The Study of Acoustic waves in Semiconductor in Symmetric pair plasmas

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Abstract: - **The propagation of Acoustic waves is studied in semiconductor in symmetric pair plasma by derive the Korteweg-de Vries equation. In the present study we discuss the properties of collisionless Vlasov-Poisson model in fluid approximation in context of pair plasmas. Symmetric pair plasmas have different collective behavior than ordinary asymmetric electron-ion plasmas. . In this paper, we assume a thermodynamic unequilibrium of pair plasma when temperatures of species are not equal. It is proved that in symmetric pair plasma, but with not equal temperature of species acoustic mode may exist. In this paper , we consider the Symmetric pair plasmas, C^-_{60} and C^+_{60} plasmas having mass opposite charged fullerene is almost equal with two kind of electrons: cold and hot.**

Key Words — **Acoustic waves, Pair Plasmas, Semiconductor Plasma, Waves.**

I. INTRODUCTION

The pair plasmas have been an important challenge for many plasma physicists. The difference between the electron and ion masses in ordinary electron-ion plasma gives rise to different time-space scales [1] which are used to simplify the analysis of low- and high-frequency modes. Such time-space parity disappears when studying a pure pair plasma which consisting of only positive- and negative-charged particles with an equal mass, because the mobility of the particles in the electromagnetic fields is the same. Begelman et al. in 1984 and Miller & Witta in 1987 play an important role in the physics of electron-positron plasmas of a number of astrophysical situations [2, 3]. Sturrock in 1971 and Michel in 1991 suggested that the creation of electron-positron plasma in pulsars is essentially by energetic collisions between particles which are accelerated as a result of electric and magnetic fields in such systems [6, 7 and 8]. Oohara et al. in 2005 have experimentally examined the electrostatic modes are propagating along the magnetic-field lines in a fullerene pair plasma for excite effectively the collective modes [12, 13]. The successful achievements for creation of the electron-positron plasmas in laboratories have been frequently reported in the scientific literatures [17, 18 and 19].

Symmetric pair plasmas, C^-_{60} and C^+_{60} plasmas [14] having mass opposite charged fullerene is almost equal have a possibility to investigate the collective behavior of symmetric pair-ion plasma experimentally under controlled conditions. The effective masses of electrons and holes are equal then electron (e^-) - hole (e^+) plasmas [16] in pure semiconductors also are symmetric pair plasmas. In the astrophysics the Symmetric pair plasmas are the most interesting subject among scientists. In the numerical research, the main difficulty of electron-ion plasmas is the large difference between the two involved time scales. The large differences between the electron and ion masses typically give rise to different scales, in single and multiion plasmas. These differences are removed in case of Symmetric pair plasmas, in which the equal masses and opposite charges destroy the scales.

This paper explains the acoustic structure is lies when temperatures of species are not equal in Symmetric pair plasmas and the thermodynamic unequilibrium is assumed [11]. It means the plasma dynamics time scale is less than the ordinary collisional time scale. Acoustic structures are removed when temperatures of species are equal. Symmetric pair plasmas, C^-_{60} and C^+_{60} plasmas having mass opposite charged fullerene is almost equal have cold and hot electrons and acoustic mode in it. In this paper we study the properties of collisionless Vlasov-Poisson model in fluid approximation in context of pair plasmas [9, 10].

Symmetric pair plasmas have different collective behavior than ordinary asymmetric electron-ion plasmas. There are number of theoretical considerations gave the proof of acoustic structure such as stationary solitary electrostatic waves in symmetric unmagnitized pair plasmas [15]. There are number of proof which is based on the analysis of solutions of momentum and Poisson equation and continuity equations of species means that the thermodynamic equilibrium is assumed and temperature of species are equal. The lifetime of electron-positron pairs in the plasma is much longer than the characteristic time scales [20, 21 and 22].

II. MATHEMATICAL FORMULATION

Consider the situation in which the conditions is acoustic waves in a symmetric pair fullerene plasmas such as C^-_{60} and C^+_{60} with two kind of electrons system such as

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cold and hot in one-dimensional form is in fluid approximation is –

$$\frac{\partial N_1}{\partial t}+\frac{\partial}{\partial x}\left(N_1U_1\right)=0 \quad (1)$$

$$\frac{\partial U_1}{\partial t}+U_1\frac{\partial U_1}{\partial x}=\frac{\partial V}{\partial x} \quad (2)$$

$$\frac{\partial N_2}{\partial t}+\frac{\partial}{\partial x}\left(N_2U_2\right)=0 \quad (3)$$

$$\frac{\partial U_2}{\partial t}+U_2\frac{\partial U_2}{\partial x}=-\frac{\partial V}{\partial x} \quad (4)$$

$$\frac{\partial^2 V}{\partial x^2}=N_1-\left(1+a_1+a_2\right)N_2+a_1e^{\gamma V}+a_2e^{V} \quad (5)$$

Where, N_1 is the negative and N_2 is the positive fullerene number density normalized by its equilibrium value n_{10} and n_{20}, U_1 is the negative and U_2 is the positive fullerene fluid speed normalized by $c = (k_BT_2/m)^{1/2}$, V is the wave potential electrical field normalized by k_BT_2/e, m is the mass of the fullerene, e is the electronic charge, $\gamma = T_2/T_1$, T_1 is the temperature of hot and T_2 is the temperature of cold electrons, k_B is the Boltzmann constant, a_2 electrons cold and a_1 electrons hot number density normalized by n_{10}. Now, we derive the Korteweg-de Vries equation from (1)-(5) by employing the reductive perturbation technique and the stretched coordinates $\delta= \varepsilon^{1/2}$ (x-Mt) and $\Gamma = \varepsilon^{3/2}$ t, where ε is a smallness parameter measuring the weakness of the dispersion.

We can express (1) - (5) in terms of δ and ε as -

$$\varepsilon^{3/2}\frac{\partial N_1}{\partial \Gamma}-M\varepsilon^{1/2}\frac{\partial N_1}{\partial \delta}+\varepsilon^{1/2}\frac{\partial}{\partial \delta}\left(N_1U_1\right)=0 \quad (6)$$

$$\varepsilon^{3/2}\frac{\partial U_1}{\partial \Gamma}-M\varepsilon^{1/2}\frac{\partial U_1}{\partial \delta}+\varepsilon^{1/2}U_1\frac{\partial U_1}{\partial \delta}=\varepsilon^{1/2}\frac{\partial V}{\partial \delta} \quad (7)$$

$$\varepsilon^{3/2}\frac{\partial N_2}{\partial \Gamma}-M\varepsilon^{1/2}\frac{\partial N_2}{\partial \delta}+\varepsilon^{1/2}\frac{\partial}{\partial \delta}\left(N_2U_2\right)=0 \quad (8)$$

$$\varepsilon^{3/2}\frac{\partial U_2}{\partial \Gamma}-M\varepsilon^{1/2}\frac{\partial U_2}{\partial \delta}+\varepsilon^{1/2}U_2\frac{\partial U_2}{\partial \delta}=-\varepsilon^{1/2}\frac{\partial V}{\partial \delta} \quad (9)$$

$$\varepsilon\frac{\partial^2 V}{\partial \delta^2}=N_1-\left(1+a_1+a_2\right)N_2+a_1e^{\gamma V}+a_2e^{V} \quad (10)$$

We can expand the variables and N_1, U_1, N_2, U_2 and V in a power series of ε as -

$$N_1=1+\varepsilon N_1^{(1)}+\varepsilon^2N_1^{(2)}+.... \quad (11)$$

$$U_1=0+\varepsilon U_1^{(1)}+\varepsilon^2U_1^{(2)}+.... \quad (12)$$

$$N_2=1+\varepsilon N_2^{(1)}+\varepsilon^2N_2^{(2)}+.... \quad (13)$$

$$U_2=0+\varepsilon U_2^{(1)}+\varepsilon^2U_2^{(2)}+.... \quad (14)$$

$$V=0+\varepsilon V^{(1)}+\varepsilon^2V^{(2)}+.... \quad (15)$$

Electrons number density is treated as parameters.

Now, using (11)-(15) in (6) - (10) and taking the coefficient of $\varepsilon^{3/2}$ from (6)-(9) and ε from (10) we get -

$$N_1^{(1)}=U_1^{(1)}/M \quad (16)$$

$$U_1^{(1)}=-V^{(1)}/M \quad (17)$$

$$N_2^{(1)}=U_2^{(1)}/M \quad (18)$$

$$U_2^{(1)}=V^{(1)}/M \quad (19)$$

$$N_1^{(1)}-(a_1+a_2)N_2^{(1)}+a_1\gamma V^{(1)}+a_2V^{(2)}=0 \quad (20)$$

Now, using (16) - 20) we have -

$$N_1^{(1)}=-V^{(1)}/M^2 \quad (21)$$

$$N_2^{(2)}=V^{(1)}/M^2 \quad (22)$$

$$M^2=\frac{2+a_1+a_2}{\gamma a_1+a_2} \quad (23)$$

Equation (23) is the linear dispersion relation for acoustic waves propagating in our fullerene pair plasma model. Now substituting (11) - (15) into (6) - (10) and equating the coefficient of from (6) – (9) and from (10), we obtains -

$$\frac{\partial N_1^{(1)}}{\partial \Gamma} - \frac{\partial N_1^{(2)}}{\partial \delta} + \frac{\partial U_1^{(2)}}{\partial \delta} + \frac{\partial}{\partial \delta}\left[N_1^{(1)} U_1^{(1)}\right] = 0 \quad (24)$$

$$\frac{\partial U_1^{(1)}}{\partial \Gamma} - M \frac{\partial U_1^{(2)}}{\partial \delta} + U_1^{(1)} \frac{\partial U_1^{(1)}}{\partial \delta} = \frac{\partial V^{(2)}}{\partial \delta} \quad (25)$$

$$\frac{\partial N_2^{(1)}}{\partial \Gamma} - M \frac{\partial N_2^{(2)}}{\partial \delta} + \frac{\partial U_2^{(2)}}{\partial \delta} + \frac{\partial}{\partial \delta}\left[N_2^{(1)} U_2^{(1)}\right] = 0 \quad (26)$$

$$\frac{\partial U_2^{(1)}}{\partial \Gamma} - M \frac{\partial U_2^{(2)}}{\partial \delta} + U_2^{(1)} \frac{\partial U_2^{(1)}}{\partial \delta} = -\frac{\partial V^{(2)}}{\partial \delta} \quad (27)$$

$$\frac{\partial^2 V^{(1)}}{\partial \delta^2} = N_1^{(2)} - (1 + a_1 + a_2) N_2^{(2)} + a_1 \gamma V^{(2)} + \frac{1}{2} a_1 \gamma^2 \left[V^{(1)}\right]^2 + a_2 V^{(2)} - \frac{1}{2} a_2 \left[V^{(1)}\right]^2 \quad (28)$$

Now, using above equation and eliminating $N_1^{(2)}$, $N_2^{(2)}$, $U_1^{(2)}$, $U_2^{(2)}$ and $V^{(2)}$ we obtain -

$$\frac{\partial V^{(1)}}{\partial \Gamma} + A V^{(1)} \frac{\partial V^{(1)}}{\partial \delta} + B \frac{\partial^3 V^{(1)}}{\partial \delta^3} = 0 \quad (29)$$

Where the nonlinear coefficient *A* and the dispersion coefficient *B* are given by -

$$A = \frac{1}{2M[2 + a_1 + a_2]}\left[3(1 + a_1 + a_2) - 3 - M^4(\gamma^2 a_1 + a_2)\right] \quad (30)$$

$$B = \frac{M^3}{2(2 + a_1 + a_2)} \quad (31)$$

Equation (29) is the Korteweg-de Vries equation of the acoustic waves the nonlinear propagation in our fullerene pair plasmas with semiconductor. The solution of Korteweg-de Vries equation is found by transforming the independent variables δ and г to

$$K = \delta - C_0 \Gamma, \quad \Gamma = \Gamma \quad (32)$$

Where, C_0 is a constant velocity normalized by c.
The boundary condition is –

$$V^{(1)} \to 0, \frac{\partial V^{(1)}}{\partial K} \to 0, \frac{\partial^2 V^{(1)}}{\partial K^2} \to 0 at K \to \pm\infty$$

Therefore, the solution of the Korteweg-de Vries equation is –

$$V^{(1)} = V_m \sec h^2\left(\frac{K}{\Delta}\right) \quad (33)$$

Where V_m is the amplitude which is normalized by $k_B T_2/e$ and Δ is the width which is normalized by λ_D is given by –

$$\left.\begin{aligned} V_m &= \frac{3C_0}{A} \\ \Delta &= \sqrt{\frac{4B}{C_0}} \end{aligned}\right\} \quad (34)$$

III. Result And Discussion

The analysis of propagation acoustic waves in solid state plasma has been a very important research topic. Symmetric pair plasmas, consisting of two species with opposite charge and equal masses is an exciting field where not only unexpected phenomena have been experimentally identified, but also where new theoretic problems have been defined. Electron-hole plasmas in pure semiconductors also are symmetric pair plasmas if effective masses of electrons and holes are equal. Although pair plasmas consisting of electrons and positrons have been experimentally produced, however, because of fast annihilation and the formation of positronium atoms and also low densities in typical electron-positron experiments, the identification of collective modes in such ex-periments is practically very difficult.

In this paper, we consider acoustic waves in symmetric pair fullerene plasmas with two kinds of electrons: cold and hot. In the present study we discuss the properties of collisionless Vlasov-Poisson model in fluid approximation in context of pair plasmas. In this paper, we have studied the acoustic-like modes in Symmetric pair plasmas, C^-_{60} and C^+_{60} plasmas having mass opposite charged fullerene is almost equal have cold and hot electrons. The fullerenes are molecules containing 60 carbon atoms in a very regular geometric arrangement It is hoped that the present paper would be useful for explanation of the intriguing low and high frequency modes in pair plasma, which are out of the scope of the plasma fluid theory and the Boltzmann-Gibbs statistics. Equation (29) is the Korteweg-de Vries equation of the acoustic waves the nonlinear propagation in our fullerene pair plasmas with semiconductor is derived. The steady state solution of Korteweg-de Vries equation is obtained.

It is clear that from equation (34) as C_0 increases, the width of the solitary wave's decreases. If A> 0 then it is clear that from equations (30), (33) and (34) the solitary potential profile is positive, and if A<0 then solitary potential profile is negative. It is clear that from equations (30), (31), (33) and (34) a number density of electrons a_1 and a_2 decreases then width Δ increases and amplitude V_m increases which means soliton wave disappear. It means that acoustic waves are absent in a pure symmetric pair plasma and acoustic waves are present only when impurity of electrons are added. In this paper, we have found the nonlinear coefficient *A* and the dispersion coefficient *B*.

CONCLUSION

The present work deals with the analysis of propagation acoustic waves in solid state plasma. The analysis enables one to draw the following conclusions.

1. a pure symmetric pair plasma the acoustic structures are absent.
2. Equation (29) is the Korteweg-de Vries describing the nonlinear propagation of the acoustic waves in our fullerene pair plasmas with electron impurities.
3. The dynamics of the acoustic waves in fullerene pair plasmas with two population of electrons system in one-dimensional form is in fluid approximation.
4. In symmetric pair plasmas, where both species have the same temperature, acoustic mode are impossible, but in that plasmas exists nonlinear amplitude modulation of electrostatic mode. These mode mixed higher harmonics with basic waves and can gives envelope solitons. It is not a pure acoustic mode according to above remarks.

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