ISSN No:-2456-2165

Exposure of Human Body to Radio Frequency Electromagnetic Radiation: Effects and Precautions

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Abstract:- Since the advent of Global System for Mobile Communication (GSM), which brought the perception of any and all people to the existence of electromagnetic fields in their environment, there have been widespread trepidation about the possible effects of electromagnetic radiation on human body with particular allusion to the ones present at our living and work places. This paper therefore analyzes the interaction and effects of electromagnetic fields, the radio frequency radiations in particular, have on human body. The interplay of EMF with human tissues is expressed with Maxwell's equations; and the human body tissues possess the dielectric properties of permittivity and conductivity, and are equally dispersive and frequency dependent. The EMF energy being conveyed by photon determines its effects on any medium of interaction with its energy ionization potentials (IPs) on biomolecular system, lying between 8-10eV energy range, which is somewhat lows and hence cannot trigger ionization. Therefore, electromagnetic field within the range of RF spectrum is generally considered non-ionizing, and since all significant consequences of EMF radiation are believed to be directly proportional to the degree of ionization and the deposited energy engendered in the biological organism, we deduced that the RF radiation does not possess the capacity to ionize, and its effects on human tissues are for that reason inferred insignificant.

Keywords:- *Electromagnetic Radiation, Radio Frequency, Photons, Biomolecular System, Ionization.*

I. INTRODUCTION

There have been widespread trepidation about the possible effects of electromagnetic radiation on human body with particular allusion to the ones present at our living and work places. This became very rife since the advent of Global System for Mobile Communication (GSM), which brought the perception of any and all people to the existence of electromagnetic fields in their environment. There is no doubt that many people are aware of the electromagnetic waves like the X-rays and gamma rays which are quite hazardous; but since they are not common place in our living and work biosphere they cause little or no apprehensiveness to them. Electromagnetic fields are everywhere. They are serviceable to us, as we need them for illumination, medical services, audio and video communications, mobile telephony etc. We generate them even when performing a simple task of actuating our common light switch or make use of our electrical devices. As a result of this continuous growth in electromagnetic field emitting contrivances around us coupled with the highly conspicuous GSM base stations, there is the need to get the members of the general public have a balanced knowledge of the subject in order to douse the apprehension and set their perception of the subject matter aright. Most commonly, the uninformed have the misconception that electromagnetic field emissions from telecommunication facilities are the same with radioactive radiations. Several reason are responsible for this common misconceptions and anxieties. These include mass media publication of recent and unsubstantiated scientific reports; thereby leaving them with horrendous impressions of angst. [1] posited that it is important to investigate, understand and communicate any potential public health impact from mobile phones which work by transmitting radio waves through base transceiver stations.

This paper therefore seeks to analyze the interaction and effects of electromagnetic fields especially the non-ionizing radiating (NIR) where the radio frequency belongs, have on human body. This, is believed will lay bare some facts and correct some misinformation and misconceptions, thereby laying to rest some unnecessary uneasiness among the people about the subject.

II. WHAT ARE ELECTROMAGNETIC FIELDS?

Broadly speaking, electromagnetic fields (EMF) is a term used for fields of forces produced by electrical charges or magnetic fields. It does not need a medium to propagate; to be precise, it can travel through a vacuum. Electromagnetic waves have capacity to change between positive and negative; and the number of changes per second is referred to as the frequency which is expressed in Hertz (Hz). I Hz = 1 full cycle of change per second.

The electromagnetic spectrum is classified according to frequency of radiation. This ranges from Extremely Low Frequency ELF of a couple of Hertz to Gamma rays which are up to 3PicoHertz. Figure 1 depicts the spectrum of electromagnetic radiation.

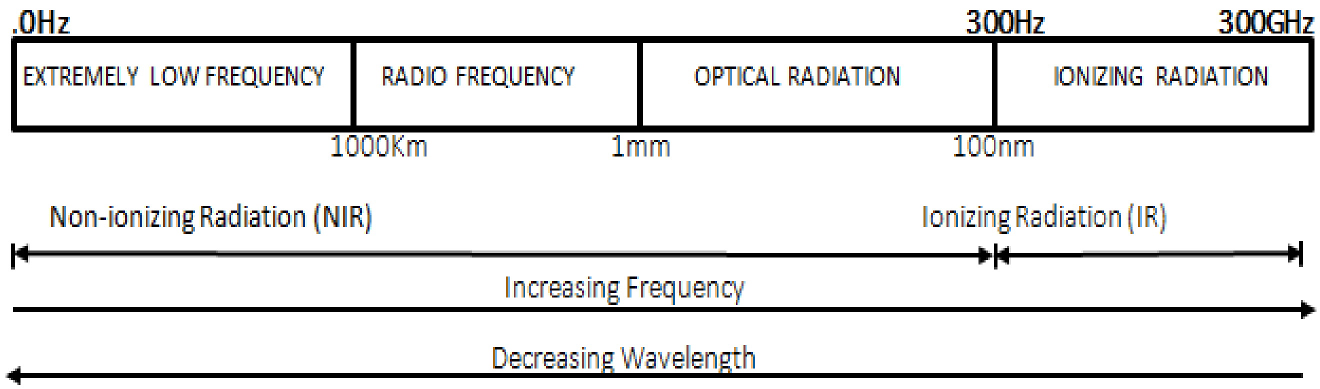

Fig 1:- Electromagnetic Spectrum

In most cases when one talks about electromagnetic radiation, what comes to the mind of the people is radiation associated with radioactive radiation or X-rays. This is a clear misunderstanding of the subject.

III. TYPES OF ELECTROMAGNETIC RADIATION

The electromagnetic radiation is broadly divided into two groups namely: *Ionizing* and *Non-ionizing radiation.* Electromagnetic radiation is said to be ionizing if it exudes sufficient energy to extricate orbiting electrons from atoms and/ or break covalent bonds holding molecules together thereby producing ions or charged particles. Consequently, ionization in tissues could cause express damage to cells giving rise to harmful health effects. X-rays, gamma rays and cosmic rays fall within this category of ionizing radiation. This class of radiations oscillate more swiftly than visible light and thus, are hazardous.

Conversely, the non-ionizing radiations (NIR) do not wield sufficient energy to dislodge electrons from atoms neither can they break molecular bonds. In this section of the spectrum, we have the following distinct bands: Extremely low Frequency (RF), Microwave radiation, Infra-red radiation, visible light, and Ultra violet radiation as shown in Figure 2. Each of these bands has peculiar behavioral dynamics with living tissues. This deals with the non-ionizing radiation EMFs with particular reference to radio frequency (RF) field which is with the frequency range of 300Hz to 300GHz.

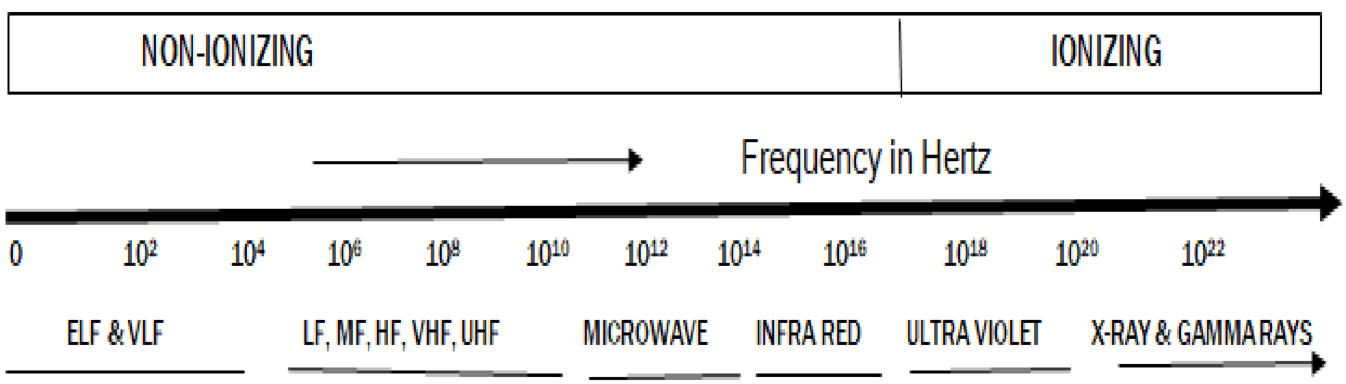

Fig 2:- Electromagnetic Field Spectrum (with their distinct bands indicated)

IV. SOURCES OF ELECTROMAGNETIC RADIATION

Electromagnetic radiations emanate from two sources namely natural radiation and man-made electromagnetic fields. The man-made EF is either deliberately produced or may stem from usage of electrical gadgets and systems [2]. The usual power supply from the distribution line comes at the nominal frequency of 50Hz-60Hz but can become awful and abnormal when it comes in contact with some equipment which distorts its frequency to higher frequency signals within the range of RF. [3] posited that man-made sources of high level electromagnetic fields are usually found in medical appliances and at some specified workstations. Examples of such medical devices include diverse kinds of RF ablation equipment, magnetic resonance imaging apparatuses, medical and surgical diathermy devices etc.

Yet again, GSM base stations and other mobile communication networks cause some relatively significant electromagnetic field radiations in the public domain. Succinctly put, the modern world is propelled by electrical and electronic devices, and so, they form the major man-made sources of electromagnetic radiation [5].

Some of the foremost vehicles of ER are: cell phone mast/ base stations, electronic apparatuses, electrical appliances and systems, computer and allied devices, microwave ovens, cellular phones, information networks and power lines of various voltage levels etc.

V. REACTION OF HUMAN BODY TO RF EXPOSURE

The response of human body to electromagnetic field stimulus is clinched by the dielectric properties of the tissues, which are the cell membranes and cellular fluids. These properties are characterized by significant parameters of *conductivity* and *permittivity*. While the permittivity represents the ability of the tissue to store electric energy, the conductivity determines its ability to transport charge as response to applied electric field.

The interplay of EMF with human tissues is expressed with Maxwell's equations which explain how magnetic and electric fields are generated, as well as control the relationship between the currents and charges. Explicitly, all non- quantum (conventional) electromagnetic phenomena are governed by these set of equations [6].

Assuming we have a time-dependent $e^{j\omega t}$ for angular frequency ω, then we have the equation of Maxwell as:

$$\nabla \times H = J_C + j\omega D \qquad \text{(i)}$$

$$\nabla . B = 0 \qquad \text{(ii)}$$

$$\nabla \times E = -j\omega B \qquad \text{(iii)}$$

$$\nabla . B = \rho \qquad \text{(iv)}$$

Where H = the magnetic field intensity in ampere per meter (A/m);

J_C= the volume conduction current density vector in ampere per square meter (A/m^2);

D = the electric flux density in Coulombs per Square meter (C/m^2);

B = the magnetic flux density in vector tesla (T);

E = the electric field intensity vector in volts per meter (V/m) and

ρ = the volume charge density in Coulombs per cubic meter (C/m^3)

The operator ∇ (pronounced 'del') expresses how strongly a quantity varies in space.

The charge and current densities ρ and J_C are believed to be the origin of the electromagnetic fields. When the electric and magnetic fields are generated and emitted from source, the can be transmitted far away from sources, and constrained in space spurt on the receiving antenna.

The human body tissue possess the dielectric properties of permittivity and conductivity, and are equally dispersive and frequency dependent [7].

[7] noted that the electric field component of the Maxwell's equation can be represented as

$$D = \epsilon_O \,[e'(\omega) - je''(\omega)]\ \mathrm{E} \qquad \text{(v)}$$

Where ϵ_O = 8.854x10^{-14} Farads per meter (F/m) is the permeability of free space

$e'(\omega)$ = the real part of the complex relative permittivity that represents the displacement current; and

$e''(\omega)$ = the imaginary part of the complex relative permittivity that represents the dielectric loss due to the displacement of bond charges.

On the magnetic field component of Maxwell's equation, it should be noted that human tissue is non-magnetic. It is thus represented as:

$$\mathrm{B} = \mu_o H \qquad \text{(vi)}$$

Where μ_o = 4π x 10^7 Henry per meters (H/m) is the permeability of free space J_c and E are related as

$$J_c = \sigma_1\ \mathrm{E} \qquad \text{(vii)}$$

Where σ_1 is the static ionic conductivity

Therefore Equation (i) can be represented as:

$$\nabla \times H = J_C + j\omega D = J_C + J_d \quad = J \qquad \text{(viii)}$$

Where $J_d = j\omega D = \omega\epsilon_O\,[e''(\omega) + j\ e'(\omega)]$ E is the displacement current density and is the total current density

Hence $J = j\omega\epsilon_O\,\epsilon_r^*(\omega)$ E (ix)

Where $\epsilon_r^*(\omega)$ is defined as

$$\epsilon_r^*(\omega) = [\epsilon'(\omega) - j\epsilon''(\omega)] - j\ \frac{\sigma_1}{\omega\epsilon_o} \qquad \text{(x)}$$

In the same vein, (ix) can be represented using the complex conductivity σ_ω^* of tissue as

$$J = \sigma_\omega^* \mathrm{E} \qquad \text{(xi)}$$

$$\text{Where } \sigma_\omega^* = j\omega\epsilon_o\epsilon_r^*(\omega) = \sigma_i + \omega\epsilon_o\epsilon''(\omega) + j\omega\epsilon_o\epsilon'(\omega)$$

$$= \sigma_{eff}(\omega) + j\omega\epsilon_o\epsilon'(\omega) \qquad \text{(xii)}$$

Where $\sigma_{eff}(\omega) = \sigma_i + \omega\epsilon_o\epsilon''(\omega)$ is the effective conductivity.

[8] advanced that the real value of the complex relative permittivity $\epsilon'(\omega)$ and the effective conductivity $\sigma_{eff}(\omega)$ of tissue display diverse peculiar steps as frequency rises.

These step by step transition is termed dispersion, which is described as the exhibition or display of polarization and kinesis of charge carriers in tissues. Nearly all tissues have tripartite dispersion subdivisions namely: alpha (α), Betta (β) and gamma (γ) dispersions. The low frequency α dispersion has been said to be connected with the transport of ions across a biological membrane. Alpha (α) dispersion frequency lies between 1Hz and 10^4Hz. There is scarcely any tissue conductivity increase in the (α) dispersion and permittivity in this region experiences sizable decrease.

The β and γ regions of dispersion are ranked between frequency of hundreds of kilo Hz and microwave frequencies. The dispersion is very weak in the γ distribution, and it wields minimal influence on the electrical properties of body tissue which carry protein bond tissues.

In an effort to present a mathematical model for the dielectric properties of tissues, [9] came up with an equation which shows the variation of dielectric properties of tissue over a broad frequency range as:

$$\in_r^*(\omega) = \in_\infty + \sum_n \frac{\Delta \in_n}{1+(j\omega\tau_n)(1-\alpha_n)} - j\frac{\sigma_1}{\omega \in_o} \quad \text{(xiii)}$$

This can be used to predict the dielectric characteristics of biological tissues of which the human body typifies.

Where $\in_\infty$ is the permittivity at terahertz frequency; n is the dispersion identifier and $\Delta \in_n$, τ_n and α_n are Tissue parameters for each dispersion region.

VI. THE RF FIELD AND ITS IONIZATION CAPABILITY

Electromagnetic energy is believed to be conveyed by photons. Photons function as discrete quanta which interrelates with individual electrons, atoms, molecules etc. Therefore, the energy borne by the photon determines its effects.

In this context, energy of the photon is measured in electron volt (eV), which is the unit of measuring the energy of subatomic particles, and is equal to that energy attained by an electron accelerated through a potential difference of one volt.

1 eV is therefore the energy attained by an electron accelerated through a potential difference of 1 volt. In this instance, the energy of photon is given by:

$$E = \frac{hc}{\lambda} \text{ or } E = hf \quad \text{(xiv)}$$

Where h = Plank's constant (6.625 X 10^{-34} J.s)
c = speed of light (3x 10^8 m/s)
λ = wavelength (in meters)
f = frequency (in Hertz)

The frequency of 1eV photon is equal to 2.418 X 10^{14}Hz, while its energy is 1.602 X 10^{-19} J.

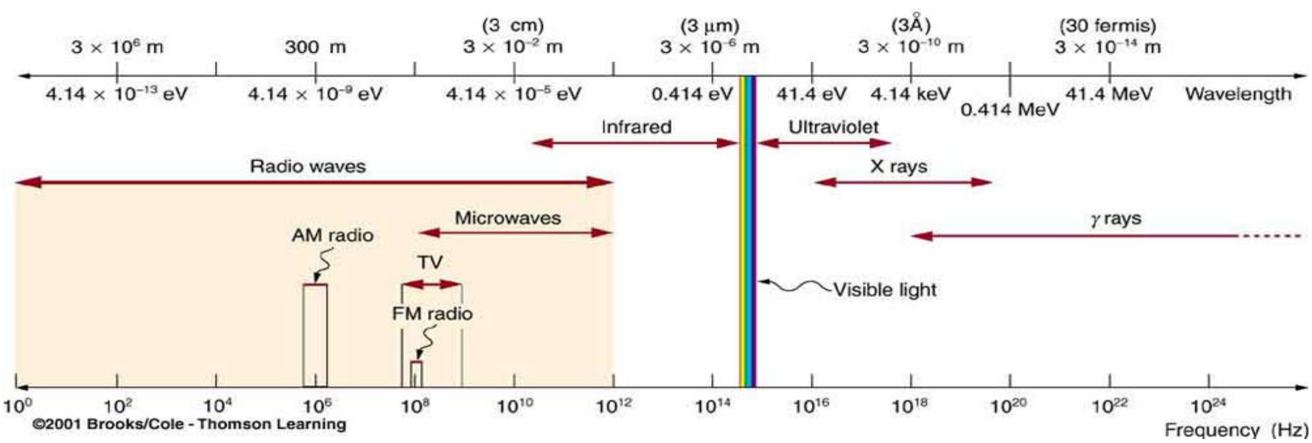

Fig 3:- The EM spectrum, showing major categories as a function of photon energy in eV, as well as wavelength and frequency. Certain characteristics of EM radiation are directly attributable to photon energy alone, (Source: [10])

A specific amount of photon energy is obligatory if ionization must take place in the atom of any substance through which RF wave is propagated; and [4] posited that the higher the frequency, the higher the energy per photon. [11] observed that photon energy ionization potentials (IPs) of biomolecular system, consisting essentially water, carbon, hydrogen, nitrogen and oxygen typically lie between 8-10eV energy range, and that one photon of RF radiation possess somewhat low energy levels, lower than 1.24x10^{-5}eV. Figure 3 depicts the location of this energy range falls in the EM spectrum. As a consequence, it cannot trigger ionization. Therefore, electromagnetic field within the range of RF spectrum is generally considered non-ionizing radiations.

[12] noted that even the hazardous ionizing radiation of the X-rays and gamma radiation on biomolecular cells and tissues are not accomplished by a single photon of RF radiation. Pithily, the RF radiation usually does not have

energy to impact ionization nay, substantial harm to bio-molecular system like the human body.

VII. DISCUSSION AND CONCLUSION

Since all significant consequences of RF radiation are believed to be directly proportional to the degree of ionization and the deposited energy engendered in the biological organism, we can deduce from this study that since the RF radiation does not possess the capacity to ionize, its effects on biological tissues are insignificant.

Generally, it can be deduced that RF fields permeates tissues to depths which is determined by frequency. For instance, [13] mentioned that at mobile phone frequencies the RF energy is absorbed to a depth in tissue of about 1 centimeter, which is converted to heat that is usually carried away by the body. Virtually all recognized undesirable health effects of RF radiations are caused by heating. This is probably in the situation of exceedingly localized exposure on some body part, in which case, substantial temperature upsurge may possibly take place in the vicinity of the exposed body part giving rise to thermal injury in the tissue. Otherwise, the RF energy interacts with tissues at levels that do not cause any significant heating.

While a wide range of skewed symptoms such as migraine, fatigue, skin itches, headaches etc. have been attributed to various RF sources both at home and at work, scientific studies have not offered substantial correlation linking RF exposure and those subjective and self-reported symptoms or electromagnetic hypersensitivity (EHS).

RF exposure limits are however given in terms of the rate of radio frequency energy absorption per unit mass of the body denoted by Specific Absorption Rate (SAR). These said limits are given as guidelines which are based on comprehensive valuation of existing scientific data. The import of this is that there is still the need for some cautious approach in terms of exposure to RF radiations.

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