

A New Model To Study The Effect Of Magnetodiffusivity In The Growth Rate Of Magnetosonic Waves In A Two Dimensional Spin-1/2 Quantum Plasma

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Abstract. Starting from the governing equations for a spin half quantum plasma, we derive a basic plasma model in two-dimensional case. We studied the model in presence of magnetic diffusivity. Linear dispersion relation for the system is carried out analytically, and the results are plotted numerically for several values of the plasma parameters. Analytically we solve the cubic equation in terms of frequency and wave vector. It is found that the different plasma parameters play an important role in the plasma dynamics.

Keywords: Spin-1/2 quantum plasma, Magnetodiffusivity, Magnetosonic waves, Growth rate of linear waves.

I. INTRODUCTION

Plasma, in their full generality, constitutes a highly complex class of physical systems. Quantum effects in plasma become important when the Fermi energy of the plasma species exceeds its thermal energy. Quantum plasma has drawn significant attention because of their applications [1-4] in various fields such as technological applications, experimental progress and it also has possible astrophysical applications [5, 6-9]. From the non-relativistic domain, with its basic description in terms of the Schrodinger equation, to the strongly relativistic regime, with its natural connection to quantum field theory, quantum plasma physics provides promises of highly interesting and important applications. It also provides a link among different areas of science and possesses difficult challenges from computational perspective. The necessity for thorough understanding such plasmas arises because following reductive principle of research; one can successively build more complex models based on previous results. The simplest lower order effect due to relativistic quantum mechanics needs the introduction of spin, and as such thus provides a first step towards a partial description of quantum plasmas.

The important step of including spin in quantum plasmas was taken rather recently [6-9]. Spin plasma physics was developed from the Pauli Hamiltonian formulation and generalization of the Madelung decomposition for the two-component spinor wave function. However, in strong magnetic fields, single electron effects that depend on electron spin properties, such as Landau quantization will be important. Collective spin effect can influence the wave propagation in strongly magnetized quantum plasma [5, 10-12].

The electron/positron $-1/2$ -spin effect occurs due to random orientation of the plasma particles in a non-uniform magnetic field. In thermodynamic equilibrium, some of the electron spins tend to align with an external magnetic field. Subsequently, there emerges a plasma magnetization in the direction of this field. When the variation of the magnetic field occurs on a time scale shorter than the characteristic spin-relaxation time, the degree of spin alignment can be approximated as constant. Spontaneous spin changes do not occur for single electron (owing to angular momentum conservation) and as a result spin relaxation time [13] is also larger than the inverse electron-collision frequency. The electron spin modifies the plasma current density and introduces a magnetic moment-force on the electrons. Accounting for this anomalous magnetic moment, characterized by the electron-spin g -factor ($g \approx 2.002319$), Brodin et al. [14] have developed a spin force modified kinetic theory for magnetized plasma with immobile ions. A new high frequency ordinary mode appears which is polarized parallel to the external magnetic field direction.

Of late, there have been several approaches to treat collective interactions [15, 16] in dense quantum plasmas. The quantum hydrodynamical model is such an example. Here this model includes a number of forces acting on the electrons. The Fermi pressure arises because of high density, the quantum force due to collective electron tunneling is expressed the so-called Bohm potential and finally we have to take into account the electrostatic force. The net effect of these forces is that the electrons oscillate around the heavy ions what is called electron plasma oscillations. The model of Brodin et al. extends these ideas by introducing the effect of the anomalous electron spin. Brodin et al stress that their model is only valid in the weak quantum regime where the characteristic length scale is larger than the thermal de-Broglie wavelength and the Zeeman energy density is much smaller than the electron thermal energy density.

It has been shown that the collective spin $1/2$ effect significantly modifies the dynamics [17]. Recently Li et al. [18] studied the Magnetosonic wave's interactions in spin $1/2$ degenerate quantum plasma. Chatterjee et al. [19] studied the phase shifts of magneto acoustic solitons in spin $1/2$ fermionic quantum plasma during head-on collision. Sahu et al. [20] numerically studied the nonlinear propagation of arbitrary amplitude Magnetosonic solitary and shock structures in spin- $1/2$ quantum plasma. Misra [21] studied the spin Magnetosonic shock-like waves in quantum plasmas. Sahu et al. [22] studied the small and arbitrary shock structures in spin $1/2$ magnetohydrodynamic quantum plasma.

However, many basic problems of the Magnetosonic wave behaviors are still the subject of intense experimental and theoretical interest now-a-days. The Magnetosonic wave behavior in spin- $1/2$ quantum plasma is still unclear and leaves scope for further studies. And also to the best of our knowledge there is no work related to the two-dimensional spin- $1/2$ quantum plasma model. Therefore, the main reason for carrying out the present work is to investigate a suitable theoretical model for studying the quantum effects as well as spin effects in plasma in two dimensions.

While studying the Magnetosonic solitons in fermionic quantum plasma, Marklund and Eliason derived a Sagdeev potential for the one-dimensional system [19]. However, they did not extend it to the two-dimensional case.

The plan of this paper is as follows: we derive a basic plasma model in two-dimension case in section II and investigate the linear waves in section III. Section IV is kept for results and discussions. Section V is kept for conclusions. Our basic aim is to see the cumulative effects of the quantum term, magnetic diffusivity parameter and normalized Zeeman energy on dispersion relation. We shall also study the growth rate of linear waves.

II. NONLINEAR GOVERNING EQUATIONS

We start with the governing equations for a quantum magnetoplasma, where spin-1/2 effects are included. We define the total mass density $\rho \equiv (m_e n_e + m_i n_i)$, the centre-of-mass fluid velocity $\vec{V} = \frac{(m_e n_e v_e + m_i n_i v_i)}{\rho}$ and the current density $\vec{j} = (en_e v_e + en_i v_i)$. Here m_e (m_i) is the electron (ion) mass, (n_i) n_e is the electron (ion) number density, v_e (v_i) is the electron (ion) fluid velocity, and e is the magnitude of the electric charge. The general set of spin-fluid equations can be written as follows

$$\frac{\partial \rho}{\partial t} + \vec{\nabla} \cdot (\rho \vec{v}) = 0, \quad (1)$$

$$\rho \left(\frac{\partial}{\partial t} + \vec{v} \cdot \vec{\nabla} \right) \vec{v} = \vec{j} \times \vec{B} - \vec{\nabla} p + \vec{F}_Q, \quad (2)$$

where p is the scalar pressure in the centre-of-mass frame, current density $\vec{j} = \frac{1}{\mu_0} \vec{\nabla} (\vec{B} - \mu_0 \vec{M})$, \vec{M} is the plasma magnetization due to electron spin given by $\vec{M} = \frac{\mu_B \rho}{m_i} \tanh\left(\frac{\mu_B B}{K_B T_e}\right) \hat{B}$, where $\mu_B = \frac{e\hbar}{2m_e}$ is the Bohr Magneton, \hbar is the Planck constant and \vec{F}_Q is the quantum force due to collective tunneling and spin alignment, being represented by,

$$\vec{F} = \frac{\hbar^2 \rho}{2m_e m_i} \vec{\nabla} \left(\frac{1}{\sqrt{\rho}} \nabla^2 \sqrt{\rho} \right) + \frac{\mu_B \rho}{m_i} \tanh\left(\frac{\mu_B B}{K_B T_e}\right) \vec{\nabla} B \quad (3)$$

Where K_B as the Boltzmann constant and T_e as the electron temperature. The generalized Faraday law is given by,

$$\frac{\partial \vec{B}}{\partial t} = \vec{\nabla} \times [\vec{v} \times \vec{B} - \frac{[\vec{v} \times (\vec{B} - \mu_0 \vec{M})] \times \vec{B}}{e\eta\mu_0} - \eta \vec{j} - \frac{m_e}{e^2 \mu_0} \left[\frac{\partial}{\partial t} - \left(\frac{\vec{\nabla} \times \vec{B}}{e\mu_0 n_e} \right) \cdot \vec{\nabla} \right] \frac{\vec{\nabla} \times \vec{B}}{\eta_e} - \frac{\vec{F}_Q}{e\eta_e}], \quad (4)$$

where η is the plasma resistivity. Here we assume that the magnetic field is along the z direction i.e. $\vec{B} = B(x, y, t) \hat{z}$ and the velocity $\vec{V} = (\hat{i}v_x + \hat{j}v_y)$ and the density $\rho = \rho(x, y, t)$. We assume the quasineutrality condition i.e. $n_e = n_i$.

Using the above assumptions, the governing equations reduce to, the continuity equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho v_x)}{\partial x} + \frac{\partial(\rho v_y)}{\partial y} = 0, \quad (5)$$

the momentum equations

$$\left(\frac{\partial v_x}{\partial t} + v_x \frac{\partial v_x}{\partial x} + v_y \frac{\partial v_x}{\partial y} \right) = -\frac{B}{\mu_0 \rho} \frac{\partial B}{\partial x} - c_s^2 \frac{\partial \ln \rho}{\partial x} + 2c^2 \lambda_c^2 \frac{m_e}{m_i} \frac{\partial}{\partial x} \frac{1}{\sqrt{\rho}} \left(\frac{\partial^2 \sqrt{\rho}}{\partial x^2} + \frac{\partial^2 \sqrt{\rho}}{\partial y^2} \right) + \frac{\mu_B}{m_i \rho} \frac{\partial}{\partial x} \left[\rho \frac{B \tan h(\mu_B B)}{k_B T_e} \right], \quad (5a)$$

$$\left(\frac{\partial v_y}{\partial t} + v_x \frac{\partial v_y}{\partial x} + v_y \frac{\partial v_y}{\partial y} \right) = -\frac{B}{\mu_0 \rho} \frac{\partial B}{\partial y} - c_s^2 \frac{\partial \ln \rho}{\partial y} + 2c^2 \lambda_c^2 \frac{m_e}{m_i} \frac{\partial}{\partial y} \frac{1}{\sqrt{\rho}} \left(\frac{\partial^2 \sqrt{\rho}}{\partial x^2} + \frac{\partial^2 \sqrt{\rho}}{\partial y^2} \right) + \frac{\mu_B}{m_i \rho} \frac{\partial}{\partial y} \left[\rho \frac{B \tan h(\mu_B B)}{k_B T_e} \right], \quad (5b)$$

and the generalized Faraday equation:

$$\frac{\partial B}{\partial t} + \frac{\partial(v_x B)}{\partial x} + \frac{\partial(v_y B)}{\partial y} - \frac{\eta}{\mu_0} \left(\frac{\partial^2 B}{\partial x^2} + \frac{\partial^2 B}{\partial y^2} \right) = 0. \quad (6)$$

Here $\lambda_c = \frac{c}{w_c} = \frac{\hbar}{2m_e}$ is the Compton wavelength, c is the velocity of light, \hbar is the Planck constant and w_c is the Compton frequency, $c_s = \left[\frac{K_B(T_e + T_i)}{m_i} \right]^{\frac{1}{2}}$ is the sound speed, $\frac{\eta}{\mu_0}$ is the magnetic diffusivity. The last terms in equation (5a) and (5b) are the spin forces divided by m_i , we have neglected the inertial term in the Faraday law (6). After normalization, we get the normalized equation as,

the continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho v_x)}{\partial x} + \frac{\partial(\rho v_y)}{\partial y} = 0, \quad (7)$$

the momentum equations:

$$\left(\frac{\partial v_x}{\partial t} + v_x \frac{\partial v_x}{\partial x} + v_y \frac{\partial v_x}{\partial y}\right) = -\frac{B}{\rho} \frac{\partial B}{\partial x} - c_s^2 \frac{\partial \ln \rho}{\partial x} + \beta \frac{\partial}{\partial x} \frac{1}{\sqrt{\rho}} \left(\frac{\partial^2 \sqrt{\rho}}{\partial x^2} + \frac{\partial^2 \sqrt{\rho}}{\partial y^2}\right) + \frac{\mu}{V_B^2 \rho} \frac{\partial}{\partial x} [\rho B \tan h(\mu B)], \quad (8)$$

$$\left(\frac{\partial v_y}{\partial t} + v_x \frac{\partial v_y}{\partial x} + v_y \frac{\partial v_y}{\partial y}\right) = -\frac{B}{\rho} \frac{\partial B}{\partial y} - c_s^2 \frac{\partial \ln \rho}{\partial y} + \beta \frac{\partial}{\partial y} \frac{1}{\sqrt{\rho}} \left(\frac{\partial^2 \sqrt{\rho}}{\partial x^2} + \frac{\partial^2 \sqrt{\rho}}{\partial y^2}\right) + \frac{\mu}{V_B^2 \rho} \frac{\partial}{\partial y} [\rho B \tan h(\mu B)], \quad (9)$$

and the generalized Faraday equation:

$$\frac{\partial B}{\partial t} + \frac{\partial(v_x B)}{\partial x} + \frac{\partial(v_y B)}{\partial y} - \lambda \left(\frac{\partial^2 B}{\partial x^2} + \frac{\partial^2 B}{\partial y^2}\right) = 0. \quad (10)$$

Here \vec{B} is the magnetic field along the z axis, i.e. $\vec{B} = B(x, y, z)\hat{z}$, normalized to its equilibrium value B_0 ; $\rho \equiv \rho(x, y, z)$ is the total mass density normalized to its equilibrium value ρ_0 ; and $\vec{V} = \hat{i}v_x + \hat{j}v_y$ is the centre of mass fluid velocity normalized to the Alfvén speed $C_A^2 = B_0^2 / \mu_0 \rho_0$. The space and time variables are normalized by, respectively, $\frac{C_A}{w_{ci}}$ and ion gyroperiod w_{ci}^{-1} , where $w_{ci} = \left(\frac{eB_0}{m_i}\right)$. Also, $\beta = 2c^2 \lambda_c^2 \left(\frac{m_e}{m_i}\right) \frac{w_{ci}^2}{C_A^4}$ where λ_c is the Compton wavelength and w_c is the Compton frequency. C_s is the sound speed normalized to C_A . More over $V_B^2 = \frac{m_i C_A^2}{K_B T_e} = [m_i C_A^2 / (\frac{1}{\mu}) \mu_B B_0]$ with $\mu_B = e\hbar/2m_e$ is the Bohr magneton, K_B is the Boltzman constant, T_e is the electron temperature and $\mu = \mu_B B_0 / K_B T_e$ is the normalized Zeeman energy. Furthermore, $\lambda = \frac{\eta}{\mu_0} [w_{ci} / C_A^2]$ is the non-dimensional dissipative parameter and η is the plasma resistivity.

III. LINEAR ANALYSIS

To derive the dispersion relation for the plasma waves in the presence of diffusivity term λ , we assume that ρ, v_x, v_y, B each have a constant part to added to a small oscillation part i.e.

$$\rho = (1 + \bar{\rho}) \quad (11)$$

$$v_x = \bar{v}_x, \quad (12)$$

$$v_y = \bar{v}_y, \quad (13)$$

$$B = (1 + \bar{B}). \quad (14)$$

Now the oscillations are assumed to be harmonic and the oscillating parts are proportional to $e^{i(k_x x + k_y y - wt)}$. Here k_x , k_y and w are the perpendicular components of wave vector and wave frequency, respectively.

Then after some straight forward algebraic steps, we obtain the following cubic equation in w :

$$w^3 + P_1 w^2 + P_2 w + P_3 = 0, \quad (15)$$

Here $P_1 = i\lambda k^2$, $P_2 = k^2 \left(-c_s^2 - 1 + \frac{\mu}{v_B^2} \cdot 2 \tanh \mu + \frac{\mu^2}{v_B^2} \cdot \text{sech}^2 \mu \right) - \frac{\beta}{2} k^4$, and

$P_3 = \lambda k^4 \left(c_s^2 - \frac{\beta}{2} k^2 + \frac{\mu}{v_B^2} \cdot \tanh \mu \right)$. If we consider one dimensional case i.e. $k_x = k$, and $k_y = 0$ then equation (15) will be same as equation (6) of Ref. [22], provided one consider $\vec{M} = [\mu_B \rho / m_i] \left(\frac{\mu_B \rho}{K_B T_e} \right) \hat{B}$.

Now in absence of magnetic diffusivity term i.e. $\lambda = 0$ then $P_1 = P_3 = 0$, and we get the dispersion relation as,

$$w^2 = P_2, \quad (16)$$

$$w^2 = k^2 \left[1 + c_s^2 - \frac{\mu}{v_B^2} \cdot 2 \tanh \mu + \frac{\mu^2}{v_B^2} \text{sech}^2 \mu + \frac{\beta}{2} k^2 \right]. \quad (17)$$

So in absence of λ the dispersion relation containing purely real coefficients. But the presence of magnetic diffusivity λ , the basic character of wave frequency becomes complex i.e.

$w = (w_R + iw_I)$. In the subsequent analysis, we get the following relationship,

$$w_R^2 = 3w_I^2 + 2w_I p_1 - P_2, \quad (18)$$

$$8w_I^3 + 8w_I^2 p_1 + 2(p_1^2 - P_2)w_I + (p_3 - P_2 p_1) = 0, \quad (19)$$

where $p_1 = \lambda k^2$, $p_3 = \lambda k^4 \left(-c_s^2 - \frac{\beta}{2} k^2 + \frac{\mu}{v_B^2} \cdot \tanh \mu \right)$. Now to solve the equation (19) we apply the Cardan's method. Now equation (19) reduces to

$$aw_I^3 + 3bw_I^2 + 3cw_I + d = 0, \quad (20)$$

where $a = 8$, $b = 8p_1/3$, $c = 2[(p_1^2 - P_2)/3]$, and $d = (p_3 - P_2 p_1)$.

Let $Z = a(w_I + b)$. Then equation (20) reduces to

$$Z^3 + 3HZ + G = 0, \quad (21)$$

where $H = (ac - b^2)$ and $G = (a^2d - 3abc + 2b^3)$.

Now to solve the equation (21), let us assume that

$$Z = (u + v). \quad (22)$$

Then

$$Z^3 - 3uvZ - (u^3 + v^3) = 0. \quad (23)$$

Now comparing equations (21) and (23) we get $uv = -H$ and $(u^3 + v^3) = -G$.

Then $u^3 = \frac{1}{2} [-G + \sqrt{G^2 + 4H^3}]$ and $v^3 = \frac{1}{2} [-G - \sqrt{G^2 + 4H^3}]$.

When the value of $(G^2 + 4H^3) > 0$ then equation (23) has one real root and the root is given

by $Z = \left(p - \frac{H}{p}\right)$, where $p = \left(\frac{1}{2}[-G + \sqrt{G^2 + 4H^3}]\right)^{\frac{1}{3}}$.

The real root of equation (20) is given by

$$w_I = \frac{1}{a} \left[\left(p - \frac{H}{p}\right) - b \right].$$

Correspondingly we get w_R from this equation

$$w_R = \sqrt{(3w_I^2 + 2w_I p_I - P_2)} \quad (24)$$

IV. RESULTS AND DISCUSSIONS

In this manuscript, we carried out a basic plasma model in two dimensional spin1/2 quantum plasma case. We assume that the magnetic field is along the z direction i.e. $\vec{B} = B(x, y, t)\hat{z}$ and the velocity $\vec{V} = (\hat{i}v_x + \hat{j}v_y)$ and the density $\rho = \rho(x, y, t)$. We also assume the quasi neutrality condition. Putting the above assumptions in equations (1), (2) and (4). Then we get a standard mathematical model [i.e. eqns. (7) to (10)] and investigate the linear waves. We used

the basic equations to derive the linear dispersion relation. We noticed that the presence of magnetic diffusivity parameter λ is fully responsible for the plasma wave frequency turning complex i.e. $w = (w_R + iw_I)$. For this reason, λ play the role of dissipation. Then after some straight forward algebra we get the following equation (18) and (19). Equation (19) is a cubic equation. So we apply Cardan's method to get the root of the equation (19). Now $(G^2 + 4H^3) > 0$ condition implies that equation (19) has only one real root. Then we get the real root of equation (20) and correspondingly get w_I and w_R . The different plasma parameters affect the linear dispersion relation in various ways. The real and imaginary parts of the plasma frequency w_R and w_I are plotted against the wave vector k for different values of plasma parameters.

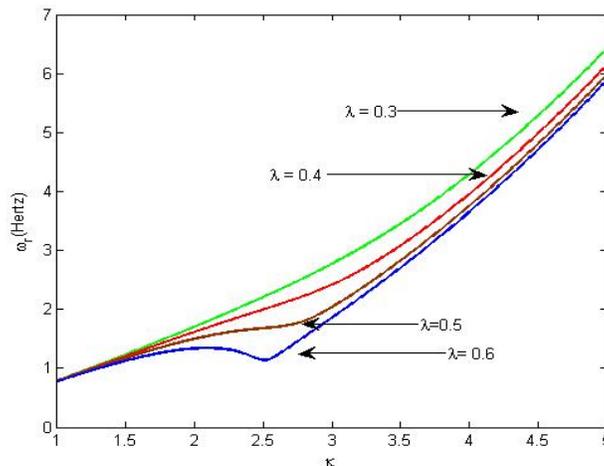


FIGURE 1. Plot against real part of w vs. wave vector k for the different data set $\beta=0.12, c_s=0.1, \mu=0.5, V_B=1$ and $\lambda = 0.3, 0.4, 0.5, 0.6$.

To draw the figure 1 i.e. w_R vs k , we consider $\beta = 0.12, c_s = 0.1, \mu = 0.5, V_B = 1$ and $\lambda = 0.3, 0.4, 0.5, 0.6$. We noticed that rate of increase of w_R with respect to k decreases with increase of the value of λ .

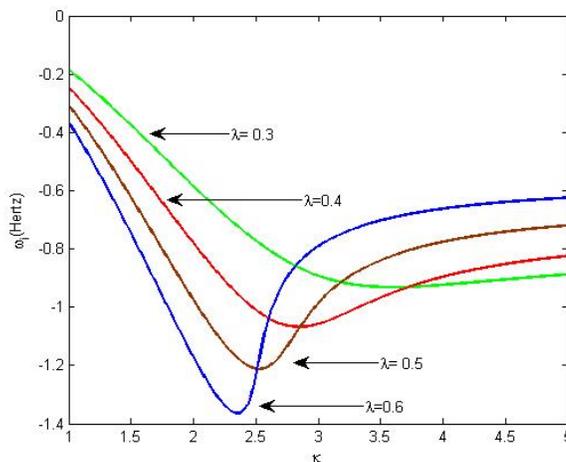


FIGURE 2. Plot against imaginary part of w vs. wave vector k for the different data set $\beta=0.12, c_s=0.1, \mu=0.5, V_B=1$ and $\lambda = 0.3, 0.4, 0.5, 0.6$.

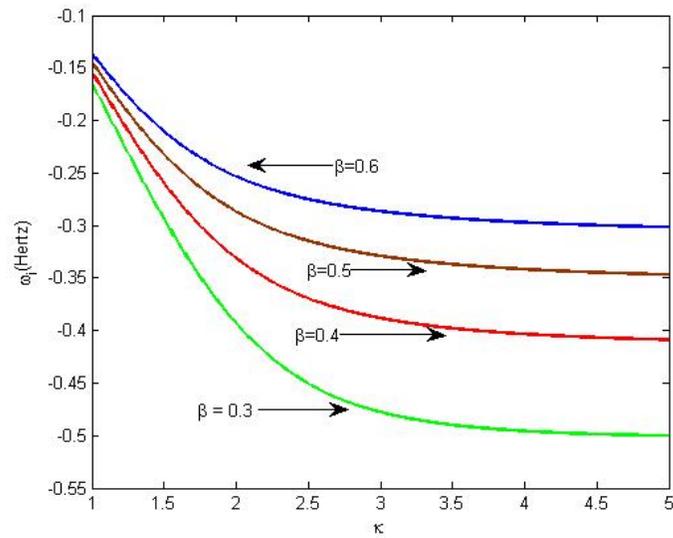


FIGURE 3. Plot against imaginary part of w vs wave vector k for the different data set $\lambda = 0.3, c_s = 0.1, \mu = 0.5, V_B = 1$ and $\beta = 0.3, 0.4, 0.5, 0.6$.

In figure 2, we plotted the imaginary part of frequency against k keeping other parameters same. It is seen that the magnitude of first increases with increase of the value of λ . The value of w_I increases then decreases with k and finally attaining a constant value. So, magnetic diffusivity plays a crucial role. To draw figure 3, we took $\lambda = 0.3, c_s = 0.1, \mu = 0.5, V_B = 1$ and $\beta = 0.3, 0.4, 0.5, 0.6$ respectively. Figure 3 represents the variation of imaginary part of w with respect to k for different values of β . The quantum parameter β has significant effects. When we consider the imaginary part, dissipation increases for lower values of β .

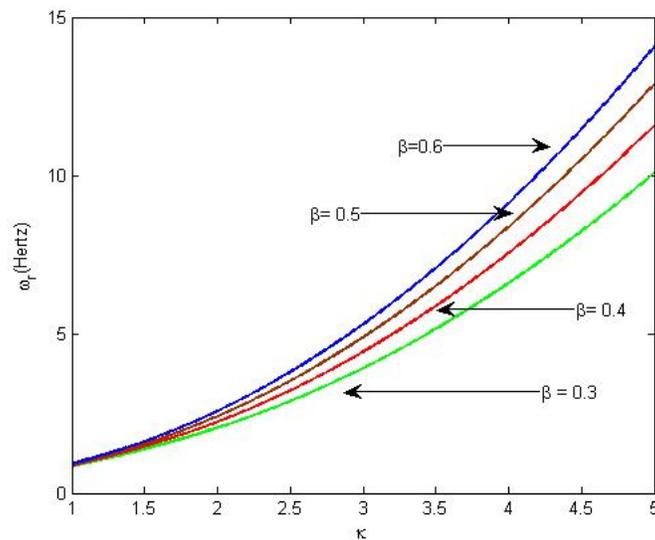


FIGURE 4. Plot against real part of w vs. wave vector k for the different data set $\lambda = 0.3, c_s = 0.1, \mu = 0.5, V_B = 1$ and $\beta = 0.3, 0.4, 0.5, 0.6$.

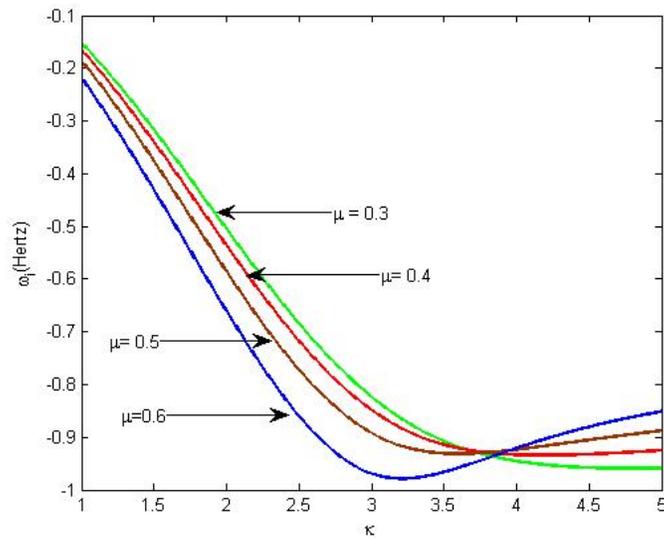


FIGURE 5. Plot against imaginary part of w vs. wave vector k for the different data set set $\lambda=0.3$, $c_s=0.1$, $\beta=0.12$, $V_B=1$ and $\mu=0.3, 0.4, 0.5, 0.6$.

In figure 4 we use the same values of the parameters as in Figure 3 and noticed that quantum parameter has the reverse effect on w_R compared to w_I , the rate of increase of w_R with respect to k slows down. In figure 5 we have plotted against w_I vs k with varying c_s . We used the data $\lambda = 0.3$, $\beta = 0.12$, $\mu = 0.5$, $V_B = 1$ and $c_s = 0.3, 0.4, 0.5, 0.6$ respectively. We noticed that imaginary part of frequency i.e. dissipation increases for lower values of c_s .

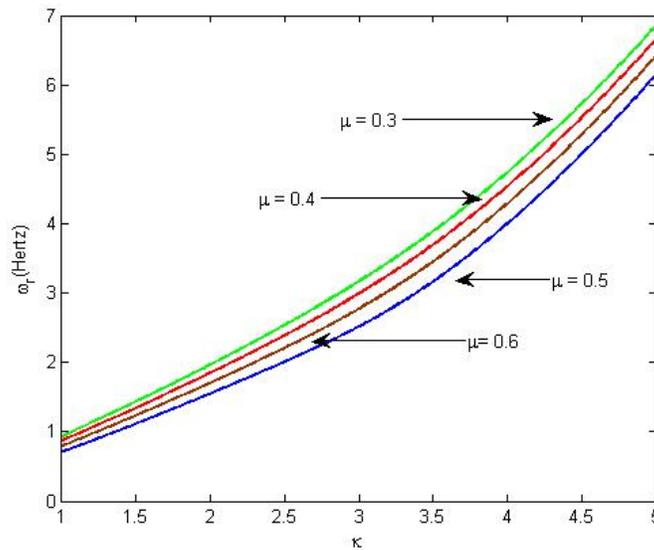


FIGURE 6. Plot against real part of w vs. wave vector k for the different data set $\lambda = 0.3$, $c_s = 0.1$, $\beta = 0.12$, $V_B = 1$ and $\mu = 0.3, 0.4, 0.5, 0.6$.

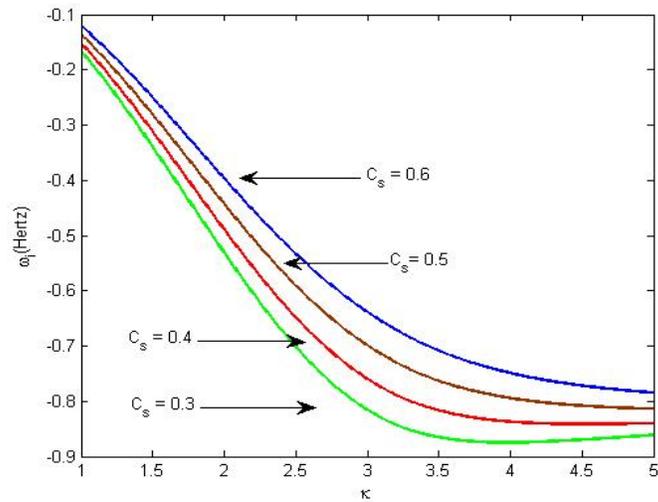


FIGURE 7. Plot against imaginary part of w vs wave vector k for the different data set $\lambda = 0.3, \mu = 0.1, \beta = 0.12, V_B = 1$ and $c_s = 0.3, 0.4, 0.5, 0.6$.

Figure 6 represents the variation of real part of w against k . We took data $\lambda = 0.3, c_s = 0.1, \beta = 0.5, V_B = 1$ and $\mu = 0.3, 0.4, 0.5, 0.6$. We noticed that the rate of increase of w_R is more or less unchanged with respect to k . In figure 7 we plot w_I vs k , taking $\lambda = 0.3, \beta = 0.12, V_B = 1, \mu = 0.1$ and $c_s = 0.3, 0.4, 0.5, 0.6$ respectively. When c_s increases, the magnitude of w_I increases slowly with respect to k . And in figure 8 we plot the real part of w_R vs k for the same values of the parameters as in Fig 7. Here we noticed that the rate of change of w_R with respect to k decreases with μ .

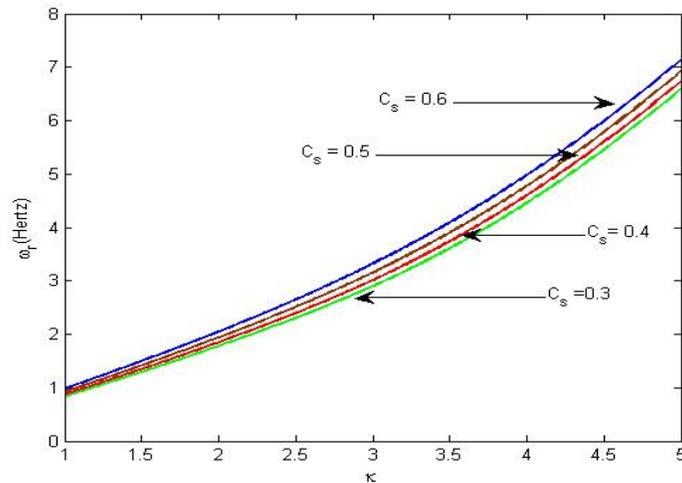


FIGURE 8. Plot against real part of w vs. wave vector k for the different data set $\lambda = 0.3, \mu = 0.1, \beta = 0.12, V_B = 1$ and $c_s = 0.3, 0.4, 0.5, 0.6$.

The results obtained here indicate that the effect of plasma parameters plays a crucial role in linear dispersion relation. The growth rate of linear waves is explicitly shown.

V. CONCLUSIONS

In this work, we derived a basic plasma model in two-dimensional spin-1/2 quantum plasma, in the presence of magnetic diffusivity. For this purpose, we assumed the quantum hydrodynamic model and used standard mathematical technique to derive the linear dispersion relation. We plotted a number of graphs when we check how different parameters affect the linear dispersion relation. We observed that the presence of magnetic diffusivity parameter is solely responsible for the plasma wave frequency turning complex. So, that magnetic diffusivity parameter plays the role of dissipation.

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