Journal of the Nigerian Association of Mathematical Physics
Volume **12 (May, 2008), 161 - 164**

Electromagnetic fields and biotissue interactions

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Abstract

The interaction and effects of weak non-ionizing electromagnetic (EM) fields on biotissues have been considered. The application of linear response theory (LRT) shows that EM radiations may be absorbed at natural biotissue resonant frequencies. Although in-vitro studies have shown that physiological and chemical processes can be altered by the passage of EM fields, it has not been rigorously established that these effects are causative agents for cancer and gene mutation. The natural background thermal noise in biotissues is known to exceed the threshold for effects induced by weak external EM fields. Safe practice in the use of EM field generators, such as, cell phones, and the installation of base stations are advocated as a means of mitigating against yet unknown possible long term effects in humans.

1.0 Introduction

Technology has placed before people diverse equipment and tools operating on, and generating electromagnetic fields (EMF). Some familiar devices in this regard include the computer display screen, microwave oven and the cell phone. Because of their simplicity and greater bandwidth enhancement, wireless linkages utilizing EMF are also becoming a preferred mode of data transfer. The environment is thereby being inundated with non-ionizing radiation and there is increasing concern about the health implications. Studies have been conducted to ascertain the effects of these radiations, but there have been different results.

The bio-effects literature is not conclusive, with many unexplained or non-reproducible phenomena [1]. It is, therefore, of continuing interest to study the interaction and the resulting effects of EMF with bio-tissues. This paper looks at the basis of the interaction of EM waves with bio-tissues and the pathways for any attendant effects.

2.0 Linear response theory

Electromagnetic field (EMF) is made up of the orthogonal magnetic and electric fields. These are force fields, and when they act as external perturbations on biotissue, the associated particles of the incident media respond accordingly. When the exciting fields are weak, the interaction of the orthogonal fields with the medium is assumed to be independent, i.e. the fields are decoupled, and the reactions are determined by the internal properties of the bio-tissues. We shall consider the electrons in the incident medium as the particles responding to the fields. The responses to the independent fields are considered as follows:

2.1 The Electric Field

The electric field $E(\omega)$ polarizes the medium. The dielectric constant, $\varepsilon(\omega)$ is given by

$$\varepsilon(\omega) = \frac{D(\omega)}{E(\omega)} = \frac{E(\omega) + 4\pi \ P(\omega)}{E(\omega)} = 1 + \frac{4\pi\rho \ e^2}{m}(\omega_0^2 - \omega^2 - i\eta\omega)^{-1} \tag{2.1}$$

where $D(w)$ is the electric induction, $P(w)$ is the polarization, ρ is the density of electrons, e is the electronic charge, m is the mass of electron, ω is the frequency of E.M. waves, ω_o is the resonance frequency of the medium and η is the damping factor for the medium. If the medium has conductivity, σ the electric field is able to penetrate a distance into the medium characterized by the skin depth, δ, given by

$$\delta = \left(\frac{2}{\omega\sigma\mu}\right)^{\frac{1}{2}} \tag{2.2}$$

where the magnetic permeability of the medium is μ.

It is observed from equation (2.1) that absorption of the EM radiation occurs strongly at the resonant frequencies of the medium.

2.2 The magnetic field

The magnetic field, H on interaction with the medium can cause magnetic induction, B

$$\mu = \frac{B}{H} \tag{2.3}$$

If the permeability of vacuum is μ_0 , and the relative permeability of the medium is μ_r and the susceptibility is χ_m, then

$$\mu = \mu_0\mu_r \tag{2.4}$$

By definition,

$$\mu_r = 1 + \chi_m \tag{2.5}$$

Therefore,

$$B = \mu H = \mu_0\mu_r H = \mu_0(1+\chi_m)H = \mu_0 H + \mu_0\chi_m H = \mu_0 H + \mu_0 J \tag{2.6}$$

where the intensity of magnetization is J. That is, the external magnetizing field introduces an extra magnetic field in the medium.

3.0 Discussion

Biotissues act as dielectrics which possess the associated parameters. From the above equations, it is obvious that a physical basis exists for the interaction of EMF with biotissues. These interactions depend on the strength of the inducing fields and on the physical properties of the biotissue. The resultant effects could be thermal or non-thermal.

Thermal effects are those resulting from a measurable temperature increase. The EMF energy absorbed results in increased thermal agitation of the tissue particles, hence, the increase in temperature.

Non thermal effects are due to the alteration of biological and physiological processes in the tissues. The physiological processes involving the transport of nutrients and the removal of waste products by cells are carried through the water in the cytoplasm. For optimal function, the cell needs a stable environment, thus, the composition of the cytoplasmic fluid must be kept fairly constant. It is known that the conductivity and pH of water in-vitro are altered on exposure to EM fields [2]. Water is also known to have strong absorptions in the microwave region. If these changes should occur in biotissue cells exposed to EMF, then biologic and physiologic changes can occur.

There are many physical mechanisms by which EMF can interact with biologic systems. These include field-permanent dipole and field-induced dipole interactions (both electric and magnetic) and membrane excitation [3,4].

Liboff [6] reported a strongly frequency dependent effect of weak alternating magnetic fields on the uptake of calcium by lymphocytes. This effect was attributed to cyclotron resonance of calcium in cell membranes. This finding could not be confirmed in a study with improved methods and a blind design [6]. The cyclotron resonance explanation can also be criticized on theoretical basis [7].

The processes of rectification and signal averaging by cells have been studied [8,9]. Generally, an exogenous EM field induces an endogenous EM field, very small compared to the local field in the cell. If rectification occurs, the rectified back current in the cell is given by the Nernst equation:

$$I = I_0(\exp^{Vq/kT} - 1) \xrightarrow{Vq \ll kT} I_0\left(\frac{Vq}{kT} + \frac{1}{2}\left(\frac{Vq}{kT}\right)^2\right) \tag{3.1}$$

The incremental voltage *V*, across the cell membrane is given by

$$V = V_0 \cos(\omega t) \tag{3.2}$$

where the charge on an ion is q and I_0 is the maximum back current.

The mean d.c. rectified current is then

$$< I > = \frac{I_0}{4}\left(\frac{V_0 q}{kT}\right)^2 \tag{3.3}$$

The instantaneous *r.m.s.* noise current by Nyquist theorem is

$$I_{kT} \approx I_0 \tag{3.4}$$

That is

$$\frac{< I >}{I_{kT}} = \left(\frac{V_0 q}{2kT}\right)^2 \tag{3.5}$$

Typical values of the parameters encountered in biotissues are; internal electric field E_i = 0.01V/m, representative cell radius r = 1.0mm, charge on Ca^{++} ion q = 2e and ambient temperature T = 300K. Then

$$V_0 \approx E_i r = 1.0 \ x \ 10^8 \text{ V} \tag{3.6}$$

and

$$\frac{< I >}{I_{kT}} = 10^{-8} \tag{3.7}$$

Hence, the ambient cellular thermal noise field outweighs the effect of the exogenous field. Although non-ionizing EM radiations do not give rise to the breaking of chemical bonds, it has been suggested [10] that change in topological factors can alter biological activity. A topological shift can result if the DNA strands twist as a result of the coupling of the large number of nitrogen atoms in genetic base pairs to the oscillatory exogenous magnetic fields, via the Einstein – de Haas effect [11]. Also, biological cooperativity by more than one of the membrane – integral receptor proteins in the cell has been proposed as an enhancement factor for the relationship between the exogenous and endogenous fields [12]. These may lead to terological changes in the biotissues.

A number of workers have measured the dielectric properties of mammalian tissues and typical values for the dielectric constants and conductivities are found in Laogun [13] and Agba et al [14]. From these works and the application of equation (2.1) to determine the frequency variation of these parameters, one obtains the canonical parameters listed in Table 3.1. The frequencies ϖ = 314 rad/s and ϖ = 5.0 x 10^9 rad/s were employed, being those for EM waves in the power lines and a typical cell phone.

Table 3.1: Canonical dielectric properties for mammalian tissues.

Angular frequency ϖ (rad/s)	Dielectric constant ε	Conductivity σ (S/m)	Permeability μ (KgmS^{-2}A^{-2})
314	1500	1	$4\pi \times 10^{-7}$
5.0×10^9	100	1000	$4\pi \times 10^{-7}$

The permeability $\mu = \mu_0$ was used since the tissues are not ferromagnetic. The parameters from Table 1 when employed in equation 2 yield $\delta = 71m$ and $\delta = 5.6 \times 10^{-4}$ m $\approx$ 1 *mm* at the low and high frequencies, respectively.

4.0 Conclusion

The proliferation of devices emitting EMF has elicited much public debate and scientific studies. The values of the dielectric constant show that molecules in mammalian tissues can become polarized by the passage of EM waves and the calculated skin depths also show that EM waves can penetrate human bodies, thereby leading to cellular dysfunctions. However, calculations have shown that the induced internal effects are far less than that produced by thermal noise. Since appliances, such as, cell phones radiate a few hundred milliwatts, there should be no cause for alarm [15] if such phones are operated within the Specific Absorption Rate (SAR). Base stations radiate about a hundred watts, which is about a million times the power radiated by a cell phone. The proper citing of such stations away from the populace and the proper usage of home appliances that radiate EMF is advocated.

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