Streaming instability in negative ion plasma

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The streaming instability in an unmagnetized negative ion plasma has been studied by computational and theoretical methods. A one dimensional electrostatic Particle In Cell Simulation and fluid dynamical description of negative ion plasma showed that, if the positive ions are having a relative streaming velocity, four different wave modes corresponding to Langmuir wave, fast and slow ion waves and ion acoustic waves are produced. Below a critical wave number, instead of two distinct fast and slow ion waves, we observed a coupled wave mode. The value of the critical wave number is strongly determined by the ion streaming velocity. The thermal velocities of electrons and ions influence the growth rate of instability. *Published by AIP Publishing.*
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I. INTRODUCTION

Plasma systems which contain positive ions, negative ions, and electrons are considered as negative ion plasma. The presence of heavier negatively charged constituents and reduced number of electrons leads to peculiar wave natures and instabilities in negative ion plasma. Space and planetary[1] plasma environments such as earth's ionosphere,[2] cometary coma,[3] etc. are the examples for natural negative ion plasma systems.[4] Pair ion plasma is a special case of negative ion plasma and it is significant in recent plasma physics.[5,6] There have been many experimental and theoretical studies on the production and characteristics of negative ion plasma. Study of ion acoustic solitons and the wave breaking mechanism in negative warm ion plasma was carried out by Das and Tagare,[7] Das,[8] and Ludwig *et al.*[9] They observed a critical density ratio of negative and positive ions for the generation of solitary waves. A theoretical study of ion acoustic solitary waves in negative ion plasma with adiabatic positive and negative ion temperature and isothermal electrons was performed by Tagare based on the perturbation method.[10] The properties of ion acoustic solitons in warm plasma with non isothermal electrons were also studied by Tagare and Reddy.[11] Wong *et al.* carried out an experimental study of fast ion modes generated by the out of phase motion between positive and negative ions in a multi species plasma consisting of SF_6^-, Ar^+, and electrons.[12] Experimental and theoretical study of beam plasma instability in negative ion plasma containing SF_6^-, Ar^+, and a very small fraction of electrons was done by Intrator *et al.*[13] Song *et al.* investigated the propagation and damping characteristics of ion acoustic waves in the Q machine consisting of Ar^+, SF_6^-, and electron components.[14] The shock formation in collisional negative ion plasma for different cases of relative density was experimentally studied by Luo *et al.*[15] Another experimental study of shock formation in negative ion plasma was performed by Takeuchi *et al.*[16]

In the present work, we performed a one dimensional particle in cell simulation[17] of streaming instability in a negative ion plasma consisting of positive ions, negative ions, and electrons. In order to justify the simulation results, we numerically solved the dispersion relationship and observed identical characteristics. The positive and negative ions have equal and opposite charges, but different masses. The electron concentration is very much less than that of the negative ion concentration and satisfies the charge neutrality condition, $n_p = n_n + n_e$, where n_p, n_n, and n_e are the positive ion density, negative ion density, and electron density, respectively. The electrons and positive ions have a relative streaming velocity with respect to negative ions. The plasma was treated as unmagnetized and collisionless.

An outline of the simulation setup and observations are given in Sec. II and the theoretical model is given in Sec. III. Section IV contains the numerical solution of the dispersion relationship and Sec. V is the conclusion.

II. PARTICLE IN CELL SIMULATION (PIC) SIMULATION

One dimensional electrostatic PIC simulation was carried out by using the PIC code KEMPO1(Kyoto Electro Magnetic Pic cOde)[18] with periodic boundary conditions. The space and time were normalized to the Debye length (λ_D) and plasma time period (ω_{pe}^{-1})of electrons, respectively. The simulation domain was taken as $2048\lambda_D$ with grid length $1\lambda_D$. The total number of super particles corresponding to electrons, positive ions, and negative ions was 65 536, 262 144, and 196 608, respectively. The charge to mass ratios of the electrons, positive ions, and negative ions were -1, 0.01, and -0.001, respectively. In order to avoid the numerical instability and also our main objective was the qualitative understanding of the phenomena, the numerical values in the simulations were taken as little different from the real particle plasma system. The oscillation frequencies of electrons, positive ions, and negative ions were ω_{pe}, $0.24\omega_{pe}$, and $0.068993\omega_{pe}$, respectively. For the first run, the streaming velocities of electrons and positive ions were chosen as $10\lambda_D\omega_{pe}$ and $3\lambda_D\omega_{pe}$, respectively. The electron thermal velocity was $0.1\lambda_D\omega_{pe}$ and the positive ion thermal velocity

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