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Concept of the Dispersion of Electric and Magnetic Inductivities and its Physical Interpretation

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CONCEPTOFTHEDISPERSIONOFELECTRICANDMAGNETICINDUCTIVITIESANDITSPHYSICALINTERPRETATION

Strictly as per the compliance and regulations of:

Concept of the Dispersion of Electric and Magnetic Inductivities and its Physical Interpretation

F.F. Mende

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I. Introduction

How the idea of ε and μ-dispersion appeared and evolved is illustrated vividly in the monograph of well-known specialists in physics of plasma [1]: while working at the equations of electrodynamics of material, media, G. Maxwell looked upon electric and magnetic inductivities as constants (that is why this approach was so lasting). Much later, at the beginning of the XX century, G. Heavisidr and R.Wull put forward their explanation for phenomena of optical dispersion (in particular rainbow) in which electric and magnetic inductivities came as functions of frequency. Quite recently, in the mid-50ies of the last century, physicists arrived at the conclusion that these parameters were dependent not only on the frequency but on the wave vector as well. That was a revolutionary breakaway from the current concepts. The importance of the problem is clearly illustrated by what happened at a seminar held by L. D. Landau in 1954, where he interrupted A. L. Akhiezer reporting on the subject: “Nonsense, the refractive index cannot be a function of the refractive index”. Note, this was said by L. D. Landau, an outstanding physicist of our time.

What is the actual situation? Running ahead, I can admit that Maxwell was right: both ε and μ are frequency – independent constants characterizing one or another material medium. Since dispersion of electric and magnetic inductivities of material media is one of the basic problems of the present – day physics and electrodynamics, the system of views on these questions has to be radically altered again.

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II. Plasma Media

It is noted in the introduction that dispersion of electric and magnetic inductivities of material media is a commonly accepted idea [1-5]. The idea is however not correct.

To explain this statement and to gain a better understanding of the physical essence of the problem, we start with a simple example showing how electric lumped-parameter circuits can be described [6]. As we can see below, this example is directly concerned with the problem of our interest and will give us a better insight into the physical picture of the electro dynamic processes in material media.

In a parallel resonance circuit including a capacitor *C* and an inductance coil *L*, the applied voltage *U* and the total current I_Σ through the circuit are related as

$$I_\Sigma = I_C + I_L = C\frac{dU}{dt} + \frac{1}{L}\int U\,dt\ ,$$

where $I_C = C\frac{dU}{dt}$ is the current through the capacitor, $I_L = \frac{1}{L}\int U\,dt$ is the current through the inductance coil. For the harmonic voltage $U = U_0 \sin \omega t$

$$I_\Sigma = \left(\omega C - \frac{1}{\omega L}\right) U_0 \cos \omega t\ . \qquad (2.1)$$

The term in brackets is the total susceptance σ_x of the circuit, which consists of the capacitive σ_c and inductive σ_L components

$$\sigma_x = \sigma_c + \sigma_L = \omega C - \frac{1}{\omega L}\ .$$

Eq. (2.1) can be re-written as

$$I_\Sigma = \omega C\left(1 - \frac{\omega_0^2}{\omega^2}\right) U_0 \cos \omega t\ ,$$

Where $\omega_0^2 = \dfrac{1}{LC}$ is the resonance frequency of a parallel circuit.

From the mathematical (i.e. other than physical) standpoint, we may assume a circuit that has only a capacitor and no inductance coil. Its frequency – dependent capacitance is

$$C^*(\omega) = C\left(1 - \frac{\omega_0^2}{\omega}\right) . \qquad (2.2)$$

Another approach is possible, which is correct too. Eq. (2.1) can be re-written as

$$I_\Sigma = -\frac{\left(\dfrac{\omega^2}{\omega_0^2} - 1\right)}{\omega\ L} U_0 \cos\ \omega\ t .$$

In this case the circuit is assumed to include only an inductance coil and no capacitor. Its frequency – dependent inductance is

$$L^*(\omega) = \frac{L}{\left(\dfrac{\omega^2}{\omega_0^2} - 1\right)} . \qquad (2.3)$$

Using the notion Eqs. (2.2) and (2.3), we can write

$$I_\Sigma = \omega\ C^*(\omega) U_0 \cos\ \omega\ t , \qquad (2.4)$$

or

$$I_\Sigma = -\frac{1}{\omega\ L^*(\omega)} U_0 \cos\ \omega\ t . \qquad (2.5)$$

Eqs (2.4) and (2.5) are equivalent and each of them provides a complete mathematical description of the circuit. From the physical point of view, $C^*(\omega)$ and $L^*(\omega)$ do not represent capacitance and inductance though they have the corresponding dimensions. Their physical sense is as follows:

$$C^*(\omega) = \frac{\sigma_X}{\omega} ,$$

i.e. $C^*(\omega)$ is the total susceptance of this circuit divided by frequency:

$$L^*(\omega) = \frac{1}{\omega\ \sigma_X} ,$$

and $L^*(\omega)$ is the inverse value of the product of the total susceptance and the frequency.

Amount $C^*(\omega)$ is constricted mathematically so that it includes *C* and *L* simultaneously. The same is true for $L^*(\omega)$.

We shall not consider here any other cases, e.g., series or more complex circuits. It is however important to note that applying the above method, any circuit consisting of the reactive components *C* and *L* can be described either through frequency – dependent inductance or frequency – dependent capacitance.

But this is only a mathematical description of real circuits with constant – value reactive elements.

It is well known that the energy stored in the capacitor and inductance coil can be found as

$$W_C = \frac{1}{2} C\ U^2 , \qquad (2.6)$$

$$W_L = \frac{1}{2} L\ I^2 . \qquad (2.7)$$

But what can be done if we have $C^*(\omega)$ and $L^*(\omega)$? There is no way of substituting them into Eqs. (2.6) and (2.7) because they can be both positive and negative. It can be shown readily that the energy stored in the circuit analyzed is

$$W_\Sigma = \frac{1}{2} \cdot \frac{d\ \sigma_X}{d\ \omega} U^2 , \qquad (2.8)$$

or

$$W_\Sigma = \frac{1}{2} \cdot \frac{d\left[\omega\ C^*(\omega)\right]}{d\ \omega} U^2 , \qquad (2.9)$$

or

$$W_\Sigma = \frac{1}{2} \cdot \frac{d\left(\dfrac{1}{\omega\ L^*(\omega)}\right)}{d\ \omega} U^2 . \qquad (3.10)$$

Having written Eqs. (2.8), (2.9) or (2.10) in greater detail, we arrive at the same result:

$$W_\Sigma = \frac{1}{2} C\ U^2 + \frac{1}{2} L\ I^2 ,$$

Where U is the voltage at the capacitor and I is the current through the inductance coil. Below we consider the physical meaning jog the magnitudes $\varepsilon(\omega)$ and $\mu(\omega)$ for material media.

A superconductor is a perfect plasma medium in which charge carriers (electrons) can move without friction. In this case the equation of motion is

$$m\frac{d\vec{V}}{d\,t} = e\,\vec{E}\,, \qquad (2.11)$$

Where m and e are the electron mass and charge, respectively; $\vec{E}$ is the electric field strength, $\vec{V}$ is the velocity. Taking into account the current density

$$\vec{j} = n\,e\,\vec{V}, \qquad (2.12)$$

we can obtain from Eq. (2.11)

$$\vec{j}_L = \frac{n\,e^2}{m}\int \vec{E}\,d\,t\,. \qquad (2.13)$$

In Eqs. (2.12) and (2.13) n is the specific charge density. Introducing the notion

$$L_k = \frac{m}{n\,e^2}\,,$$

we can write

$$\vec{j}_L = \frac{1}{L_k}\int \vec{E}\,d\,t\,. \qquad (2.14)$$

Here L_k is the kinetic inductivity of the medium [7-11]. Its existence is based on the fact that a charge carrier has a mass and hence it possesses inertia properties.

For harmonic fields we have $\vec{E} = \vec{E}_0\,\sin\,\omega\,t$ and Eq. (2.14) becomes

$$\vec{j}_L = -\frac{1}{\omega\,L_k}E_0\cos\omega\,t\,. \qquad (2.15)$$

Eqs. (2.14) and (2.15) show that $\vec{j}_L$ is the current through the inductance coil.

In this case the Maxwell equations take the following form

$$rot\,\vec{E} = -\mu_0\frac{\partial\,\vec{H}}{\partial\,t},$$

$$rot\,\vec{H} = \vec{j}_C + \vec{j}_L = \varepsilon_0\frac{\partial\,\vec{E}}{\partial\,t} + \frac{1}{L_k}\int \vec{E}\,d\,t, \qquad (2.16)$$

Where ε_0 and μ_0 are the electric and magnetic inductivities in vacuum, $\vec{j}_C$ and $\vec{j}_L$ are the displacement and conduction currents, respectively. As was shown above, $\vec{j}_L$ is the inductive current.

Eq. (2.16) gives

$$rot\;rot\;\vec{H} + \mu_0\varepsilon_0\frac{\partial^2\vec{H}}{\partial\,t^2} + \frac{\mu_0}{L_k}\vec{H} = 0\,. \qquad (2.17)$$

For time-independent fields, Eq. (2.17) transforms into the London equation [12]

$$rot\;rot\;\vec{H} + \frac{\mu_0}{L_k}\vec{H} = 0\,,$$

where $\lambda_L^2 = \frac{L_k}{\mu_0}$ is the London depth of penetration.

As Eq. (2.16) shows, the inductivities of plasma (both electric and magnetic) are frequency – independent and equal to the corresponding parameters for vacuum. Besides, such plasma has another fundamental material characteristic – kinetic inductivity.

Eqs. (2.16) hold for both constant and variable fields. For harmonic fields $\vec{E} = \vec{E}_0\,\sin\,\omega\,t$, Eq.(2.16) gives

$$rot\,\vec{H} = \left(\varepsilon_0\omega - \frac{1}{L_k\omega}\right)\vec{E}_0\cos\,\omega\,t\,. \qquad (2.18)$$

Taking the bracketed value as the specific susceptance σ_x of plasma, we can write

$$rot\,\vec{H} = \sigma_X\vec{E}_0\cos\,\omega\,t\,, \qquad (2.19)$$

where

$$\sigma_X = \varepsilon_0\omega - \frac{1}{\omega\,L_k} = \varepsilon_0\omega\left(1 - \frac{\omega_\rho^2}{\omega^2}\right) = \omega\,\varepsilon^*(\omega), \qquad (2.20)$$

and $\varepsilon^*(\omega) = \varepsilon_0\left(1 - \frac{\varpi_\rho^2}{\omega}\right)$, where $\omega_\rho^2 = \frac{1}{\varepsilon_0 L_k}$

is the plasma frequency.

Now Eq. (2.19) can be re-written as

$$rot\ \vec{H} = \omega\ \varepsilon_0\left(1 - \frac{\omega_\rho^2}{\omega^2}\right)\vec{E}_0 \cos\ \omega\ t\ ,$$

or

$$rot\ \vec{H} = \omega\ \varepsilon^*(\omega)\vec{E}_0 \cos\ \omega\ t\ .$$

The $\varepsilon^*(\omega)$ –parameter is conventionally called the frequency-dependent electric inductivity of plasma. In reality however this magnitude includes simultaneously the electric inductivity of vacuum aid the kinetic inductivity of plasma. It can be found as

$$\varepsilon^*(\omega) = \frac{\sigma_X}{\omega}\ .$$

It is evident that there is another way of writing σ_X

$$\sigma_X = \varepsilon_0\omega - \frac{1}{\omega\ L_k} = \frac{1}{\omega\ L_k}\left(\frac{\omega^2}{\omega_\rho^2} - 1\right) = \frac{1}{\omega\ L_k\ *}, \qquad (2.21)$$

where

$$L_k*(\omega) = \frac{L_k}{\left(\frac{\omega^2}{\omega_\rho^2} - 1\right)} = \frac{1}{\sigma_X\omega}\ .$$

$L_k*(\omega)$ written this way includes both ε_0 and L_k.

Eqs. (2.20) and (2.21) are equivalent, and it is safe to say that plasma is characterized by the frequency-dependent kinetic inductance $L_k*(\omega)$ rather than by the frequency-dependent electric inductivity $\varepsilon^*(\omega)$.

Eq. (2.18) can be re-written using the parameters $\varepsilon^*(\omega)$ and $L_k*(\omega)$

$$rot\ \vec{H} = \omega\ \varepsilon^*(\omega)\vec{E}_0 \cos\ \omega\ t\ , \qquad (2.22)$$

or

$$rot\ \vec{H} = \frac{1}{\omega\ L_k*(\omega)}\vec{E}_0 \cos\ \omega\ t\ . \qquad (2.23)$$

Eqs. (2.22) and (2.23) are equivalent.

Thus, the parameter $\varepsilon^*(\omega)$ is not an electric inductivity though it has its dimensions. The same can be said about $L_k*(\omega)$.

We can see readily that

$$\varepsilon^*(\omega) = \frac{\sigma_X}{\omega}\ ,$$

$$L_k*(\omega) = \frac{1}{\sigma_X\omega}\ .$$

These relations describe the physical meaning of $\varepsilon^*(\omega)$ and $L_k*(\omega)$.

Of course, the parameters $\varepsilon^*(\omega)$ and $L_k*(\omega)$ are hardly usable for calculating energy by the following equations

$$W_E = \frac{1}{2}\varepsilon\ E_0^2$$

and

$$W_j = \frac{1}{2}L_k\ j_0^2\ .$$

For this purpose the Eq. (2.9)-type fotmula was devised in [2]:

$$W = \frac{1}{2}\cdot\frac{d\left[\omega\ \varepsilon^*(\omega)\right]}{d\ \omega}E_0^2\ . \qquad (2.24)$$

Using Eq. (2.24), we can obtain

$$W_\Sigma = \frac{1}{2}\varepsilon_0 E_0^2 + \frac{1}{2}\cdot\frac{1}{\omega^2 L_k}E_0^2 = \frac{1}{2}\varepsilon_0 E_0^2 + \frac{1}{2}L_k\ j_0^2$$

The same result is obtainable from

$$W = \frac{1}{2}\cdot\frac{d\left[\frac{1}{\omega\ L_k*(\omega)}\right]}{d\ \omega}E_0^2\ .$$

As in the case of a parallel circuit, either of the parameters $\varepsilon^*(\omega)$ and $L_k*(\omega)$, similarly to $C^*(\omega)$ and $L^*(\omega)$, characterize completely the electro dynamic properties of plasma. The case

$\varepsilon^*(\omega) = 0$

$L_k*(\omega) = \infty$

corresponds to the resonance of current.

We have found that $\varepsilon(\omega)$ is not dielectric inductivity permittivity. Instead, it includes two frequency-independent parameters ε_0 and L_k. What is the reason for the physical misunderstanding of the parameter $\varepsilon(\omega)$? This occurs first of all because for the case of plasma the $\frac{1}{L_k}\int \vec{E}\, d\, t$ - type term is not explicitly present in the second Maxwell equation.

There is however another reason for this serious mistake in the present-day physics [2] as an example. This study states that there is no difference between dielectrics and conductors at very high frequencies. On this basis the authors suggest the existence of a polarization vector in conducting media and this vector is introduced from the relation

$$\vec{P} = \Sigma\ e\ \vec{r}_m = n\ e\ \vec{r}_m\ , \qquad (2.25)$$

Where n is the charge carrier density, $\vec{r}_m$ is the current charge displacement. This approach is physically erroneous because only bound charges can polarize and form electric dipoles when the external field overcoming the attraction force of the bound charges accumulates extra electrostatic energy in the dipoles. In conductors the charges are not bound and their displacement would not produce any extra electrostatic energy. This is especially obvious if we employ the induction technique to induce current (i.e. to displace charges) in a ring conductor. In this case there is no restoring force to act upon the charges, hence, no electric polarization is possible. In [2] the polarization vector found from Eq. (2.25) is introduced into the electric induction of conducting media

$$\vec{D} = \varepsilon_0\ \vec{E} + \vec{P},$$

Where the vector $\vec{P}$ of a metal is obtained from Eq. (2.25), which is wrong.

Since

$$\vec{r}_m = -\frac{e^2}{m\ \omega^2}\vec{E}\ ,$$

for free carriers, then

$$\vec{P}*(\omega) = -\frac{n\ e^2}{m\ \omega^2}\vec{E}\ ,$$

for plasma, and

$$\vec{D}*(\omega) = \varepsilon_0\ \vec{E} + \vec{P}*(\omega) = \varepsilon_0\left(1 - \frac{\omega_p^2}{\omega^2}\right)\vec{E}\ .$$

Thus, the total accumulated energy is

$$W_\Sigma = \frac{1}{2}\varepsilon_0\ E^2 + \frac{1}{2}\cdot\frac{1}{L_k\ \omega^2}E^2\ . \qquad (2.26)$$

However, the second term in the right-hand side of Eq. (2.26) is the kinetic energy (in contrast to dielectrics for which this term is the potential energy). Hence, the electric induction vector $D*(\omega)$ does not correspond to the physical definition of the electric induction vector.

The physical meaning of the introduced vector $\vec{P}*(\omega)$ is clear from

$$\vec{P}*(\omega) = \frac{\sigma_L}{\omega}\vec{E} = \frac{1}{L_k\ \omega^2}\vec{E}\ .$$

The interpretation of $\varepsilon(\omega)$ as frequency-dependent inductivity has been harmful for correct understanding of the real physical picture (especially in the educational processes). Besides, it has drawn away the researchers attention from some physical phenomena in plasma, which first of all include the transverse plasma resonance and three energy components of the magneto electro kinetic wave propagating in plasma [13-14].

III. Dielectric Media

Applied fields cause polarization of bound charges in dielectrics. The polarization takes some energy from the field source, and the dielectric accumulates extra electrostatic energy. The extent of displacement of the polarized charges from the equilibrium is dependent on the electric field and the coefficient of elasticity β, characterizing the elasticity of the charge bonds. These parameters are related as

$$-\omega^2\ \vec{r}_m + \frac{\beta}{m}\vec{r}_m = \frac{e}{m}\vec{E}, \qquad (3.1)$$

Where $\vec{r}_m$ is the charge displacement from the equilibrium.

Putting ω_0 for the resonance frequency of the bound charges and taking into account that $\omega_0 = \beta/m$ we obtain from Eq. (3.1)

$$\vec{r}_m = -\frac{e\vec{E}}{m\ (\omega^2\ - \omega_o^2)}$$

The polarization vector becomes

$$\vec{P}_m* = -\frac{n\ e^2}{m}\cdot\frac{1}{(\omega^2 - \omega_0^2)}\vec{E}.$$

Since

$$\vec{P} = \varepsilon_0 \ (\varepsilon - 1) \ \vec{E},$$

we obtain

$$\varepsilon'_{\partial} \ *(\omega) = 1 - \frac{n \ e^2}{\varepsilon_0 \ m} \cdot \frac{1}{\omega^2 - \omega_0^2}.$$

The quantity $\varepsilon'_{\partial} *(\omega)$ is commonly called the relative frequency dependably electric inductivity. Its absolute value can be found as

$$\varepsilon_{\partial} *(\omega) = \varepsilon_0 (1 - \frac{n \ e^2}{\varepsilon_0 m} \cdot \frac{1}{\omega^2 - \omega_0^2}). \quad (3.2)$$

Once again, we arrive at the frequency-dependent dielectric permitlivity. Let us take a closer look at the quantity $\varepsilon_{\partial} *(\omega)$. As before, we introduce $L_{k \ \partial} = \frac{m}{n \ e^2}$ and $\omega_{p.\partial} = \frac{1}{L_{k \ \partial} \varepsilon_0}$ and see immediately that the vibrating charges of the dielectric have masses and thus possess inertia properties. As a result, their kinetic inductivity would make itself evident too. Eq. (3.2) can be re-written as

$$\varepsilon_{\partial} *(\omega) = \varepsilon_0 (1 - \frac{\omega_{p \ \partial}^2}{\omega^2 - \omega_0^2}).$$

It is appropriate to examine two limiting cases: $\omega >> \omega_0$ and $\omega << \omega_0$.

If $\omega >> \omega_0$,

$$\varepsilon_{\partial} *(\omega) = \varepsilon_0 (1 - \frac{\omega_{p \ \partial}^2}{\omega^2}) \ ,$$

$$\mu_T *(\omega) = 1 - \frac{\Omega \ |\gamma| \ M_0}{\mu_0 (\omega^2 - \Omega^2)},$$

and the dielectric behaves just like plasma. This case has prompted the idea that at high frequencies there is no difference between dielectrics and plasma. The idea served as a basis for introducing the polarization vector in conductors [2]. The difference however exists and it is of fundamental importance. In dielectrics, because of inertia, the amplitude of charge vibrations is very small at high frequencies and so is the polarization vector. The polarization vector is always zero in conductors.

For $\omega << \omega_0$,

$$\varepsilon_{\partial} *(\omega) = \varepsilon_0 (1 + \frac{\omega_{p \ \partial}^2}{\omega_0^2}) \ ,$$

and the permittivity of the dielectric is independent of frequency. It is $(1 + \frac{\omega_{p \ \partial}^2}{\omega_0^2})$ times higher than in vacuum. This result is quite clear. At $\omega >> \omega_0$ the inertia properties areinactive and permittivity approaches its value in the static field.

IV. Magnetic Media

The resonance phenomena in plasma and dielectrics are characterized by repeated electrostatic-kinetic and kinetic-electrostatic transformations of the charge motion energy during oscillations. This can be described as an electrokinetic process, and devices based on it (lasers, masers, filters, etc.) can be classified as electrokinetic units.

However, another type of resonance is also possible, namely, magnetic resonance. Within the current concepts of frequency-dependent permeability, it is easy to show that such dependence is related to magnetic resonance. For example, let us consider ferromagnetic resonance. A ferrite magnetized by applying a stationary field H_0 parallel to the *z*-axis will act as an anisotropic magnet in relation to the variable external field. The complex permeability of this medium has the form of a tensor [15]:

$$\mu = \begin{pmatrix} \mu_T *(\omega) & -i \ \alpha & 0 \\ i \ \alpha & \mu_T *(\omega) & 0 \\ 0 & 0 & \mu_L \end{pmatrix} \ ,$$

where

$$\alpha = \frac{\omega \ |\gamma| \ M_0}{\mu_0 (\omega^2 - \Omega^2)}, \qquad \mu_L = 1,$$

$$\Omega = |\gamma| H_0. \quad (4.1)$$

Being the natural professional frequency, and

$$M_0 = \mu_0 (\mu - 1) H_0 \quad (4.2)$$

is the medium magnetization.

Taking into account Eqs. (4.1) and (4.2) for $\mu_T *(\omega)$, we can write

$$\mu_T *(\omega) = 1 - \frac{\Omega^2 (\mu - 1)}{\omega^2 - \Omega^2} \ . \quad (4.3)$$

Assuming that the electromagnetic wave propagates along the *x*-axis and there are H_y and H_z components, the first Max well equation becomes

$$rot \ \vec{E} = \frac{\partial \ \vec{E}_Z}{\partial \ x} = \mu_0 \mu_T \frac{\partial \ \vec{H}_y}{\partial \ t} \ .$$

Taking into account Eq. (4.3), we obtain

$$rot\ \vec{E} = \mu_0\left[1-\frac{\Omega^2(\mu-1)}{\omega^2-\Omega^2}\right]\frac{\partial\ \vec{H}_y}{\partial\ t}\ .$$

For ω>>Ω

$$rot\ \vec{E} = \mu_0\left[1-\frac{\Omega^2(\mu-1)}{\omega^2}\right]\frac{\partial\ \vec{H}_y}{\partial\ t}\ . \qquad (4.4)$$

Assumeng $\vec{H}_y = \vec{H}_{y0}\ sin\omega t$ and taking into account that

$$\frac{\partial\ \vec{H}_y}{\partial\ t} = -\omega^2\int\vec{H}_y\ d\ t\ .$$

Eq. (4.4) gives

$$rot\ \vec{E} = \mu_0\frac{\partial\ \vec{H}_y}{\partial\ t} + \mu_0\ \Omega^2(\mu-1)\int\vec{H}_y\ d\ t\ ,$$

or

$$rot\ \vec{E} = \mu_0\frac{\partial\ \vec{H}_y}{\partial\ t} + \frac{1}{C_k}\int\vec{H}_y\ d\ t\ .$$

For ω<<Ω

$$rot\ \vec{E} = \mu_0\mu\frac{\partial\ \vec{H}_y}{\partial\ t}\ .$$

The quantity

$$C_k = \frac{1}{\mu_0\ \Omega^2(\mu-1)}$$

can be described as kinetic capacitance[16-17]. What is its physical meaning? If the direction of the magnetic moment does not coincide with that of the external magnetic field, the vector of the moment starts precessional motion at the frequency Ω about the magnetic field vector. The magnetic moment $\vec{m}$ has the potential energy $U_m = -\vec{m}\cdot\vec{B}$. Like in a charged condenser, U_m is the potential energy because the precessional motion is inertia less (even though it is mechanical) and it stops immediately when the magnetic field is lifted. In the magnetic field the processional motion lasts until the accumulated potential energy is exhausted and the vector of the magnetic moment becomes parallel to the vector $\vec{H}_0$.

Magnetic resonance occurs at the point ω=Ω and μ_T*(ω)→–∞. It is seen that the resonance frequency of the macroscopic magnetic resonator is independent of the line size and equals Ω.

Thus, the parameter

$$\mu_H{}^*(\omega) = \mu_0\left[1-\frac{\Omega^2(\mu-1)}{\omega^2-\Omega^2}\right]$$

is not a frequency-dependent permeability.

V. Conclusion

Thus, it has been found that along with the fundamental parameters $\varepsilon\varepsilon_0$ and $\mu\mu_0$ characterizing the electric and magnetic energy accumulated and transferred in the medium, there are two more basic material parameters L_k and C_k. They characterize kinetic and potential energy that can be accumulated and transferred in material media. L_k was sometimes used to describe certain physical phenomena, for example, in super conductors, C_k has never been known to exist. These four fundamental parameters $\varepsilon\varepsilon_0$, $\mu\mu_0$, L_k and C_k clarify the physical picture of the wave and resonance processes in material media in applied electromagnetic fields. Previously, only electromagnetic waves were thought to propagate and transfer energy in material media. It is clear now that the concept was not complete. In fact, magneto electro kinetic, or electro magneto potential waves travel in material media. The resonances in these media also have specific features. Unlike closed planes with electromagnetic resonance and energy exchange between electric and magnetic fields, material media have two types of resonance – electro kinetic and magneto potential. Under the electro kinetic resonsnce the energy of the electric field changes to kinetic energy. In the case of magneto potential resonance the potential energy accumulated during the precessional motion can escape outside at the precession frequency.

The notions of permittivity and permeability dispersion thus become physically groundless though ε*(ω) and μ*(ω) are handy for a mathematical description of the processes in material media. We should however remember their true meaning especially where educational processes are involved.

It is surprising that Eq. (3.29) actually accounts for the whole of electrodynamics beause all current electrodynamics problems can be solved using this equation. What is then a magnetic field? This is merely a convenient mathematical procedure which is not necessarily gives a correct result (e.g., in the case of parallel-moving charges). Now we can state that electrocurrent, rather than electromagnetic, waves travel in space. Their electric field and displacement current vectors are in the same plane and displaced by π/2.

Any theory is dead unless important practical results are obtained of its basis. The use of the previously unknown transverse plasma resonance [14] is one of the most important practical results following from this study.

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