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ELECTRICAL CONDUCTIVITY OF EXTERNAL ELECTROMAGNETIC FIELD

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ABSTRACT

The internal generated electric field due to the interaction of matter with electromagnetic field is usually described by polarization. An alternative way based on the notion of internal field and current density is introduced in this wark . The mathematical model is based on RCL circuits and the effective values; as well as complex representations. It shows that the external field induces external field is perpendicular to it ,beside two current components ,One parallel and the other one is perpendicular to it also, The material act as a resister and a conductor connected in series.

***Keywords**: Electric conductivity, current density, resistance, capacitor.*

I. INTRODUCTION

The subject matter of electronics may be divided into two broad categories: the application of physical properties of materials in the development of electronic control devices and the utilization of electronic control devices in circuit applications [1,2].The interaction of light with matter has aroused interest – at least among poets, painters, and physicists [3]. This interest stems not so much from our curiosity about materials themselves, but rather to applications, should it be the exploration of distant stars, the burning of ships of ill intent, or the discovery of new paint pigments [4,5]. Optics, as defined is concerned with the interaction of electromagnetic radiation with matter. The theoretical description of the phenomena and the analysis of the experimental results are based on Maxwell's equations and on their solution for time-varying electric and magnetic fields. The optical properties of solids have been the subject of extensive treatise [6]. After introducing Maxwell's equations, we presented the time dependent solution of the equations leading to wave propagation. In order to describe modifications of the fields in the presence of matter, the material parameters which characterize the medium have to be introduced; the conductivity and the dielectric constant. In the following step, we defined the optical constants which characterize the propagation and dissipation of electromagnetic waves in the medium, the refractive index and the impedance. Next, phenomena which occur at the interface of free space and matter (or in general between two media with different optical constants) are described. This discussion eventually leads to the introduction of the optical parameters which are accessible to experiment: the optical reflectivity and transmission. The electromagnetic field interact with matter for insulators it penetrate it for dielectric it causes polarization ,for conductor it cannot penetrate but induces current one needs to find total(E) inside can or any material .In text books the internal field is described by polarization .This model is complex[7,8,9,10] . Attempts wave made to internal field concept [11]. This model succeed in explain amplification thus this work is can corned with using the same model to find total electric field ,total conductivity and resistivity.

1. Electric conductivity by using RLC circuits' relations

In resistance, capacitor and inductor circuit, There is a phase difference between currents and voltages.

$$V = L\frac{di}{dt} + Ri(1)$$

$$wli_0\, coswt + Ri_0\, sinwt$$

$$v_0 \sin(\omega t + \emptyset) = x_L icoswt + Ri_0\, sinwt$$

$$v_0 \sin \omega t cos\emptyset + v_0 cos\emptyset sinwt = x_L i_0 \, coswt = R i_0 \, sinwt$$

$$v_0 sinw = x_L i_0 \, v_0 cos\emptyset = R i_0$$

$$v_0{}^2 sin^2\emptyset + v_0{}^2 cos^2\emptyset = [x_L{}^2 + R^2] i_0{}^2$$

$$v_0 = \sqrt{x_L{}^2 + R^2}\, i_0 \quad (2)$$

This situation resembles that of the electron vibrating in an
oscillating electric field the equation of motion of electron is given by

$$m\frac{dv}{dt} = -eE - \gamma m v \qquad \gamma = \frac{1}{\tau} \qquad (3)$$

Consider the electron velocity be in the form

$$V = v_0 \sin wt \qquad (4)$$

Thus inserting this expression (4) in (3) yields

$$m w v_0 \cos wt = eE - \gamma m v_0 \sin wt$$

$$m[w v_0 \cos wt + \gamma v_0 \sin wt] = eE$$

Multiplying both sides by the conductor length α the potential is given by

$$\frac{md}{ne^2}[new v_0 \cos wt + \gamma ne v_0 \sin wt] = Ed = V \quad (5)$$

But the maximum current i_0 and current density j_0 are given by

$$ne v_0 = j_0 i_0 = j_0 A$$

Hence equation(5)can be re written as

$$V = \frac{md}{ne^2 A}[\frac{x_L}{L} i_0 \cos wt + \gamma i_0 \sin wt] \qquad (6)$$

Where $x_L = wL$,thus

$$V = [\frac{md x_L}{ne^2 AL} i_0 \cos wt + \frac{md\gamma}{ne^2 A} i_0 \sin wt] \quad (7)$$

Comparing (6)and(7)yields

$$\sigma = \frac{ne^2\tau}{m} \rho = \frac{1}{\sigma} = \frac{m}{ne^2\tau} = \frac{m\gamma}{ne^2} \qquad L = \frac{md}{ne^2 A}$$

But the resistance R and inductive reactance x_L are given by

$$R = \frac{\rho d}{A} = \frac{m\gamma d}{ne^2 A} x_L = \frac{mdw}{ne^2 A} = wL \qquad (8)$$

Thus the potential can be written as

$$V = x_L i_0 coswt + R i_0 sinwt \qquad (9)$$

But one can write

$$V = v_0 \sin(\omega t + \emptyset) = v_0 sin\emptyset coswt + v_0 cos\emptyset sinwt \quad (10)$$

Comparing equation (9) and (10)

$$v_0 sin\emptyset = x_L i_0 v_0 cos\emptyset = \ R i_0$$

There for

$$v_0{}^2 sin^2\emptyset + v_0{}^2 cos^2\emptyset = v_0{}^2 = [x_L{}^2 + R^2] i_0{}^2$$

$$v_0 = \sqrt{x_L{}^2 + R^2}\, i_0 \quad (11)$$

Hence the impedance is given by

$$Z = \frac{v_e}{i_e} = \frac{\frac{v_0}{\sqrt{2}}}{\frac{i_0}{\sqrt{2}}} = \frac{v_0}{i_0} = \sqrt{x_L{}^2 + R^2} = \frac{1}{y}$$

The admittance can thus be given to be

$$y = \frac{i_0}{v_0} = \frac{\sigma A}{d} = \frac{1}{\sqrt{x_L{}^2 + R^2}} \quad (12)$$

Using equation (8) the total conductivity is given by

$$\sigma = \frac{1}{\rho} = \frac{d}{AR} = \frac{d}{AZ} = \frac{d}{A} y = \frac{d}{A} \frac{1}{\sqrt{x_L{}^2 + R^2}} \quad (13)$$

where the potential takes the form [see(10)]

$$V = Ed = E_0 \mathrm{d}\sin(wt + \emptyset)$$

$$= E_0 \mathrm{d}\sin(wt + \emptyset) = v_0 \sin(wt + \emptyset) \quad (14)$$

Thus according to equation (14) the electric field inside the medium is given by

$$\mathrm{E} = E_0 \sin(wt + \emptyset)$$

$$\mathrm{E} = E_0 \sin\emptyset\, coswt + E_0 cos\emptyset sinwt \quad (15)$$

In view of equation (5) the part including w is related to inductance which is proportional w thus the internal field is generated electromagnetic induction, since the resistive term in equation (5) most stand for resistance to the external field E through friction coefficient

$$V_i = L \frac{di}{dt}$$

But the current i takes the form: $i = neAv$ thus the inductive voltage is related to the internal generated potential according to the relation

$$V_i = E_i d = \frac{enALdv}{dt} = \frac{enALd(v_0 sinwt)}{dt}$$

$$= enALv_0 coswt = dE_{0i} coswt = dE_i$$

Thus the internal field is given by $E_i = E_{0i} coswt$ (16)

Hence according to equation (15) $E_i = E_0 \sin\emptyset\, coswt$

Which means that $E_{0i} = E_0 \sin\emptyset$ (17)

The external field is thus given by

$$E_e = E_{0i} \sin wt = E_i = E_0 \cos\emptyset\, sinwt \quad (18)$$

Thus σ_1 can be found to be from equation (8) to get

$$R = \frac{d}{\sigma_1 A} = \frac{\rho_1 d}{A} \quad (19)$$

But $x_L = wl = \frac{d}{\sigma_2 A}$

$$x_L = \frac{wmd}{ne^2 A} = c_0 \frac{d}{A} = \frac{1}{\sigma_2}\frac{d}{A} \quad (20)$$

Thus the conductivity for inductance takes the form

$$c_0 = \frac{wm}{ne^2} = \frac{1}{\sigma_2} = \rho_2 \quad (21)$$

$$\sigma = (\frac{d}{A}) = \frac{1}{(\frac{d}{A})\sqrt{(\frac{1}{\sigma_1})^2 + (\frac{1}{\sigma_2})^2}}$$

thus

$$\frac{1}{\sigma} = \sqrt{(\frac{1}{\sigma_1})^2 + (\frac{1}{\sigma_2})^2} \quad (22)$$

Therefore the net resistivity is given by

$$\rho = \sqrt{\rho_1{}^2 + \rho_2{}^2} \quad (23)$$

2. Electric conductivity by using effective values.

The electric conductivity can also be found by using directly
the concept of current density and electric field. The electric field E and current density J are related by

$$j_e = \sigma E_e \quad (24)$$

Where J_e and E_e are the effective values which are related to the maximum values J_0 and E_0 , thus

$$J_e = \frac{J_0}{\sqrt{2}}$$

$$E_e = \frac{E_0}{\sqrt{2}}$$

$$j_0 = \sigma E_0 \qquad (25)$$

According to equation the electron equation of motion becomes.
$mwv_0 \cos wt + \gamma m v_0 \sin wt$

$$= eE_0 \sin(wt + \emptyset) \qquad (26)$$

$$= eE_0 \sin\emptyset \cos wt + eE_0 cos\emptyset sinwt)$$

$$= eE_{e0} coswt + eE_{i0} sinwt \qquad (27)$$

Where the total electric field is given by
$E = E_0 \sin(wt + \emptyset) = E_0 \sin\emptyset \cos wt + E_0 cos\emptyset sinwt \qquad (28)$

Comparing equation (26) and (28) yields

$$mwv_0 = eE_{i0} = eE_0 \sin\emptyset$$

$$m\gamma v_0 = eE_{e0} = eE_0 \cos\emptyset \qquad (29)$$

But the current density is related to the velocity by

$$j_0 = nev_0 \qquad (30)$$

Using equation (29) by squaring both sides one gets

$$[m^2 w^2 + m^2 \gamma^2] v_0{}^2 = e^2 E_0{}^2 [sin^2\emptyset + \cos^2\emptyset] = e^2 E_0{}^2$$

Hence

$$eE_0 = m\sqrt{w^2 + \gamma^2}\, v_0 \qquad (31)$$

$$v_0 = \frac{eE_0}{m\sqrt{w^2 + \gamma^2}} \qquad (32)$$

Inserting equation (32) in (31) yields

$$j_0 = \frac{ne^2 E_0}{m\sqrt{w^2 + \gamma^2}} \qquad (33)$$

Comparing equations (33) and (24) yield

$$\sigma = \frac{1}{\sqrt{\frac{m^2 w^2}{n^2 e^4} + \frac{m^2 \gamma^2}{n^2 e^4}}} \qquad (34)$$

in view of equations (8) and (20)

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$$\sigma = \frac{1}{\sqrt{(\frac{1}{\sigma_1})^2 + (\frac{1}{\sigma_2})^2}}$$

$$\frac{1}{\sigma} = \sqrt{(\frac{1}{\sigma_1})^2 + (\frac{1}{\sigma_2})^2} \qquad (35)$$

Hence

$$\rho = \sqrt{{\rho_1}^2 + {\rho_2}^2} \qquad (36)$$

3. Electric conductivity using complex representation.

Another alternative can be also used to find the total conductivity and resistivity by suggesting V to be in a complex form as

$$v = v_0 e^{i\omega t} \qquad (37)$$

But the electron equation in a resistive medium is given by

$$m\frac{dv}{dt} = -eE - \gamma m v \qquad (38)$$

Substituting equation (37) in (38)yields

$$imwv = -eE - \gamma m v$$

$$(imw + \gamma m)v = eE \qquad (39)$$

Since external field is related to conductor resistance through V and γ which recognizes resistance thus $E_e = E_0 \cos\emptyset \, sinwt$

This is the real part of E stands for external field .Hence

Let$E = (E_e + iE_i)e^{i\omega t}$

$$= (E_0 \cos\emptyset + iE_0 \sin\emptyset)e^{i\omega t} = E_0 \quad e^{i(\omega t + \emptyset)} \qquad (40)$$

Inserting equation(40) in equation (39)yields

$$m(iw + \gamma)v_0 e^{i\omega t} = eE_0 \quad e^{i(\omega t + \emptyset)}$$

Therefore

$$m(iw + \gamma)v_0 = eE_0 \quad e^{i\emptyset}$$

$$m(iw + \gamma)v_0 = eE_0(\cos\emptyset + i\sin\emptyset)$$

Hence

$$eE_0 \cos\emptyset = m\gamma v_0 \, eE_0 \sin\emptyset = mwv_0 \qquad (41)$$

Squaring both sides, gives

$$e^2E_0{}^2[sin^2\emptyset + \cos^2\emptyset] = m^2[w^2+\gamma^2]v_0{}^2$$

$$eE_0 = m\sqrt{w^2+\gamma^2}\,v_0$$

$$v_0 = \frac{eE_0}{m\sqrt{w^2+\gamma^2}} \quad (42)$$

But the current density is given by

$$j_0 = nev_0 = \sigma E_0 \quad (43)$$

Substituting (42) gives

$$j_0 = \frac{ne^2E_0}{m\sqrt{w^2+\gamma^2}} = \frac{E_0}{\sqrt{\frac{mw^2}{n^2e^4}+\frac{m^2}{n^2e^4\tau^2}}}$$

As a result

$$\sigma E_0 = \frac{E_0}{\sqrt{\frac{mw^2}{n^2e^4}+\frac{m^2}{n^2e^4\tau^2}}} \quad (44)$$

Thus the view of equation(8) and (21)yields

$$\sigma = \frac{1}{\sqrt{(\frac{1}{\sigma_1})^2+(\frac{1}{\sigma_2})^2}}$$

$$\frac{1}{\sigma} = \sqrt{(\frac{1}{\sigma_1})^2+(\frac{1}{\sigma_2})^2} \quad (45)$$

$$\rho = \sqrt{\rho_1{}^2+\rho_2{}^2} \quad (46)$$

4. Travelling wave solution and internal current.

Conceder travelling wave electric field of the form

$$E = E_0\sin(kx-wt) = E_0 sin\theta(x,t) \quad (47)$$

The electron equation of motion is

$$m\frac{dv}{dt} = -eE - \gamma mv \quad (48)$$

The velocity which satisfy this equation must be

$$v = v_0\sin(kx-wt+\varphi) = v_0\sin(\theta+\varphi) \quad (49)$$

Thus

$$m\frac{dv}{dt} = -wv_0\cos(\theta+\varphi) \quad (50)$$

Inserting equation (49), (50), (47) in (48) yields

$-mwv_0\cos\varphi\cos\theta + mwv_0\sin\varphi\sin\theta =$

$= eE_0\sin\theta - m\gamma v_0\cos\varphi\sin\theta - m\gamma v_0\sin\varphi\cos\theta$

Equating coefficients of $\cos\theta$ and $\sin\theta$ an both sides yields

$-mwv_0\cos\varphi = m\gamma v_0\sin\varphi$

$mwv_0\sin\varphi = eE_0 - m\gamma v_0\cos\varphi$ (51)

$\tan\varphi = \frac{w}{\gamma}$ $\sin\varphi = \frac{w}{\sqrt{w^2+\gamma^2}}$ $\cos\varphi = \frac{\gamma}{\sqrt{w^2+\gamma^2}}$ (52)

$m[w\sin\varphi + \gamma\cos\varphi]v_0 = eE_0$ (53)

$$m\left[\frac{w^2}{\sqrt{w^2+\gamma^2}} + \frac{\gamma^2}{\sqrt{w^2+\gamma^2}}\right]v_0 = eE_0$$

$$m\left[\frac{w^2+\gamma^2}{\sqrt{w^2+\gamma^2}}\right]v_0 = eE_0 \qquad (54)$$

$$v_0 = \frac{eE_0}{m\sqrt{w^2+\gamma^2}} \qquad (55)$$

Using the same procedures as in equation (31- (35),one gets

$$\rho = \sqrt{{\rho_1}^2 + {\rho_2}^2} \qquad (56)$$

This means that the incidence of travelling electromagnetic wave causes electron to travel also with speed shown by equation (49).The materials behaves as inductor and resistor in series. In view of equations (47)(49)and(55) one have two currents , the one resulting from the external field (47) and it takes the form

$J_e = \sigma_e E_e = nev_0\cos\varphi\sin(wt - kx)$ (57)

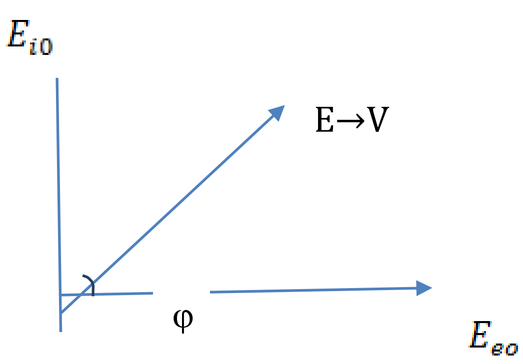
The other is due to an internally induced electromagnetic field by oscillating charge, and is given by

$J_i = \sigma_i E_i = nev_0\sin\varphi\sin(wt - kx)$ (58)

Such that

$E_{eo} = nev_0\cos\varphi$

$E_{i0} = nev_0\sin\varphi$



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The resultant field is due to the effect of external and internal field.

II. DISCUSSION

The interaction of electromagnetic field with mater resuts in generating internal electromagnetic field a equation (15) shows.The material respond to the external field by dissipating energy by friction, while the response to the internal field manifests itself through inducing inductive current and inductive reactance as shown by equation (29) .The net electric field inside matter subtends an angle φ with respect to E_g as equation (26) reads. The net current flowing inside matter faces a total resistance resulting from friction and induction current. This resistance is that of a resistor and inductor connected in series as shown by equations (23), (24), (36) and (55). When friction is neglected equation (29) indicates that φ is 90. And only induction current and electromotive internal field exists. If electromagnetic field is a travelling wave [in equation (47)], this wave induces frictional current generated by external field [see equation (52),(56)]beside induction current generated by internal field [see equation (52),(57)].

III. CONCLUSION

The transmition of electromagnetic field through amedium induces electromotive internal field ,acting as an inductor. The net effect of the interaction corresponds to resistor and inductor connected in series.

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