RADIATION AND LIGHT - THE INTERACTION OF RADIATION WITH THE SUBSTANCE

Student Ph.D. Candidate Gîrdu Constantin Cristinel *University* ***Transilvania from Brașov****, ROMÂNIA*
from Târgu-Jiu, ROMÂNIA
Lecturer PhD Eng. Mileșan Mihaela *University* ***Transilvania from Brașov****, ROMÂNIA*
Lecturer PhD Eng. Rădulescu Constanța., *University ,,Constantin Brâncuși,, from Târgu-Jiu, ROMÂNIA*

ABSTRACT: The paper treats aspects of light and its interaction with substance. A theory of electromagnetic field described by Maxwell's equations and a theory of black body radiation described by Planck are created in this manner. The objectives of this study were to specify the energy density of the light field and the specific spectral density of the radiation. Radiation emitted by a heated body is considered as thermal radiation. The Poyting vector defines the energy flow of light. The described mathematical relationships define the fundamental physical quantities treated in thermal radiation theory and field theory.

KEY WORDS: field theory, thermal radiation

1. INTRODUCTION

Quantum mechanics revolutionized physics in the first half of the twentieth century. Planck, Einstein, Bohr, Heisenberg, Schrödinger managed to capture microscopic phenomena in their theories. Nature plays honestly, does not forgive and always tries to transmit something to us. Planck stated that the glow of hot bodies is due to quantum. Light rays are emitted by bright substances. Einstein hypothesized that light is a flow of particles. Bohr discovered that the energy of an atom changes by a discrete value given by a quantum. If an atom emits light, then it passes into a quantum state with lower energy. Max Planck tried to fine-tune the clarification of the concept of light which was based on the interaction between theory and consciousness. At the same time, he assumed that electrons are very small particles stiring in a hot body emitting electromagnetic radiation. Conclusion: electrons shake atoms regardless of the nature of the material, and quantum of vibration with a very short duration like a pulse of light. Planck discovered the formula for thermal radiation. He explains that electrons get energy from hot atoms by performing quantum jumps. According to Albert Einstein, light shining on a metal causes electrons to appear suddenly. He also showed that light is a flux of photons with energy equal to h X ν. Photons are created and emitted when electrons emit light. When light is ultraviolet or blue the light is radiated by the natural phenomenon of emission. Heisenberg explains that light has a dual wave-corpuscle character, so it results that we are dealing with a special property of matter and radiation when we talk about electrons and photons [7].

2. RADIATION – SUBSTANCE INTERACTION

As a steel sheet heats up and becomes hotter, it can be deduced that the thermal agitation increases, the electrons reach a higher speed emitting a wave through the material at high frequency. The hotter the steel, the brighter the incandescence. An atom vibrates if it is hit by a neighboring atom moving through the hot material. The electron is a particle that performs a quantum jump losing energy by emitting a photon. The electrons of the atoms radiate energy in quanta of light. The energy of a quantum is equal to the Planck X constant and the vibration frequency of the electron. The electron suddenly radiates a electrons are emitted with high energy. In the case of yellow light, the frequency is lower and the energy of the photons decreases. The higher the frequency of light, the higher the energy of the electrons emitted from the metal. High energy light gives energy to electrons for them to leave the metal [4], [5], [6], [7].

3. MATHEMATICAL MODELING

Lev Davidovici Landau calculated the energy flow of radiation in Electromagnetic Field Theory. He started from the equation of the electromagnetic field through substance [2]:

$$rot\vec{H} = -\frac{1}{c}\frac{\partial \vec{E}}{\partial t} + \frac{4\pi}{c}\cdot\vec{j} \qquad (1)$$

As well, we will consider that there is a displacement and movement of electric charges and a variation of the field potential - the Poynting vector.

$$rot\vec{E} = -\frac{1}{c}\frac{\partial \vec{H}}{\partial t} \qquad (2)$$

We propose the following calculations:

$$rot\vec{H} = \left[-\frac{1}{c}\frac{\partial \vec{E}}{\partial t} + \frac{4\pi}{c}\cdot\vec{j}\right] X\vec{E}$$

$$rot\vec{E} = \left[-\frac{1}{c}\frac{\partial \vec{H}}{\partial t}\right] X\vec{H}$$

$$\vec{E}rot\vec{H} = -\frac{1}{c}\vec{E}\frac{\partial \vec{E}}{\partial t} - \frac{4\pi}{c}\cdot\vec{j}\vec{E}$$

$$\vec{H}rot\vec{E} = -\frac{1}{c}\vec{H}\frac{\partial \vec{H}}{\partial t}$$

$$\frac{1}{c}\vec{E}\frac{\partial \vec{E}}{\partial t} + \frac{1}{c}\vec{H}\frac{\partial \vec{H}}{\partial t} = -\frac{4\pi}{c}\cdot\vec{j}\vec{E} - (\vec{E}rot\vec{H} + \vec{H}rot\vec{E})$$

$$\frac{1}{c}\vec{E}\frac{\partial \vec{E}}{\partial t} + \frac{1}{c}\vec{H}\frac{\partial \vec{H}}{\partial t} = -\frac{4\pi}{c}\cdot\vec{j}\vec{E} - div\left[\vec{E}\vec{H}\right]$$

$$\frac{1}{4\pi}\vec{E}\frac{\partial \vec{E}}{\partial t} + \frac{1}{4\pi}\vec{H}\frac{\partial \vec{H}}{\partial t} = -\vec{j}\vec{E} - \frac{c}{4\pi}div\left[\vec{E}\vec{H}\right]$$

$$\frac{1}{8\pi}2\vec{E}\frac{\partial \vec{E}}{\partial t} + \frac{1}{8\pi}2\vec{H}\frac{\partial \vec{H}}{\partial t} = -\vec{j}\vec{E} - \frac{c}{4\pi}div\left[\vec{E}\vec{H}\right]$$

$$\frac{1}{8\pi}\frac{\partial}{\partial t}(\vec{E}^2 + \vec{H}^2) = \frac{1}{8\pi}(\vec{E}'^2 + \vec{H}'^2) = -\vec{j}\vec{E} - \frac{c}{4\pi}div\left[\vec{E}\vec{H}\right]$$

(3)

From the last relation results the energy flow, given by the Poynting vector:

$$\mathrm{P} = \frac{c}{4\pi}div\left[\vec{E}\cdot\vec{H}\right] \qquad [4]$$

The minus sign indicates that we have a radiation emission. The equation of the radiation energy flow becomes:

$$P = -\vec{j}\cdot\vec{E} - \frac{1}{8\pi}\frac{\partial}{\partial t}(\vec{E}^2 + \vec{H}^2) = -\vec{j}\cdot\vec{E} - \frac{\partial}{\partial t}\frac{\vec{E}^2 + \vec{H}^2}{8\pi} = -\vec{j}\cdot\vec{E} - \frac{\partial w}{\partial t} \qquad [5]$$

where:

$w = \frac{\vec{E}^2 + \vec{H}^2}{8\pi}$ is the energy density of the electromagnetic field which is defined as energy per volum unit.

The intensity of the light field I is proportional to the electric field and the nature of the environment.

4. RESULTS

Electromagnetic field formulas are applied in the electrodynamic theory of the laser. The red light beam scans the barcodes coming from a laser. In the case of personal computers, a laser writes and reads a DVD, DWD. A powerful laser pierces the ultra-hard steel.

Fig. The CO_2 laser pierces the ultra-hard steel.

Lasers generate light for fiber optic communications. With a concentrated energy laser an ophthalmologist fixes the detached retina [7]. A laser generates a converging beam of light concentrated in a very small space. The maximum intensity of the laser is in the focal spot which measures microns, and the laser spot has an area of about hundreths of mm. When an incident photon - a particle of light that possesses the energy of a quantum interacts with an electron of an excited atom it stimulates the emission of an induced photon which is a clone of the incident photon.

The direction of the stimulated photon is identical to that of the incident photon resulting in two photons. Continuing the process in the sense that if these two photons meet other excited atoms they enter them and collide 2 electrons resulting in the appearance of 4 photons (two incidents and two stimulated).

The light amplification reaction can continue due to the stepwise multiplication of the number of photons. The light passes back and forth through the laser material reflecting between two mirrors resulting in amplification of the incident intensity of the laser radiation [3].

The field represents the radiant energy of the laser light that is emitted in the form of energy quanta called photons. The photon has no resting mass, is electrically neutral, has no electric charge. The mass of the photon is directly proportional to the frequency of the radiation.

The number of photons in the active medium is calculated using the geometric progression in which the first term is $a_1 = 2$ with the ratio r = 2.

The general formula is given by the relation:

$$S_n = a_1 \frac{r^n - 1}{r - 1} = 2 \times (1 + 2 + 2^2 + 2^3 + 2^4 + ... + 2^{n-1})$$

[6]

5. INTERPRETATION OF RESULTS

The laser impact on a sheet of steel consists in heating the sheet very strongly in the working area. Due to the thermal conductivity of steel, the speed of heat penetration into the material of the steel plate does not heat up very quickly. Instead, in the cutting area, the temperature rises a lot. This parameter characterizes the heating state of a body. By the interaction of steel with laser radiation the material is heated resulting in thermal radiation. This radiation is electromagnetic in nature and it is emitted by the body heated to temperatures above 500 degrees Celsius. The energy flow through a slot is [1]:

$$\phi = \iiint_{\lambda S \Omega} I_\upsilon \cos\theta d\lambda dS d\Omega \qquad [7]$$

The energy of the radiation emitted in the volume unit (energy density) is described by the relation:

$$\varepsilon = \iint_{\lambda V} \rho_\lambda d\lambda dV \qquad [8]$$

Depending on the frequency of the emitted radiation we have:

$$\Phi = \iint_{\lambda V} \rho_\lambda d\lambda dV = \iint_{\nu V} \rho_\nu d\nu dV = \iint_{\nu V} \rho_\nu d\nu \cos\theta d(cS)$$

$$\iiint_{\lambda S \Omega} I_\upsilon \cos\theta d\lambda dS d\Omega = 4\pi \iint_{\lambda S} I_\nu \cos\theta d\lambda dS =$$

$$= 4\pi \iint_{\nu S} I_\nu \cos\theta d\nu dS = \iint_{\nu S} c\rho_\nu \cos\theta d\nu dS$$

$$4\pi I_\nu = c\rho_\nu \qquad [9]$$

The spectral intensity of the radiation is expressed as a function of the specific spectral density according to the relation:

$$I_\nu = \frac{c}{4\pi}\rho_\nu \qquad [10]$$

The ions in the nodes of the crystal net of the material vibrate emitting thermal energy, heat through the plate. The average vibrational energy of the ion is:

$$\bar{E} = \frac{h\vartheta}{e^{\frac{h\vartheta}{kT}} - 1} \qquad [11]$$

The specific spectral density calculated by Planck results from the formula:

$$\rho_\nu = \frac{8\pi\nu^2}{c^3} \cdot \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1} \qquad [12]$$

The specific spectral intensity becomes:

$$I_\nu = \frac{c}{4\pi}\rho_\nu = \frac{c}{4\pi} \cdot \frac{8\pi\nu^2}{c^3} \cdot \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1}$$

$$I_\nu = \frac{2\nu^2}{c^2} \cdot \frac{h\nu}{e^{\frac{h\nu}{kT}} - 1}$$

$$I_\nu = \frac{2\nu^2}{c^2} \cdot \frac{h\nu}{e^{\frac{E_2 - E_1}{kT}} - 1}$$

$$I_\nu = \frac{2\nu^2}{c^2\lambda} \cdot \frac{hc}{e^{\frac{E_2 - E_1}{kT}} - 1} = \frac{2\nu^2}{c} \cdot \frac{h}{\lambda} \cdot \frac{1}{e^{\frac{E_2 - E_1}{kT}} - 1}$$

$$I_\nu = \frac{2\nu^2}{c} \cdot \frac{p}{e^{\frac{E_2 - E_1}{kT}} - 1} \qquad [13]$$

The metaphysical conception about of light: Faraday observed that through the vacuum propagate electric and magnetic fields ($\vec{E}$ și $\vec{H}$) with finite speed. He made the same observation about a substance that transmits electric and magnetic fields over time. Maxwell in his conception shows that any variation in time and space of the electric field gives rise to a displaceable load current surrounded by a magnetic field. Also, any variation of the magnetic field is surrounded by electric field lines [9]. Independent variations of the electric and magnetic field generate the electromagnetic wave. In his conception, Faraday shows that a ray of light carries an electromagnetic wave. The variations in time of the electric and magnetic fields determine the variation of the energy density. Energy is a form of existence of matter, where fields have a material component, they propagate through substance. It comes to the situation where the fields can carry light quanta and electrical charges that are an integer number of elementary charges. Albert Einstein proved that every field possesses energy, and energy corresponds to a mass. Einstein's famous formula shows that a variation of mass corresponds to a variation of energy. The field possesses energy and has a continuous structure, and the particles possess discrete forms of energy. Quantums are particles of light that possess energy. Mathematically the field is defined on a set D_3 included in R^3 with values in R. So electromagnetic waves, that is, light, carry the quantum, light particles, full of energy that make up a field of photon. Einstein made calculations about field problems until the last moment of his life. He was the only man in the world who knew about the dual aspect of light. He had a dilemma: does light is formed of waves or quantum fluxes? He could not be closer to the quantum light [8].

6. CONCLUSIONS

1. Light is an electromagnetic wave composed of two time-varying fields, E and H, the electric field and the magnetic one oscillating and generating each other, being perpendicular, resulting in a wave that propagates at speed c.
2. The energy density of the field depends on the square of the electric and magnetic field intensity.
3. The intensity of the light field is proportional to the energy contained in the unit volume.
4. The radiation emitted by heated bodies is physically described by the spectral intensity and specific spectral density established by Planck's formulas.
5. Vibrations of ions in the substance give rise to oscillations that carry energy.
6. The radiation emitted by heated bodies is emitted in the infrared range.
7. The energy of an ion has discrete values being an integer multiple of a quantum of energy called a photon.
8. The intensity of light is different from the intensity of thermal radiation.
9. At n-1 interactions are 2^n photons, the multiplication is given by the exponential function 2^n.

7. REFERENCES

[1] Optica, fizica plasmei, fizica atomică și nucleară, Editura Didactică și Pedagogică, București 1983

[2] Teoria Cîmpului, L.D. Landau, E.M. Lifșiț, Editura Tehnică, 1963

[3] Velculescu V.G., Despre laseri, referent Ion Agârbiceanu

[4] I.M. Popescu, Fizica și ingineria laserilor, Editura Tehnică, București,2000, ISBN973-31-1475-8

[5] D. Poenaru, Fizica modernă în România: Marii precursori și fondatori, Revista Știință & Tehnică, Mai 2017

[6] R. P. Feynman, Șase lecții ușoare, Bazele fizicii explicate de cel mai strălucitor profesor, Editura Humanitas, București, 2015, ISBN 978-973-50-5057-3.

[7] Enigma cuantică, Bruce Rosemblum și Fred Kuttner, Editura Prestige, București, 2011, ISBN 978-606-92379-3-9

[8] Albert Einstein și frontierele fizicii, Editura Humanitas, București, 2012, ISBN 978-973-50-3808-3

[9] Fizica Generală, A. Cișman, Editura Tehnică, București, 1962

[10] Ecuațiile Fizicii Matematice, vol II, Editura Didactică și Pedagogică, București, 1965