THE NEW MECHANISM OF MAGNETIC SUSCEPTIBILITY OF DIAMAGNETIC MATTER AND SOLUTION OF THE "KT PROBLEM"

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It is shown that rather big constant torques affect the charged Brownian particles of matter in a weak magnetic field.

At present time there is a considerable amount of experimental information on strong influence of weak magnetic field (MF) (order of Earth's MF) on diamagnetics [1-4].

In diamagnetic matter the charge of a particle is responsible for its magnetic susceptibility. According to quantum mechanics, the energy of a charged particle in MF may have a set of discrete values (Landau levels). The difference in energy between Landau levels equals to $\Delta\varepsilon = \hbar\Omega_C$, where $\Omega_C = (q/m)B$ is the cyclotron frequency, q and m are the charge and the mass of the particle, B is the magnetic induction. The magnetization is determined by the population difference between the Landau levels, i.e. by the ratio $\hbar\Omega_C / \kappa T$. At room temperatures $\Delta\varepsilon \ll \kappa T$. For electrons this ratio is on the order of 10^{-7} and is difficult to measure. For protons and other heavy particles the magnetization is even 3 orders of magnitude smaller than for electrons. The theory of magnetic susceptibility of diamagnetic matter considers this situation as the "kT problem." It is generally believed that the polarization of diamagnetic is impossible because of the Brownian motion of the charged particles.

On the other hand, the level of susceptibility depends on the relaxation time τ, which is inversely proportional to the probability W of the rate of radiationless and induced transitions between energy levels. Therefore, the magnetization is zero if $\Omega_C\tau \ll 1$. However, there are no methods available for calculation of τ in scientific literature.

This work gives the ways to approach and solve the "kT problem" and suggests the method of calculating the relaxation time.

Here, we discuss the dynamics of vibrations of a charged particle with the charge q, mass m in constant MF with magnetic induction B. The solution of the corresponding equation has the form:

$$\vec{\xi}_0 = \frac{q}{m}\,\frac{a_0}{a_0^2 - \Omega_c^2\,\omega^2}\,\vec{e} + i\,\frac{q^2}{m^2}\,\frac{\omega}{a_0^2 - \Omega_c^2\,\omega^2}\left[\vec{e}\times\vec{B}_0 + i\,\frac{q}{m}\,\frac{\omega}{a_0}\left(\vec{e}\,\vec{B}_0\right)\vec{B}_0\right], \qquad (1)$$

where $\vec{e}(\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\vec{E}(t)\exp\left(-i\omega t\right)dt$, $\vec{\xi}_0 = \frac{1}{2\pi}\int_{-\infty}^{\infty}\vec{r}(t)\exp\left(-i\omega t\right)dt$, $a_0 = \omega_0^2 - \omega^2 + i\,\omega/\tau$, $\vec{\Omega}_c = (q/m)\vec{B}_0$, $\vec{E}(t)$ is the strength of the electric field (EF), $\vec{r}(t)$ is the displacement vector, and ω_0 is the natural frequency. In this work $\vec{E}(t)$ is considered to be a thermal EF in the matter.

The average[♦] by ensemble constant rotational moment acting on the particle with respect to the center of vibrations equals to:

$$\langle \vec{M} \rangle = \frac{2}{3} i \frac{q^3}{m^2} \vec{B}_0 \int_{-\infty}^{\infty} \frac{\omega}{a_0^2 - \Omega_c^2 \omega^2} g_e(\omega) \, d(\omega), \tag{2}$$

where $g_e(\omega)$ is the spectral density of the electric component of electromagnetic field (EMF).

In order to determine $g_e(\omega)$ and relaxation time $\tau(\omega)$, we have applied the fluctuation-dissipation theorem [5]. The spectral density $g_e(\omega)$ can be found from the correlation properties of the thermal EMF, for instance using Maxwell's equations [6]. To calculate the relaxation time, we have used [5]:

$$g_e(\omega)\,\tau(\omega) = \left(3m/\pi q^2\right)\theta(\omega,T), \tag{3}$$

where $\theta(\omega,T) = (\hbar\omega/2)\,Cth(\hbar\omega/2kT)$ is the average energy of a quantum oscillator.

As a result, we get from the formula (2) with $\omega_0 \tau \gg 1$:

$$\langle M \rangle = 2kT\Omega_c \left[\frac{\partial}{\omega\,\partial\omega} \left(\frac{1}{\tau} \right) \right]_{\omega = \omega_0}, \tag{4}$$

where the classical approximation $\theta(\omega,T) = \kappa T$ was chosen provided that $\hbar\omega_o << \kappa T$.

As it follows from (4), the constant rotational moment aligned with B_0 is drastically increased with $\omega_o \rightarrow 0$. In this case the free particle ($\omega_o = 0$) has a large rotational moment

$$\langle M \rangle = -2kT\ \Omega_c\ \tau\,. \tag{5}$$

It may be concluded that the equivalently charged Brownian particles in MF possess equivalently directed rotational moments.

This is equivalent to an existence of solenoidal EF around each charged particle. Assuming that the EF appears as a result of a certain equivalent alternating MF B_e, the rate of change of that EF equals to:

$$\frac{\partial B_e}{\partial t} = \frac{4\langle M \rangle}{r_0^2\, q}, \tag{6}$$

where r_o is the amplitude of thermal oscillations.

♦ Averaged by time if the system is ergodic.

The estimates according to (5) and (6) for weak water solutions indicate that the constant rotational moments for the weak MF considered here are on the order of $10^{-30} - 10^{-32}$ Newton·m, and the rate $\partial B_e / \partial t$ for $r_o \sim 0{,}2$ Å is huge, $\sim 10^9 - 10^{11}$ Tesla/s.

If the particle has not only a charge but also a magnetic moment, then the ratio of the rotational moments originated from MF acting on the charge and on magnetic moment is $\sim \kappa T \tau / \hbar$. This quantity is not small at room temperatures. Therefore, this work proves that the Brownian motion of the particles in the matter in MF triggers the polarization of the matter. The polarization increases with the rise of temperature. It seems that the present work shows the ways to solve the "kT problem." This, in turn, opens new possibilities for investigating the mechanisms of the influence of weak MF on condensed matter.

This work also reveals the principal difference in the results of acting on the particle of constant MF ($T > 0$) and EF. EF results in the directional forces acting on the particle, whereas constant MF results in the directional moments of the forces.

Summarizing, we should note that a similar analysis of the influence of alternating MF on the dielectric matter shows that in this case the particles are subjected to alternating rotational moments changing with the frequency Ω of the magnetic field.

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