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Phase effect between the Electric Internal Current Field and the External Current Field on Amplification of the Total Field and Intensity of the Electromagnetic Radiation

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ABSTRACT

This work is devoted for searching new mechanisms of amplification of electromagnetic radiation which are related to the phase between the external and the internal fields. It is found that amplification takes place if external and internal fields are in phase. The amplification is also found to be related to the electrical conductivity of the medium, in which imaginary conductivity disappears. Thus new lasing materials, can generate laser.

KEYWORDS: New lasing materials, phase, external field, internal field.

1.INTRODUCTION

In Einstein paper which was published(1,2,3,4,5) in 1917 by *Zeitschrift fur Physik* and entitled “On the Quantum Theory of Radiation”, Einstein described three main processes for how radiation interacts with matter. These processes were spontaneous emission, absorption, and stimulated emission. In spontaneous emission, an atom in an excited state decays to a lower energy state by itself without any external assistance. In absorption, an atom absorbs a quantum of radiation and reaches a higher energy state known as an excited state. And in stimulated emission, an atom in an excited state is caused to decay to a lower energy state by an incident photon, he asserts that the emitted quantum must be the same in all relevant aspects to the incident quantum. The principle of stimulated emission is the key for laser. By the 1950s, several different engineers and physicists using the principle of stimulated emission, at this stage they were working towards the creation of what was termed a maser. This technique was used in microwave communication systems. The maser was the precursor for the laser. Physicist Townes believed in 1958(6,7,8,9), that it was possible to create an optical maser, a device for creating powerful beams of light using higher-frequency energy to stimulate what was to be termed the lasing medium. Despite his pioneering work, it was left to Maiman in 1960(10,11,12) to invent the first laser using a lasing medium of ruby. Just before the end of 1960, published in 1961(13,14), Javan, Bennet, and Herriot made the first gas laser using Helium and Neon. This type of laser (a He-Ne laser) became the dominant laser for the next 20 years until cheap semiconductor lasers took over in the mid-80's. Atomic gas lasers were limited in power, so Patel began working with carbon dioxide, published in 1964(15) and carbon monoxide lasers. Thus Patel made the first high powered gas lasers. Earl bell then discovered the ion laser which was the first step towards the argon-ion laser developed by Bridges(16). Some further developments of laser were generating lasing effect by means of chemical reactions(17,18) instead of electric currents, dyes(19) as a medium to tune the laser across a range of wavelengths, and using p-n junctions in semiconductors(20) to create lasing effects. In 1970, Alferov in the Soviet Union and Hayashi, and Panish of Bell Telephone Laboratories independently developed laser diodes(21.22) Although laser was a technical tool, but in its early years it was a technology with no practical application. It was not powerful enough for use in beam weapons, and its usefulness for transmitting information through the atmosphere was restricted by its inability to penetrate

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clouds and rain. Fiber-optic research helped laser technology and enabled communications worldwide. The improvement of the p-n junction in the semiconductor and the application of laser in the communication these two technologies complimented each other and gave a new boost to laser application. Now there are many military, medical and commercial laser applications which have been developed since the invention of the laser in the 1958. The coherency, high monochromaticity, and ability to reach extremely high powers are all properties which allow for these specialized applications. Lasers are also used in many scientific branches, including spectroscopy. Despite the wide variety of application of laser in modern technology, its theoretical background suffers from noticeable setbacks. One of them for e.g. is related to the theory of amplification which needs to be promoted to relate amplification to more physical parameters(23)so as to produce new laser types. Amplification conditions that are responsible for inducing laser are discussed by many authors. Some of them, relate amplification to the internal field(24). Others relate it to the photon coherence(25). The aim of this work is to relate the amplification of the electromagnetic radiation to the phase between external and internal fields, as shown in sections (3) and (4). Section (2) is devoted for relating conductivity to the phase between the electric field intensity and the velocity of the electron. Discussion and conclusion are exhibited in sections (5) and (6) respectively.

2.The relation between the conductivity and the phase between the external electric field intensity(E) and the velocity of the electron(υ):

Equation of motion of the electron of mass *m* and velocity *v* under the action of electric force *eE* and resistive force $\gamma\upsilon$ is given by(26)

$$m\,\frac{dv}{dt} = eE - \gamma\upsilon \qquad (2.1)$$

Where *e* is the electron charge, *E* is the external electric field intensity, and γ is the resistance coefficient. Consider the velocity *v* and the external electric field intensity *E* to be in the form

$$\upsilon = \upsilon_0 \sin(\omega t + \phi) \qquad (2.2)$$

$$E = E_0 \sin\omega t \qquad (2.3)$$

Where ϕ is the phase, v_0 and E_0 are the velocity and the external electric field intensity amplitude respectively while ω is the angular frequency.

The current density is given by(27)

$$J = en\upsilon \qquad (2.4)$$

Where n is electron density

Substituting (2.2) in (2.4) yields

$$J = en\upsilon_0 \sin(\omega t + \phi) \qquad (2.5)$$

$$J = en\upsilon_0 (\cos\phi \sin\omega t + \sin\phi \cos\omega t) \qquad (2.6)$$

Looking at (2.6), it is clear that the phase ϕ between E and υ produces an additional oscillating cosine term. There for the definition of conductivity in terms of J and E should include two terms, one corresponds to the external field intensity E as in (2.3) the other may be defined to be representing a medium field intensity E_m in the form

$$E_m = E_{m0} \cos\omega t \qquad (2.7)$$

Where E_{mo} is the medium field intensity amplitude

Thus J can be written in terms of

$$J = \sigma_1 E + \sigma_2 E_m \qquad (2.8)$$

By substituting the value of E_m from equation (2.7) in equation (2.8) we find;

$$J = \sigma_1 E_0 \sin\omega t + \sigma_2 E_{m0} \cos\omega t \qquad (2.9)$$

Comparing the coefficients of $\sin\omega t$ and $\cos\omega t$ in (2.7) and (2.9) yields

$$ne\upsilon_0 \cos\phi = \sigma_1 E_0 \qquad (2.10a)$$

$$ne\upsilon_0 \sin\phi = \sigma_2 E_{m0} \qquad (2.10b)$$

Thus the external and medium field intensity conductivities σ_1 and σ_2 are given by

$$\sigma_1 = \frac{ne\upsilon_0}{E_0}\cos\phi \qquad (2.11a)$$

$$\sigma_2 = \frac{ne\upsilon_0}{E_{m0}}\sin\phi \qquad (2.11b)$$

This last one is an imaginary conductivity.

3.The relation between the amplification of the electromagnetic radiation and the phase between the external electric field intensity(E) and the velocity of the electron(υ):

To see how the phase angle ϕ between E and υ affect the amplification of electromagnetic radiation, it is important to utilize the expression for light intensity I which penetrates a distance Z inside a medium, which is given by[28]

$$I = I_0 e^{\beta Z} \qquad (3.1)$$

Where I_0 is the initial light intensity, β is the amplification factor it is given by[29,30]

$$\beta = \frac{\mu c \sigma_1}{n_1} \qquad (3.2)$$

Where μ , c , and n_1 are the magnetic permeability, speed of light, and refractive index respectively. Inserting (2.11-a) in (3.2) gives

$$\beta = \frac{\mu c n e \upsilon_0}{n_1 E_0}\cos\phi \qquad (3.3)$$

It is clear from this relation that amplification takes place when ϕ vanishes, i.e. when E and υ are in phase with each other, in this case

$$\beta = \frac{\mu c n e \upsilon_0}{n_1 E_0} \qquad (3.4)$$

Also it is clear that when E and υ are in phase the amplification depends only on the external conductivity, because the medium one is disappear.

And when ϕ = 90 no amplification or absorption takes place i.e.

$$\beta = 0 \qquad (3.5)$$

But when ϕ = 180 = π absorption takes place in this case equation (3.3) becomes

$$\beta = -\frac{\mu c n e \upsilon_0}{n_1 E_0} \qquad (3.6)$$

4.The relation between the amplification of the total field and also the amplification of the total intensity of the electromagnetic radiation with the phase between the external field intensity(E) and the internal field intensity(E_i):

E_i satisfying the relation

$$J = ne\upsilon = \sigma_0 E_i \qquad (4.1)$$

So $$E_i = \frac{ne\upsilon}{\sigma_0} = \frac{ne\upsilon_0 \sin(\omega t + \phi)}{\sigma_0} \qquad (4.2a)$$

$$E_i = E_{io}\sin(\omega t + \phi) \qquad (4.2b)$$

Where E_{io} is internal field intensity amplitude

E and E_i are in phase when $\phi = 0$. Thus the total field E_T in the direction of E is given by

$$E_T = (E_0 + E_{io})\sin(\omega t) = E_{To}\sin(\omega t) \qquad (4.3)$$

Where E_{To} is total field intensity amplitude.

And the total intensity of the electromagnetic radiation is given by

$$I = (E_0 + E_{io})^2 \qquad (4.4)$$

Thus the total field increases and the amplification of the intensity of the electromagnetic radiation is also takes place, increases from $E_0{}^2$ to ($E_0 + E_{io})^2$. Which is in consistent with (3.1) and (3.4). But if E and E_i are out of phase by 90. i.e. $\phi = 90$ in this case (4.2b) becomes $E_i = E_{io}\sin(\omega t + 90)$ i.e.

$$E_i = E_{io} \ \cos\omega t \qquad (4.5)$$

Thus no component of E_i in the E direction, according to the law of vectors the total field intensity amplitude in the direction of E is given by

$$E_{To} = (E_0 + E_{io}) = E_0 + 0 = E_0 \qquad (4.6)$$

Substituting (4.3) in (4.6) one found that;

$$E_T = E_{To}\sin\omega t = E_0\sin\omega t \qquad (4.7)$$

And

$$I = E_{To}{}^2 = E_0{}^2 = I_0 \qquad (4.8)$$

Thus the light passes without attenuation or amplification. This result is again in agreement with equation (3.1) and (3.5)

And when E and E_i are out of phase by, π i.e. $\phi =$ 180 in this case the resultant field in the E direction is given by

$$E_T = E_0\sin\omega t + E_{io}[\sin\omega t\cos\pi + \cos\omega t\sin\pi] \qquad (4.9)$$

So that ;

$$E_T = E_0\sin\omega t - E_{io}\sin\omega t \qquad (4.10)$$

By using equation (4.7) , equation (4.10) become;

$$E_{To}\sin\omega t = (E_0 - E_{io})\sin\omega t \qquad (4.11)$$

Divided two side of equation (4.11) by sin(ωt)

$$E_{To} = E_0 - E_{io} \qquad (4.12)$$

Thus the total field decreases i.e.

$$\begin{Bmatrix} E_{T_0} \prec E_0 \\ E_{T_0}^2 \prec E_0^2 \\ I \prec I_0 \end{Bmatrix} \qquad (4.13)$$

That is absorption takes place, this is also in consistent with (3.1) and (3.6) where

$$I = I_0 e^{-\beta z}$$

DISCUSSION

The electron equation of motion in the presence of a resistive medium see equation (2.1), requires the existence of a medium field, perpendicular to the external one, as shown in equation (2.7), when there is a phase between the velocity of the electron and the external field. See equation (2.2) and (2.3). The definition of the conductivity according to its relation to the external field, indicates the existence of two conductivity types. One of them reflects the flow of electric current in the direction of the external field according to equation (2.11a). While the other reflects the flow in the perpendicular direction to the external field. See (2.11b) This means that the internal field is also described by two components, one of them in the direction of the external field while the other is perpendicular to it. The relation (3.3) between the amplification factor of the electromagnetic radiation and the phase between the external field and the internal one, has shown that, when the internal and the external fields are in phase, amplification takes place, see equation (3.4). This requires vanishing of imaginary conductivity. But when they are perpendicular to each other no amplification takes place, as shown by equation (3.5). Absorption happens when the phase between them is π, according to equation (3.6). This work is useful for searching a new laser type material in which external and internal fields are coherent. According to equations(2.11(a & b)), the amplification factor which depends on the phase ϕ is strongly depends on the conductivities of the external and the medium currents generated by the external and the medium fields.

Conclusion:

The new amplification factor which is derived in this work shows the possibility of the existence of new lasing mechanisms. It is clear that the lasing depends on the phase relation between the external and the internal electric fields, as well as the conductivities of the external and the medium currents. Lasing takes place when external and internal fields are in phase. This requires disappearance of a medium imaginary conductivity.

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