Magnetic susceptibility and Landau diamagnetism of a quantum collisional Plasmas with arbitrary degree of degeneration of electronic gas

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Abstract

The kinetic description of magnetic susceptibility and Landau diamagnetism of quantum collisional plasmas with any degeneration of electronic gas is given. The correct expression of electric conductivity of quantum collisional plasmas with any degeneration of electronic gas (see A. V. Latyshev and A. A. Yushkanov, *Transverse electrical conductivity of a quantum collisional plasma in the Mermin approach*. - Theor. and Math. Phys., 175(1):559–569 (2013)) is used.

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Introduction

Magnetisation of electron gas in a weak magnetic fields compounds of two independent parts (see, for example, [1]): from the paramagnetic magnetisation connected with own (spin) magnetic momentum of electrons (*Pauli’s paramagnetism*, W. Pauli, 1927) and from the diamagnetic magnetisation connected with quantization of orbital movement of electrons in a magnetic field (*Landau diamagnetism*, L. D. Landau, 1930).

Landau diamagnetism was considered till now for a gas of the free electrons. It has been thus shown, that together with original approach developed by Landau, expression for diamagnetism of electron gas can be obtained on the basis of the kinetic approach [2].

The kinetic method gives opportunity to calculate the transverse dielectric permeability. On the basis of this quantity its possible to obtain the value of the diamagnetic response.

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However such calculations till now were carried out only for collisionalless case. The matter is that correct expression for the transverse dielectric permeability of quantum plasma existed till now only for gas of the free electrons. Expression known till now for the transverse dielectric permeability in a collisional case gave incorrect transition to the classical case \[3\]. So this expression were accordingly incorrect.

Central result from \[4\] connects the mean orbital magnetic moment, a thermodynamic property, with the electrical resistivity, which characterizes transport properties of material. In this work was discussed the important problem of dissipation (collisions) influence on Landau diamagnetism. The analysis of this problem is given in the present article with use of exact expression of transverse conductivity of quantum plasma.

In work \[5\] is shown that a classical system of charged particles moving on a finite but unbounded surface (of a sphere) has a nonzero orbital diamagnetic moment which can be large. Here is considered a non-degenerate system with the degeneracy temperarure much smaller than the room temperature, as in the case of a doped high-mobility semiconductor.

In work \[6\] for the first time the expression for the quantum transverse dielectric permeability of collisional plasma has been derived. The obtained in \[6\] expression for transverse dielectric permeability satisfies to the necessary requirements of compatibility.

In the present work for the first time with use of correct expression for the transverse conductivity \[6\] the kinetic description of a magnetic susceptibility of quantum collisional plasmas with arbitrary degree of degeneration of electronic gas is given. The formula for calculation of Landau diamagnetism for collisional plasmas is deduced.

The kinetic description of a magnetic susceptibility and Landau diamagnetism of a quantum collisional degenerate and Maxwellian plasma was given in our woks \[7\] and \[8\].
The graphic analysis of a magnetic susceptibility and comparison of a magnetic susceptibility Maxwellian and degenerate plasmas is made.

2. Magnetic susceptibility of quantum collisional plasmas with arbitrary degree of degeneration of electronic gas

Magnetization vector $\mathbf{M}$ of electron plasma is connected with current density $\mathbf{j}$ by the following expression \[9\]

$$\mathbf{j} = c \text{rot} \mathbf{M},$$

where $c$ is the light velocity.

Magnetization vector $\mathbf{M}$ and a magnetic field strength $\mathbf{H} = \text{rot} \mathbf{A}$ are connected by the expression

$$\mathbf{M} = \chi \mathbf{H} = \chi \text{rot} \mathbf{A},$$

where $\chi$ is the magnetic susceptibility, $\mathbf{A}$ is the vector potential.

From these two equalities for current density we have

$$\mathbf{j} = c \text{rot} \mathbf{M} = c \chi \text{rot}(\text{rot} \mathbf{A}) = c \chi [\nabla(\nabla \cdot \mathbf{A}) - \Delta \mathbf{A}].$$

Here $\Delta$ is the Laplace operator.

Let the scalar potential is equal to zero. Vector potential we take orthogonal to the direction of a wave vector $\mathbf{q}$ ($\mathbf{q} \mathbf{A} = 0$) in the form of a harmonic wave

$$\mathbf{A}(\mathbf{r}, t) = \mathbf{A}_0 e^{i(\mathbf{q} \cdot \mathbf{r} - \omega t)}.$$ 

Such vector field is solenoidal

$$\text{div} \mathbf{A} = \nabla \mathbf{A} = 0.$$ 

Hence, for current density we receive equality

$$\mathbf{j} = - c \chi \Delta \mathbf{A} = c \chi q^2 \mathbf{A}.$$ 

On the other hand, connection of electric field $\mathbf{E}$ and vector potential $\mathbf{A}$ is as follows

$$\mathbf{E} = - \frac{1}{c} \frac{\partial \mathbf{A}}{\partial t} = \frac{i\omega}{c} \mathbf{A}.$$
It is leads to the relation
\[ \mathbf{j} = \sigma_{tr} \mathbf{E} = \sigma_{tr} \frac{i\omega}{c} \mathbf{A}, \]
where \( \sigma_{tr} \) is the transverse electric conductivity.

For our case we obtain following expression for the magnetic susceptibility
\[ \chi = \frac{i\omega}{c^2 q^2} \sigma_{tr}. \] (1.1)

Expression of transversal conductivity of collisional plasmas with arbitrary degree of degeneration of electronic gas is defined by the general formula [6]:
\[ \sigma_{tr}(\mathbf{q}, \omega, \nu) = \sigma_0 \frac{i\nu}{\omega} \left( 1 + \frac{\omega B(\mathbf{q}, \omega + i\nu) + i\nu B(\mathbf{q}, 0)}{\omega + i\nu} \right), \] (1.2)
where \( \sigma_0 \) is the static conductivity, \( \sigma_0 = e^2 N / m \nu \), \( N \) is the concentration (number density) of plasmas particles, \( e \) and \( m \) is the electron charge and mass, \( \nu \) is the effective collisional frequency of plasmas particles,
\[ B(\mathbf{q}, 0) = \frac{\hbar^2}{8\pi^3 m N} \int \frac{f_k - f_{k-q}}{\varepsilon_k - \varepsilon_{k-q}} k_\perp^2 d^3k, \]
\[ B(\mathbf{q}, \omega + i\nu) = \frac{\hbar^2}{8\pi^3 m N} \int \frac{f_k - f_{k-q}}{\varepsilon_k - \varepsilon_{k-q} - \hbar(\omega + i\nu)} k_\perp^2 d^3k, \]
\[ f_k = \left[ 1 + \exp \left( \frac{\varepsilon_k - \mu}{k_B T} \right) \right]^{-1}, \quad \varepsilon_k = \frac{\hbar^2 k^2}{2m}, \]
\[ \varepsilon_T = \frac{mv_T^2}{2} = \frac{\hbar^2 k_T^2}{2m} = k_B T, \]
\( \varepsilon_k \) is the electrons energy, \( \varepsilon_T \) is the heat electrons energy, \( k_B \) is the Boltzmann’s constant, \( v_T = 1 / \sqrt{\beta} \) is the heat electrons velocity, \( \beta = m/2k_B T \), \( \hbar \) is the Planck’s constant,
\[ k_\perp^2 = k^2 - \left( \frac{kq}{q} \right)^2. \]
According to (1.1) and (1.2) magnetic susceptibility of the quantum collisional plasmas with arbitrary degree of degeneration of electronic gas is equal
\[
\chi(q, \omega, \nu) = -\frac{e^2 N}{mc^2 q^2} \left( 1 + \frac{\omega B(q, \omega + i\nu) + i\nu B(q, 0)}{\omega + i\nu} \right). \quad (1.3)
\]

From the formula (1.3) follows, that at \( \omega = 0 \) frequency of collisions plasma particles \( \nu \) drops out of the formula (1.3). Hence, the magnetic susceptibility in a static limit does not depend from frequencies of collisions of plasma and the following form also has:
\[
\chi(q, 0, \nu) = -\frac{e^2 N}{mc^2 q^2} \left[ 1 + \frac{\hbar^2}{8\pi^3 mN} \int \frac{f_{k - q} - f_{k}}{\mathcal{E}_k - \mathcal{E}_{k - q} - \hbar\omega} k_\perp^2 d^3 k \right]. \quad (1.4)
\]

From expression (1.3) follows also, that a magnetic susceptibility in collisionless quantum plasma with arbitrary degree of degeneration of electronic gas is equal
\[
\chi(q, \omega, 0) = -\frac{e^2 N}{mc^2 q^2} \left[ 1 + \frac{\hbar^2}{8\pi^3 mN} \int \frac{f_{k - q} - f_{k}}{\mathcal{E}_k - \mathcal{E}_{k - q} - \hbar\omega} k_\perp^2 d^3 k \right]. \quad (1.5)
\]

At \( \omega \to 0 \) the formula (1.5) passes in the formula (1.4).

Let’s deduce the formula for calculation of a magnetic susceptibility of quantum collisional plasmas with arbitrary degree of degeneration of electronic gas.

After obvious linear replacement of variables the formula for integral \( B(q, \omega + i\nu) \) will be transformed to the form
\[
B(q, \omega + i\nu) = \frac{\hbar^2}{8\pi^3 mN} \times \\
\times \int \frac{(\mathcal{E}_{k+q} + \mathcal{E}_{k-q} - 2\mathcal{E}_k)f_k k_\perp^2 d^3 k}{[\mathcal{E}_k - \mathcal{E}_{k-q} - \hbar(\omega + i\nu)][\mathcal{E}_{k+q} - \mathcal{E}_k - \hbar(\omega + i\nu)]}. \quad (1.6)
\]

Let’s enter dimensionless variables
\[
z = \frac{\omega + i\nu}{k_T v_T} = x + iy, \quad x = \frac{\omega}{k_T v_T}, \quad y = \frac{\nu}{k_T v_T},
\]
\[ \alpha = \frac{\mu}{k_B T}, \quad -\infty < \mu < +\infty, \quad Q = \frac{q}{k_T}, \]

\( \alpha \) is the dimensionless (normalized, reduced) chemical potential.

Let us pass to integration on the vector \( \mathbf{K} = \mathbf{k}/k_T \), where \( k_T = p_T/\hbar = m v_T/\hbar \) is the thermal wave number. Vectors \( \mathbf{K}, \mathbf{k} \) we will direct along an axis \( x \), believing \( \mathbf{K} = K_x(1, 0, 0) \) and \( \mathbf{k} = k(1, 0, 0) \).

Then

\[ \mathcal{E}_k = \frac{\hbar^2 k^2}{2m} K^2 = \mathcal{E}_T K^2, \]

\[ \mathcal{E}_k - \mathcal{E}_{k-\mathbf{q}} - \hbar(\omega + i\nu) = 2\mathcal{E}_T Q \left( K_x - \frac{z}{Q} - \frac{Q}{2} \right), \]

\[ \mathcal{E}_{k+\mathbf{q}} - \mathcal{E}_k - \hbar(\omega + i\nu) = 2\mathcal{E}_T Q \left( K_x - \frac{z}{Q} + \frac{Q}{2} \right), \]

\[ \mathcal{E}_{k+\mathbf{q}} + \mathcal{E}_{k-\mathbf{q}} - 2\mathcal{E}_k = 2\mathcal{E}_T Q^2, \]

\[ f_k = \left[ 1 + \exp \left( \frac{\mathcal{E}_k}{\mathcal{E}_T} - \alpha \right) \right]^{-1} = \left[ 1 + \exp(K^2 - \alpha) \right]^{-1}. \]

Let us notice, that for plasma with any degree of degeneration of electronic gas the numerical density in an equilibrium condition is equal

\[ N = \frac{f_2(\alpha)}{\pi^2} k_T^3, \]

where

\[ f_2(\alpha) = \int_0^\infty x^2 f_F(x) dx = \int_0^\infty \frac{x^2 dx}{1 + e^{x^2 - \alpha}} = \frac{1}{2} \int_0^\infty \ln(1 + e^{\alpha - x^2}) dx. \]

In dimensionless parameters integral \( B(q, \omega + i\nu) \) equals

\[ B(Q, z) = \frac{1}{8\pi f_2(\alpha) Q} \int \frac{(f_{\mathbf{k}} - f_{\mathbf{k}-\mathbf{q}}) K^2 \, d^3 K}{K_x - z/Q - Q/2}, \quad (1.7) \]

where

\[ K^2_\perp = K^2_y + K^2_z, \]

besides

\[ B(Q, 0) = \frac{1}{8\pi f_2(\alpha) Q} \int \frac{(f_{\mathbf{k}} - f_{\mathbf{k}-\mathbf{q}}) K^2 \, d^3 K}{K_x - Q/2}. \]
Let us notice that the integral (1.6) can be transformed to the following form
\[ B(Q, z) = \frac{1}{8\pi f_2(\alpha)} \int \frac{f_K K_\perp^2 d^3 K}{(K_x - z/Q)^2 - (Q/2)^2}. \] (1.8)

Now the magnetic susceptibility (2.3) in dimensionless parameters equals
\[ \chi(Q, x, y) = -\frac{e^2 N}{mc^2 k_T^2} \cdot \frac{1}{Q^2} \left( 1 + \frac{x}{z} B(Q, z) + \frac{iy}{z} B(Q, 0) \right). \] (1.9)

Integrals (2.7) and (2.8) can be reduced to the one-dimensional. For this purpose let us notice, that the internal double integral is equal
\[ \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{(K_y^2 + K_z^2) dK_y dK_z}{1 + e^{K_x^2 + K_y^2 + K_z^2 - \alpha}} = 2\pi \int_{0}^{\infty} \frac{\rho^3 d\rho}{1 + e^{K_x^2 + \rho^2 - \alpha}} = \] \[ = 2\pi f_3(K_x, \alpha) = 2\pi l_1(K_x, \alpha). \]

Here
\[ f_3(K_x, \alpha) = \int_{0}^{\infty} \frac{\rho^3 d\rho}{1 + e^{K_x^2 + \rho^2 - \alpha}} = \int_{0}^{\infty} \rho^3 f_F(K_x, \rho, \alpha) d\rho, \]
where
\[ f_F(K_x, \rho, \alpha) = \frac{1}{1 + e^{K_x^2 + \rho^2 - \alpha}}, \]
and
\[ l_1(K_x, \alpha) = \int_{0}^{\infty} \rho \ln(1 + e^{\alpha - K_x^2 - \rho^2}). \]

Thus, integrals (2.7) and (2.8) can be calculated to following formulas
\[ B(Q, z) = \frac{1}{4f_2(\alpha)} \int_{-\infty}^{\infty} \frac{f_3(\tau, \alpha) d\tau}{(\tau - z/Q)^2 - (Q/2)^2}, \]
\[ B(Q, z) = \frac{1}{4f_2(\alpha) Q} \int_{-\infty}^{\infty} \frac{[f_3(\tau, \alpha) - f_3(\tau - Q, \alpha)] d\tau}{\tau - z/Q - Q/2}. \]
3. Landau diamagnetism of quantum collisional plasmas with arbitrary degree of degeneration of electronic gas

Landau diamagnetism in collisionless plasma is usually defined as a magnetic susceptibility in a static limit for a homogeneous external magnetic field. Thus the diamagnetism value can be found by means of (1.1) through two non-commutative limits

\[
\chi_L = \lim_{q \to 0} \left[ \lim_{\omega \to 0} \chi(q, \omega, \nu = 0) \right].
\] (2.1)

Here \( \nu \) is the effective frequency of electrons with plasma particles. At \( y = 0 \) from formula (1.9) we have

\[
\chi(Q, x, 0) = -\frac{e^2 N}{mc^2 k_T^2} \cdot \frac{1}{Q^2} \times \\
\times \left( 1 + \frac{1}{8\pi f_2(\alpha)} \int \frac{(f_K - f_{K-Q})K_{+}^2 d^3K}{K_x - x/Q - Q/2} \right). \] (2.2)

On the basis of (2.1) and (2.2) for Landau diamagnetism we receive

\[
\chi_L = -\frac{e^2 N}{mc^2 k_T^2} \lim_{Q \to 0} \frac{1}{Q^2} \times \\
\times \left[ 1 - \frac{1}{8\pi f_2(\alpha)Q} \int \frac{(f_{K-Q} - f_K)K_{+}^2 d^3K}{K_x - Q/2} \right]. \] (2.3)

The function

\[
\varphi(Q) = \frac{f_{K-Q} - f_K}{K_x - Q/2}
\]

we will expand on degrees \( Q \) to the third order inclusive

\[
\varphi(Q) = \frac{2K_x e^{K^2-\alpha}}{1 + e^{K^2-\alpha}^2} Q + \left[ -\frac{2K_x e^{K^2-\alpha}}{(1 + e^{K^2-\alpha})^2} + \frac{4K_x e^{2(K^2-\alpha)}}{(1 + e^{K^2-\alpha})^3} \right] Q^2 + \\
+ \left[ \frac{(8K_x^2 + 6)e^{K^2-\alpha}}{(1 + e^{K^2-\alpha})^2} - \frac{48K_x^2 + 12)e^{2(K^2-\alpha)}}{(1 + e^{K^2-\alpha})^3} + \frac{48K_x^2 e^{3(K^2-\alpha)}}{(1 + e^{K^2-\alpha})^4} \right] \frac{Q^3}{6} + \cdots.
\]
Let us substitute this decomposition in (2.3). We will notice, that a free member in the received equality is equal to zero

\[
1 - \frac{1}{8\pi f_2(\alpha)} \int \frac{2e^{K^2-\alpha}K^2_\perp d^3K}{(1 + e^{K^2-\alpha})} = 1 - \frac{2}{3f_2(\alpha)} \int_0^\infty \frac{e^{K^2-\alpha}K^4 dK}{(1 + e^{K^2-\alpha})^2} = 0.
\]

Further, the integral at the first degree \( Q \) is equal to zero as integral from odd function on the real axis.

Therefore, Landau diamagnetism equals

\[
\chi_L = \frac{e^2N}{6mc^2k_T^2} \cdot \frac{1}{8\pi f_2(\alpha)} \int \left[ \frac{(8K_x^2 + 6)e^{K^2-\alpha}}{(1 + e^{K^2-\alpha})^2} \right.
- \frac{(48K_x^2 + 12)e^{2(K^2-\alpha)}}{(1 + e^{K^2-\alpha})^3} + \frac{48K_x^2e^{3(K^2-\alpha)}}{(1 + e^{K^2-\alpha})^4} \left. \right] K^2_\perp d^3K,
\]

whence

\[
\chi_L = -\frac{e^2N}{12mc^2k_T^2} \cdot \frac{f_0(\alpha)}{f_2(\alpha)}.
\] (2.4)

Here

\[
f_0(\alpha) = \int_0^\infty f_F(x, \alpha) dx = \int_0^\infty \frac{dx}{1 + e^{x^2-\alpha}}.
\]

In monograph [10] formula of Landau diamagnetism for quantum collisional plasma is given in the form, extremely inconvenient to comparison with our result (2.4).

Let us pass in the formula (2.4) to the limit, when \( \alpha \to -\infty \). In this case plasma with any degree of degeneration of electronic gas passes to Maxwellian plasma. In this limit from (2.4) we receive

\[
\chi_L = -\frac{e^2N}{6mc^2k_T^2},
\]

that in accuracy coincides with result from [7].

Having divided (1.9) on (2.4), we receive expression for the relative magnetic susceptibility of quantum collisional plasmas with any degree
of degeneration of electronic gas

\[ \frac{\chi(Q, x, y)}{\chi_L} = \frac{12 f_2(\alpha)}{f_0(\alpha)Q^2} \left( 1 + \frac{x}{z} B(Q, z) + \frac{iy}{z} B(Q, 0) \right). \]  

(2.5)

For graphic research of a magnetic susceptibility we will be to use the formula (2.5).

On Fig. 1 comparison of magnetic susceptibilities of degenerate plasmas (curve 1), Maxwellian plasmas (curve 2) and plasmas with any degree of degeneration in the case when dimensionless chemical potential \( \alpha = 0 \) (curve 3) is presented.

From the Fig. 1 follows, that into quantum collisionless plasma (\( \nu = 0 \)) in the static limit (\( \omega = 0 \)) the magnetic susceptibility is function monotonously decreasing to zero as function of wave number.

On Fig. 2 dependence of a magnetic susceptibility collisionless plasmas with any degree of degeneration of electron gas from wave number at various values of chemical potential is presented. Curves 1, 2 and 3 correspond to values of the dimensionless chemical potential \( \alpha = 0, -2 \) and 2. With growth of chemical potential values of the magnetic susceptibility grow also. From the Fig. 2 we see, that the magnetic susceptibility is monotonously decreasing function of wave number at all values of the dimensionless chemical potential.

On the Figs. 3 and 4 dependences of the magnetic susceptibility as functions of dimensionless wave number (Fig. 3), and functions of dimensionless frequency of oscillations of an electromagnetic field (Fig. 4) are presented.

On the Figs. 3 and 4 dependences of the magnetic susceptibility as functions on dimensionless wave number (Fig. 3), and functions on dimensionless frequency of oscillations of an electromagnetic field (Fig. 4) are presented.

From the Fig. 3 we see, that the magnetic susceptibility is monotonously decreasing function on wave number at all values of dimensionless chemical potential and frequency of oscillations of electromagnetic field.
Fig. 1. Magnetic susceptibility in static limit ($\omega = 0$) for collisionless plasmas ($\nu = 0$). Curve 1 corresponds to degenerate plasmas, curve 2 corresponds to Maxwellian plasmas, curve 3 corresponds to plasmas with arbitrary degree of degeneration of electronic gas at value of dimensionless chemical potential $\alpha = 0$.

Fig. 2. Magnetic susceptibility of collisionless plasmas ($\nu = 0$) with arbitrary degree of degeneration of electronic gas; curves 1, 2 and 3 corresponds to parameter
Fig. 3. Magnetic susceptibility of collisionless plasmas ($\nu = 0$) with arbitrary degree of degeneration of electronic gas in the case $\alpha = 0$; curves 1, 2 and 3 corresponds to parameter values $x = 0.001, 0.05$ and 0.1.

Fig. 4. Magnetic susceptibility of collisionless plasmas ($\nu = 0$) with arbitrary degree of degeneration of electronic gas in the case $\alpha = 0$; curves 1, 2 and 3 corresponds to parameter values $Q = 0.45, 0.5$ and 0.55.
Fig. 5. Real part of magnetic susceptibility of quantum plasmas with arbitrary degree of degeneration of electronic gas in the case $Q = 0.5$ and $\alpha = 0$; curves 1, 2 and 3 corresponds to parameter values $y = 0.001, 0.05 \text{ and } 0.1$.

Fig. 6. Imaginary part of magnetic susceptibility of quantum plasmas with arbitrary degree of degeneration of electronic gas in the case $Q = 0.5$ and $\alpha = 0$; curves 1, 2 and 3 corresponds to parameter values $y = 0.001, 0.05 \text{ and } 0.1$. 
With growth of frequency of oscillations of electromagnetic field values of the magnetic susceptibilities grow also.

From the Fig. 4 we see, that the magnetic susceptibility as function of dimensionless frequency of oscillations of the electromagnetic fields has a maximum and at great values $x$ leaves on the asymptotics

$$\frac{\chi_{as}}{\chi_L} = \frac{12 f_2(\alpha)}{f_0(\alpha)Q^2}.$$  

With growth of wave number values of the magnetic susceptibilities grow also.

On the Fig. 5 and 6 dependences of real (Fig. 5) and imaginary (Fig. 6) parts of magnetic susceptibility of collisional plasmas as functions on dimensionless frequencies of oscillations of the electromagnetic fields in the case $Q = 0.5$ are presented.

From the Fig. 5 we see, that the real part of magnetic susceptibilities has the maximum and at big $x$ leaves from above on the asymptotics

$$\frac{\text{Re} \chi_{as}}{\chi_L} = \frac{12 f_2(\alpha)}{f_0(\alpha)Q^2}.$$  

From the Fig. 6 we see, that an imaginary part of magnetic susceptibility has a minimum and then leaves from below on the asymptotics

$$\frac{\text{Im} \chi_{as}}{\chi_L} = 0.$$  

Let us notice, that the minimum moves to the right with growth $Q$. With growth frequencies of oscillations of an electromagnetic field the imaginary part tends to zero.

4. Conclusion

In the present work the kinetic description magnetic susceptibility of quantum collisional plasmas with any degree of degeneration of electronic gas is given. Earlier deduced correct formulas for electric conductivity of quantum plasma is used. For collisionless plasmas with the help of
kinetic approach the known formula of Landau diamagnetism is deduced.

Thereby the answer to a question put in work [4] on dissipation influence on diamagnetism Landau is given. Graphic research of properties of the magnetic susceptibilities depending on dimensionless wave number, chemical potential, frequency of oscillations of an electromagnetic field and frequencies of collisions of particles of plasma is carried out.

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