega_{ci} = 0.5$, $N_{d+} = 0.01$, $N_{d-} = 0.48$, $U_0 = 0.4$, $l_x = 0.6$ (b) $\Omega_{ci} = 0.5$ (thick curve), $\Omega_{ci} = 0.6$ (dashed curve), $\Omega_{ci} = 0.7$ (dotted dashed curve) with $\theta = 10$, while other parameters are same as used in (a).

of DIAWs in dusty plasmas are vigorously investigated theoretically (Shukla and Mamun, 2002) as well as experimentally (Shukla and Mamun, 2002; Merlino and Goree, 2004; Barkan et al., 1996). However, there are innumerable dusty plasma situations where large amplitude waves are excited, hence nonlinear effects are no longer of less importance. These nonlinear effects result in the formation of localized field structures such as solitons, shocks and vortices. These nonlinear waves were first observed by Bliokh and Yaroshenko (1985) while studying the waves in Saturn's ring. During the last two decades several investigators (Rao et al., 1990; Barkan et al., 1995) have studied these nonlinear structures in dusty plasmas. In the last few years, numerous theoretical attempts have been made to study the basic features of DIA solitons (Shukla and Mamun, 2002). Mainly two approaches, reductive perturbation techniques (RPT) and Sagdeev pseudopotential approach (Sagdeev, 1966) are used to study the various aspects of nonlinear DIA solitary waves. Mostly, the reductive perturbation techniques are valid to explore the small but finite amplitude solitons (Mamun and Jahan, 2008) while arbitrary amplitude solitons (Verheest et al., 2005) are studied by employing the pseudopotential approach. The basic features of large amplitude ion acoustic (IA) solitons relevant to space and laboratory dusty plasmas have been studied by Bharuthram and Shukla (1992) by treating the dust in two different ways, once fixed in background and second fluid-like. All of these studies are based on a commonly used dusty plasma model that assumes electrons, ions, and negatively charged dust. The consideration of negatively charged dust is due to the fact that in low-temperature laboratory plasmas, collection of plasma particles (viz. electrons and ions) is the only important charging process, and the thermal speeds of electrons far exceed that of ions. But, there are some other more important charging processes by which dust grains become positively charged (Chow et al., 1993; Rosenberg and Mendis, 1995; Fortov et al., 1998; Rosenberg et al., 1999). The principal mechanisms by which dust grains become positively charged are photoemission in the presence of a flux of ultraviolet photons (Rosenberg and Mendis, 1995; Fortov et al., 1998), thermionic emission induced by radiative heating (Rosenberg et al., 1999), secondary emission of electrons from the surface of the dust grains (Chow et al., 1993), etc. The existence of positively charged dust particles have also been observed in different regions of space such as cometary tails (Mamun, 2008a; Mendis and Rosenberg, 1994), Jupiter's magnetosphere (Horanyi et al., 1993), the earth's polar mesosphere (Havnes et al., 2001) and in the Martian atmosphere (Shukla and Rosenberg, 2006).

There are direct evidences of the coexistence of positively and negatively charged dust in different regions of space, viz. Earth's mesosphere (Havnes et al., 1996), cometary tails (Horanyi, 1996; Ellis and Neff, 1991), Jupiter's magnetosphere (Horanyi et al., 1993; Horanyi, 1996), dense molecular clouds (Shukla et al., 2007), etc. Chow et al. (1993) have theoretically shown that due to the size effect on secondary emission, insulating dust grains with different sizes can have the opposite polarity, smaller ones being positive and larger ones being negative. The opposite situation, i.e. larger (massive) ones being positive and smaller (lighter) ones being negative, is also possible by triboelectric charging (Shukla and Rosenberg, 2006; Lacks and Levandovsky, 2007). It is shown by experiments using Mars dust analogous in Mars simulation wind tunnel that μ-sized dust can carry net charges of around 10^5e, and there could be almost equal quantities of positively and negatively charged dust in the suspension (Shukla and Rosenberg, 2006; Merrison et al., 2004). The coexistence of positively and negatively charged dust, with larger (massive) dust being positive and smaller (lighter) dust being negative (Zhao et al., 2002, 2003; Trigwell et al., 2003) or vise versa (Sharmene Ali et al., 1998) is also observed in laboratory devices (Zhao et al., 2002, 2003; Trigwell et al., 2003; Sharmene Ali et al., 1998), where dust of poly-