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ORIGINAL ARTICLE

On the characteristics of head on collision of dust ion acoustic solitons in the adiabatic dusty plasmas

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Abstract Based on a one-dimensional mode, the characteristics of the head on collision between two dust ion acoustic solitons (DIASs), propagating in opposite directions in adiabatic dusty plasmas composed of adiabatic non-inertial electrons, adiabatic inertial ions and immersed (negatively/positively) charged dust grains have been investigated. The extended Poincaré–Lighthill–Kuo (PLK) method has been used to obtain two side Korteweg-de Vries (KdV) equations for DIASs. The analytical phase shifts and trajectories after collision of two solitons are given. The effects of adiabaticity of electron and ion fluids, concentration of negatively/positively charged static dust particles and ion temperature to electron temperature ratio on the phase shift are studied. It is found that these factors significantly affect the phase shifts.

1. Introduction

Study of various types of nonlinear phenomena in dusty plasmas is one of the most important topics in the modern plasma physics researches because of their relevance in astrophysical and space environments such as comettails, planetary ring, asteroid zones, interstellar medium, lower part of Earth's ionosphere and magnetosphere radio frequency plasma discharge (Horányi and Mendis, 1985; Northrop, 1992; Mendis, and Rosenberg, 1994; Verheest, 2000; Shukla and Mamun, 2002). In dusty plasmas, due to the presence of a high density of dust grains, different types of collective processes exist and new wave modes can be exciting. One of these modes is the low-frequency dust ion acoustic waves (DIAWs), theoretically predicted by Shukla and Silin (1992) in an unmagnetized dusty plasma and then these waves have been observed in the laboratory experiments (Barkan et al., 1996). In most space and laboratory dusty plasma environments, dust grains, immersed in the plasma would be essentially charged by the capture of the more mobile electrons; hence, they become negatively charged (Shukla and Mamun, 2002). On the other hand, the existence of positively charged dust in different regions of space (Viz., upper part of ionosphere, lower part of magnetosphere, in the Earth's mesosphere and cometary tail etc. as well as laboratory environments) was also observed (Horányi et al., 1993; Rosenberg and Mendis, 1995; Rosenberg et al., 1999; Samarian et al., 2001). Generally, there are a number of principle mechanisms by which a dust grain becomes positively charged. These include secondary emission of electrons from the surface of the dust grains, photo electron emission by UV radiation, thermionic emission, field emission, impact ionization, etc., (Rosenberg and Mendis, 1995; Rosenberg et al.,

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1999). There is also direct evidence for the existence of both positively and negatively charged dust particles in space and laboratory plasmas (Zhao et al., 2002; Mamun, 2008a). It is expected that the presence of such negative (positive) dust grain can modify or introduce new features in the propagation of the dust associated waves, particularly, the electrostatic waves of Shukla and Silin (1992). Different plasma modes arise due to a delicate balance between nonlinearity and dispersion, which leads to the generation of solitons. Currently, in the process of soliton propagation in dusty plasmas interaction represents one of the most interesting and important nonlinear phenomenon in modern plasma researches. A soliton [which was first remarked by Zabusky and Kruskal (1965)] is usually defined as a type of solitary waves which maintains its identity after its colliding with another soliton of the same kind. In fact, the solitons and their interactions have received a special attention due to the realization of their occurrence in most of different dusty plasma models. In a one dimensional model, there are two different methods to soliton interactions. One is overtaking collision which is studied by inverse scattering transformation method (Gardner et al., 1967) and the other is a head-on collision of two solitons traveling in the opposite directions (i.e., the angle between two propagation directions of two solitons is π) (Su and Mirie, 1980). Generally, for the problem of the head-on collision between two solitons, it is necessary to use or employ a suitable asymptotic expansion to solve original fluid dynamic equations in order to give the interesting features of the trajectories of solitons after collision and the corresponding phase shift. Many authors investigated the head-on collision of two solitary waves in many plasma models (Han et al., 2008; El-Shamy et al., 2009; El-Labany et al., 2010; El-Shamy, 2010; Chatterjee, 2010; Chatterjee and Ghosh, 2011; Ghosh et al., 2012; El-Shamy and Awad, 2012; Ghorui et al., 2013) by using extended Poincaré–Lighthill–Kuo (PLK) method (Jeffrey and Kawahara, 1982). For example, Han et al. (2008) studied the combined effects of electron to positron temperature ratio and the ratio of the number density of positrons to that of electrons on the phase shifts during the head-on collision between two IASWs. They found out that the ratio of electron temperature to positron temperature, and the ratio of the number density of positrons to that of electrons have significant influence on the phase shift. El Shamy (2010) studied the head-on collisions of ion thermal solitary waves in pair-ion plasma containing positive ions, negative ions and stationary (positively/negatively) charged dust grains. They found out that the phase shift is significantly affected by the presence of the positive-to-negative ion temperature ratio and positively/negatively charged dust grains. Chatterjee et al. (2010) investigated the head-on collision of ion acoustic solitary waves in electron-positron-ion plasma with superthermal electrons and Maxwell distribution of positrons. Chatterjee and Ghosh (2011) studied the head-on collision of IASWs in electron-positron-ion plasma. They took the non-Maxell' distribution (superthermal) of both electrons and positrons. They illustrated that the ratio of electron temperature to positron temperature and the ratio of the number density of positrons to that of electrons had significant influence on the phase shift of the soliton. Ghosh et al. (2012) studied the head-on collision of IASWs in two component unmagnetized plasma with cold ions and nonextensive distributed electrons. They found that the presence of nonextensive distributed electrons played a significant role in the nature of collision of IASWs. Recently, Ghorui et al. (2013) investigated the head on collision between two DIASWs in magnetized quantum dusty plasma with positively/negatively charged dust grains. They observed that the phase shifts were significantly affected by the quantum diffraction parameter, the ion cyclotron frequency and the ratio of the densities of electrons to ions. Very recently, Khaled (2014) studied the head on collision between two IASWs in a weakly relativistic plasma containing nonextensive electrons and positrons. He found that the effects of the nonextensive parameter, positron-to-electron density ratio, ion-to-electron temperature ratio, electron-to-positron temperature ratio and relativistic factor had significant influence on the phase shift.

To the best of our knowledge, the head-on collision of two solitons in dusty plasma containing non-inertial adiabatic electron fluid, inertial adiabatic ion fluid and negatively/positively charged static dust particles have not yet been studied. Therefore, this paper aims to study the same topic mentioned above by using the extended PLK method. It also attempts to study the effects of the adiabaticity of electrons and ions, ion-to-electron temperature ratio and the concentration of negatively/positively charged dust particles on the characteristics of head-on collisions of solitons.

The manuscript is organized as follows. The governing equations of one-dimensional DIASs are shown in Section 2. In Section 3, the KdV equations are derived. Also the analytical phase shifts and trajectories from the original basic equations are obtained in Section 3. Results and discussion are given in Section 4. The conclusions are finally provided in Section 5.

2. Basic equations

We consider an unmagnetized adiabatic dusty plasma system composed of hot adiabatic inertial ion fluid, hot adiabatic non-inertial electrons fluid and stationary positively/negatively charged dust grains. Thus, at equilibrium, we have $n_{i0} = n_{e0} - \alpha Z_d n_{d0}$ where n_{i0} (n_{e0}), is the equilibrium number density of ions (electrons), n_{d0} is the number density of static dust grain and Z_d is the equilibrium number of charges residing on the dust grain surface. $\alpha = -1(1)$ for negative (positive) dust grains. Also, we consider the time scale of DIASs is much faster than the dust plasma period, so that the dust grains can be considered as stationary. Accordingly, the nonlinear dynamics of DIASs is described by (Mamun, 2008b).

$$\frac{\partial n_j}{\partial t} + \frac{\partial}{\partial x}(n_j u_j) = 0, \tag{1}$$

$$\frac{\partial u_i}{\partial t} + u_i \frac{\partial u_i}{\partial x} + \frac{\partial \varphi}{\partial x} + \frac{\sigma}{n_i}\frac{\partial p_i}{\partial x} = 0, \tag{2}$$

$$\frac{\partial p_j}{\partial t} + u_j \frac{\partial p_j}{\partial x} + \gamma p_j \frac{\partial u_j}{\partial x} = 0, \tag{3}$$

$$\frac{\partial p_e}{\partial x} = n_e \frac{\partial \varphi}{\partial x}, \tag{4}$$

$$\frac{\partial^2 \varphi}{\partial x^2} = (1 + \alpha\delta) n_e - n_i - \alpha\delta. \tag{5}$$

Here Eq. (1) represents the normalized continuity equation for particle species j (with $j = e$ for electron and $j = i$ for ion),