CHAPTER THEREE

LIGHT PENOMENA

(3.1) Introduction :

What is light? This question has been debated for many centuries. The sun radiates light, electric lights brighten our darkness, and many other uses of light impact our lives daily. The answer, in short, is light is a special kind of electromagnetic energy. The speed of light, although quite fast, is not infinite. The speed of light in a vacuum is expressed as $c = 2.99 \times 10^8$ m/s. Light travels in a vacuum at a constant speed, and this speed is considered a universal constant. It is important to note that speed changes for light traveling through no vacuum media such as air (0.03% slower) or glass (30.0% slower). For most purposes, we may represent light in terms of its magnitude and direction. In a vacuum, light will travel in a straight line at fixed speed, carrying energy from one place to another. Two key properties of light interacting with a medium a: It can be deflected upon passing from one medium to another (refraction). And It can be bounced off a surface (reflection) **.**

(3.2) Light phenomena

Light waves are complex. They are not one-dimensional waves but rather are composed of mutually perpendicular electric and magnetic fields with wave motion at right angles to both fields, as illustrated in Figure 3.1. The wave carries light energy with it. The amount of energy that flows per second across a unit area perpendicular to the direction of travel is called the irradiance (flux density) of the wave.

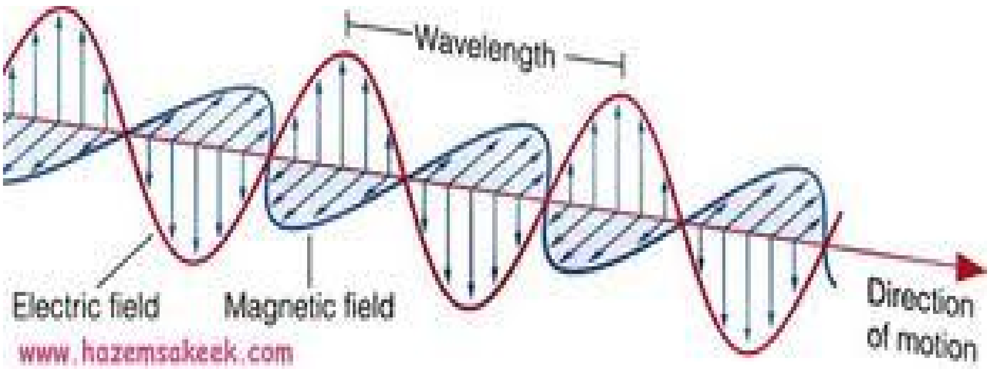

Figure (3.1) Electric and magnetic fields in a light wave [4]

The light waves describe by tow compounds, electric and magnetic fields :

$$E = E_0 \, e^{i(k.r - wt)} \tag{3.1}$$

$$H = H_0 \, e^{i(k.r - wt)} \tag{3.2}$$

Where k : wave vector $= \frac{w}{c} \; N_{Copmlex}$ (3.3)

The propagation of electromagnetic waves in a dielectric medium is given by the well known Maxwell's equations. which relate the displacement field vector (**D**) the electric field (**E**) the magnetic flux density (**B**) and the magnetic field (**H**) to the charge($\boldsymbol{\rho}$) and current density (**J**)[8][9][11] .

$$\nabla . D = 4\pi\rho \tag{3.4}$$

$$\nabla . B = 0 \tag{3.5}$$

$$\nabla \times H = \frac{1}{c} . \frac{\partial D}{\partial t} + \frac{4\pi}{c} J \tag{3.6}$$

$$\nabla \times E = -\frac{1}{c} . \frac{\partial B}{\partial t} = 0 \tag{3.7}$$

where we have assumed that the charge density is zero .

The constitutive equations are written as:

$$D = \varepsilon E \quad ,$$

$$B = H\mu \, ,$$

And $$J = \sigma E \tag{3.8}$$

(3.3) Material – Light interaction:

Interaction of photons with the electronic or crystal structure of a material leads to a number of phenomena. The photons may give their energy to the material (absorption); photons give their energy, but photons of identical energy are immediately emitted by the material (reflection); photons may not interact with the material structure (transmission); or during transmission photons are changes in velocity (refraction). At any instance of light interaction with a material, the total intensity of the incident light striking a surface is equal to sum of the absorbedI_A , reflected I_R and transmitted intensities I_T :

$$I_0 = I_A + I_R + I_T \tag{3.9}$$

Or: $$T + A + R = 1 \tag{3.10}$$

Where $$T = \frac{I_T}{I_0} \quad ,$$

$$A = \frac{I_A}{I_0} \quad ,$$

And $$R = \frac{I_R}{I_0} \tag{3.11}$$

(3.3.1) Refraction:

Light that is transmitted into the interior of transparent materials experiences decrease in velocity and as result is bent at the interface; this phenomenon is termed refraction in fig (3.2). The index of refraction n of a material is defined as the ratio of the velocity in vacuum c to the velocity in the medium v [9][10][12] :

$$n = \frac{c}{v} \tag{3.12}$$

The magnitude of n (or the degree of bending) will depend on the wavelength of the light. This effect is graphically demonstrated by the familiar dispersion or separation of a beam of white light into its component colors by a glass prism. Each color is deflected by a different amount as it passes into and out of the glass, which results in the separation of colors. If the angle of incidence from a normal to the surface isθ_i, and the angle of refraction is θ_r , the refractive index of the medium, n is given by (provided that the incident light is coming from a phase of low refractive index such as vacuum or air) :

$$n = \frac{\sin\theta_i}{\sin\theta_r} \tag{3.13}$$

Speed of light in a material can be related to its electrical and magnetic properties as :

$$v = \frac{1}{\sqrt{\varepsilon\mu}} \tag{3.14}$$

Where ε electrical permittivity and μ magnetic permeability t.

And speed of light in the vacuum is defined by:

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \qquad (3.15)$$

Where :(ε_0 electrical permittivity μ_0 magnetic permeability) in free space.

From (3.2) ,(3.4) and (3.5) :

$$n = \frac{c}{v} = \frac{\sqrt{\varepsilon\mu}}{\sqrt{\varepsilon_0 \mu_0}} = \sqrt{\varepsilon_r \mu_r} \qquad (3.16)$$

Since most materials are only slightly magnetic [9] . $\mu_r \approx 1$,

Thus $$n = \sqrt{\varepsilon_r} \qquad (3.17)$$

Snell's law : of light refraction refractive indices for light passing through from one medium with refractive index n through another of refractive index n' is related to the incident angle, θ, and refractive angle, θ', by:

$$\frac{n}{n'} = \frac{\sin\theta'}{\sin\theta} \qquad (3.18)$$

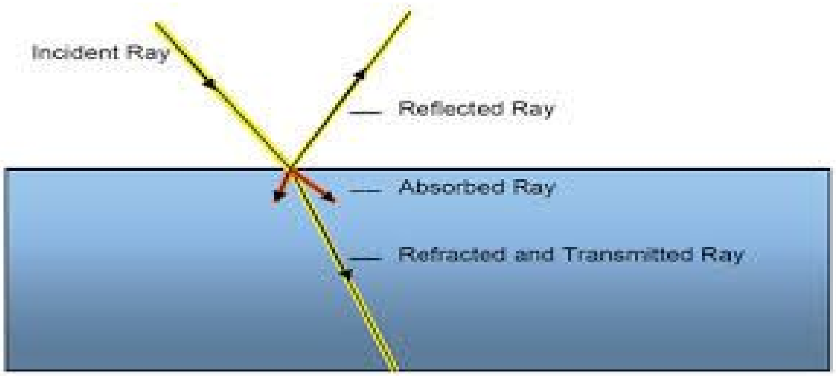

Fig (3.2) explain reflection, absorption and refraction [4].

(3.3.2) Reflection (R) :

When light radiation passes from one medium into another having a different index of refraction, some of the light is scattered at the interface between the two media even if both are transparent. The reflectivity R represents the fraction of the incident light that is reflected at the interface in fig (3.2) and (3.3):

$$R = \frac{I_R}{I_0} \qquad (3.19)$$

where $\boldsymbol{I_0}$ and $\boldsymbol{I_R}$ are the incident and reflected beams intensities respectively. If the light is normal (or perpendicular) to the interface, then :

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 \qquad (3.20)$$

where and are the indices of refraction of the two media. If the incident light is not normal to the interface, R will depend on the angle of incidence. When light is transmitted from a vacuum or air into a solid s [8][12], then :

$$R = \left(\frac{1 - n_s}{1 + n_s}\right)^2 \qquad (3.21)$$

(3.3.3) Absorption:

is a transfer of energy from the electromagnetic wave to the atoms or molecules of the medium. Energy transferred to an atom can excite electrons to higher energy states. Energy transferred to a molecule can excite vibrations or rotations. The wavelengths of light that can excite these energy states depend on the energy-level structures and therefore on the types of atoms and molecules contained in the medium. The spectrum of the light after passing through a medium appears to have certain wavelengths removed because they have been absorbed. This is called an absorption spectrum. Selective absorption is also the basis for objects having color. A red apple is red because it absorbs the other colors of the visible spectrum and reflects only red light. Much of the information about the properties of materials is obtained when they interact with electromagnetic radiation. When a beam of light (photons) is incident on a material in fig 3.2and 3.3 the intensity is expressed by the Lambert-Beer-Bouguer'S law:

$$I = I_0 \ e^{-\beta x} \qquad (3.22)$$

If this condition for absorption is met, it appears that the optical intensity of the light wave (I) is exponentially reduced while traveling through the film. If the power that is coupled into the film is denoted by (I_0), gives the transmitted intensity that leaves the film of thickness (X). (β) Is called absorption coefficient[4][9][12] from equation (3.11) is given by :

$$\beta = \frac{1}{x} \ln \left(\frac{I_0}{I}\right) \qquad (3.23)$$

(3.3.4) Transmission (T) :

The phenomena of absorption, reflection, and transmission may be applied to the passage of light through a transparent solid :

$$I_T = I_0 (1-R)^2 \ e^{-\beta x} \qquad (3.24)$$

For an incident beam of intensity $\boldsymbol{I_0}$ that impinges on the front surface of a specimen of thickness **x** and absorption coefficient ß the transmitted intensity at the back face $\boldsymbol{I_T}$ is where **R** is the reflectance. Transparent materials appear colored as a consequence of specific wavelength ranges of light that are selectively absorbed in 3.3; the color discerned is a result of the combination of wavelengths that are transmitted. If absorption is uniform for all visible wavelengths, the material appears colorless; examples include high-purity inorganic glasses and high-purity and single-crystal diamonds and sapphire. Usually, any selective absorption is by electron excitation the fraction of the visible light having energies greater than Eq = (1.8 to 3.1 eV) is selectively absorbed by valence band–conduction band electron transitions. Of course, some of this absorbed radiation is reemitted as the excited electrons drop back into their original, lower-lying energy states. It is not necessary that this reemission occur at the same frequency as that of the absorption. As a result, the color depends on the frequency distribution of both transmitted and reemitted light beams[12].

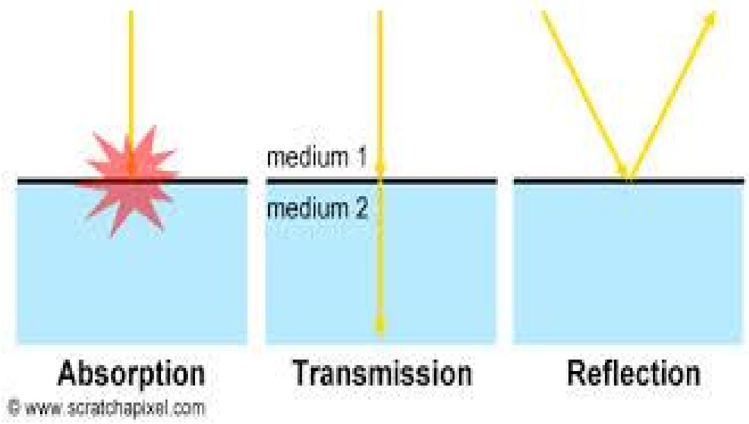

Fig (3.3) explains absorption. Transition and reflection [4]

(3.4)The dielectric

From equation (3.3) and (3.17) yield:

$$k = \frac{w}{c}\sqrt{\varepsilon_{complex}} \tag{3.25}$$

Where $\varepsilon_{complex} = \varepsilon + \frac{4\pi i\sigma}{w}$

$$= \frac{4\pi i}{w}(\sigma + \frac{\varepsilon w}{4\pi i})$$

$$= \frac{4\pi i}{w}\ \sigma_{copmlex} \tag{3.26}$$

Substitute s values of complex refractive index in equation (3.3)

$$k = \frac{w}{c}\ (N_1 + iN_2) \tag{3.27}$$

Where

$$N_{complex} = N_1 + iN_2 = n_1 + n_2 \tag{3.28}$$

From equation (3.25) ,(3.27) and (3.28) yield :

$$\varepsilon_{complex} = (n_1^2 - n_2^2) + 2\ n_1\ n_2 \tag{3.29}$$

Dielectric complex [8][9][12] defined as :

$$\varepsilon_{complex} = \varepsilon_1 + i\varepsilon_2 \tag{3.30}$$

Compare equation 3.28 and 3.30 to fiend important relations:

$$\varepsilon_1 = n_1^2 - n_2^2 \quad \text{and} \quad \varepsilon_2 = 2n_1 n_2 \tag{3.31}$$

(3.5) The reflection (R) refractive index (n) :

We can write equation (3.1) in 1-D in direction –x as:

$$\overrightarrow{E_X} = \overrightarrow{E_0}\, e^{i(k.z-wt)} \qquad (3.32)$$

From equation (3.3) and in free space we have both an incident and a reactance wave:

$$\overrightarrow{E_X} = \overrightarrow{E_1}\, e^{i(\frac{w}{c}.z-wt)} + \overrightarrow{E_2}\, e^{i(-\frac{w}{c}.z-wt)} \qquad (3.33)$$

From Equation (3.31) and (3.32) the continuity of E_x across the surface of the solid requires that :

$$\overrightarrow{E_0} = \overrightarrow{E_1} + \overrightarrow{E_2} \qquad (3.34)$$

With E in the x direction, the second relation between E_0 , E_1 and follows from the continuity condition for tangential H_0 across the boundary of the solid [8][11][12]. From Maxwell's equation (3.7) we have :

$$\nabla \times \vec{E} = \frac{-\mu}{c}.\frac{\partial H}{\partial t} = \frac{i\mu w}{c}.\vec{H} \qquad (3.35)$$

The continuity condition on H_y thus yields a continuity relation for so $\frac{\partial E_x}{\partial z}$ that from Eq. (3.35).

$$\overrightarrow{E_0}.k = \overrightarrow{E_1}\frac{w}{c} - \overrightarrow{E_2}\frac{w}{c} = \overrightarrow{E_0}\frac{w}{C}.N_{complex} \qquad (3.37)$$

Thus $\overrightarrow{E_1} - \overrightarrow{E_2} = \overrightarrow{E_0}N_{complex}$ (3.38)

From (3.33) and (3.37) yields :

$$\overrightarrow{E_1} = \frac{1}{2}\overrightarrow{E_0}(1 + N_{complex}) \tag{3.39}$$

$$\overrightarrow{E_2} = \frac{1}{2}\overrightarrow{E_0}(1 - N_{complex}) \tag{3.40}$$

The reflection coefficient is given by:

$$r = \frac{E_2}{E_1} \tag{3.41}$$

Substitute Eq (3.38) , (3.39) in (3.40) :

$$r = \frac{1 - N_{complex}}{1 + N_{complex}} \tag{3.42}$$

Reflection R is written as[8][11][12] :

$$R = (|r|)^2 \tag{3.43}$$

From Eq (3.28) , (3.41) and(3.42) yield :

$$R = \frac{(1-n_1)^2 + n_2^2}{(1+n_1)^2 + n_2^2} \tag{3.44}$$

The range of R is $0 \leftrightarrow 1$, with $R = 0$ when $n_1 = 1$ and $n_2 = 0$ and $R = 1$ when n (or κ) is large.

At $n_1 = n_s > 1$, n_2 neglected, equation (3.44) reduced in form :

$$R = \left(\frac{1-n_s}{1+n_s}\right)^2 \tag{3.45}$$