MICROBIOLOGICAL EFFECTS OF MICROWAVES AND RADIO FREQUENCIES

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Abstract
The interaction mechanisms of radio frequencies and microwaves with biological matters, as they represent the basis of any biological effects and possible hazards to health.

Key words: microbiological, microwaves, thermal effects, frequency.

INTRODUCTION

Microbiological effects of radio frequencies and microwaves are due to the interactions that take place at molecular and cellular level within the tissues. This work describes these interactions in the sense of ions and dipoles movements and the loading of cellular membrane. The work also presents the relevance of these interactive mechanisms for thermal and non thermal effects. Some of the experiments presented below, ware the result of the research in the Microwawes Technologies Laboratory, from the University of Oradea.

General considerations

There were many publications and debates about the biological effects and hazards on health through the exposure to electric and magnetic fields. In the last years, the debate became a serious controversy in terms of the existence or alternative of non – thermal effects, also called athermal.

The controversy was especially related to the ELF region, in particular on the 50 Hz or 60 Hz frequencies, but also involving the spheres of radio frequencies and microwaves[Grant, 1982]

Within this work, we will describe the interaction mechanisms of radio frequencies and microwaves with biological matters, as they represent the basis of any biological effects and possible hazards to health. We will limit to the sphere of the frequency 1MHz-300GHz in order to avoid taking into consideration the electric shocks and burns that, upon mutual consent, belong to its inferior frequencies[Krieger 1980]. The ELF frequency range also imposes other problems that are going to be discussed separately.

MATERIAL AND METHODS

Interactions of radio frequencies and microwaves with the biological environment

When an object is exposed to radio frequencies or microwaves under the conditions outside the field, the nature of interaction may have three forms, based on the ratio of wave length of the free space(λ) versus the linear dimensions of the object (d). When $d >> \lambda$, most part of the incident energy is diffracted around the body and thus the interaction is small. For a person with 1.7m in height, the frequencies under several MHz correspond to a reduced coupling.

As the frequency gets higher (low λ), there will be a situation where λ has the same order as d and there is the possibility of a strong coupling as a result of the resonance.[Jones, 1987] For an individual with average sizes, a quarter of the waves resonance will occur at 35 MHz and half of waves resonance will occur at 70 MHz, based on the situation where the individual is or not on the ground. For a shorter individual, the resonance condition occurs at higher frequencies. Beyond the resonance of the entire body, there is also the partial resonance of the body, due to the waves within cavities, as the skull.

The net result of the effects of resonance is the creation of a frequency region between 10 MHz and several hundred MHz, where the absorption of energy occurs at a certain density of the incidental power. At a higher frequency, the wave length is shorter than the dimensions of the body and the interaction can be expressed through an approximation under the form of an incident of waves within a semi – infinite environment.[Metaxas et al., 1983]

The essential purpose of these microscopic processes is that an electric field (E) and a magnetic field (H) would exist in the same environment, their values depending on the electric permittivity (ε) and the magnetic permittivity (μ).[Popovici, 2008]

For the biological matter, the value of m is close to the free space and thus, direct interactions through the magnetic field can be excluded. Indirect interactions from induced current occur and they produce a biological effect due to the penetration of current.

In contrast with the magnetic permeability, the electric permittivity is much more significant and has different properties from the free space. For the power of a certain electric field in the air, the equivalent value from the tissue is significantly lowered due to the permittivity effect. Moreover, the permittivity depends on the frequency, and the latter affects the manner in which the electrical fields are coupled with people's molecules and cells. In the following sections, we are going to discuss the dielectric properties of biological matter.

Dielectric behavior of biological tissue

Through Maxwell's equation of electromagnetic field, we can define a complex relative permittivity

$$\varepsilon^\wedge = \varepsilon' - j\varepsilon'' = \varepsilon' - j\sigma/\omega\varepsilon_o$$

Where ε' and ε'' are the real and the imaginary parts, σ is the conductibility of matter and ω is the angular frequency.

For a typical biological tissue, the values of ε' and σ depends on the higher frequencies, as illustrated in Figure 1. More precisely, there are three main dispersion regions, α, β and γ , created by Schwan (1975).

Further researches indicated the presence of a small dispersion to hundred of MHz, called the δ dispersion, created by Grant (1965 a, b). The origin of α region is the dielectric relaxation of water molecules present in the tissue, while β dispersion occurs due to the properties of cellular membranes and the rotation of various biological macromolecules. α dispersion is due, at least partially, to the movement, but there are also other matters to discuss before understanding its origin. It can be excluded within this paper, because for the entire tissue, it occurs at frequencies below the frequency of our interest, although it has been observed at over 1 MHz in aqueous solutions from large biological molecules.[Jones, 1987]

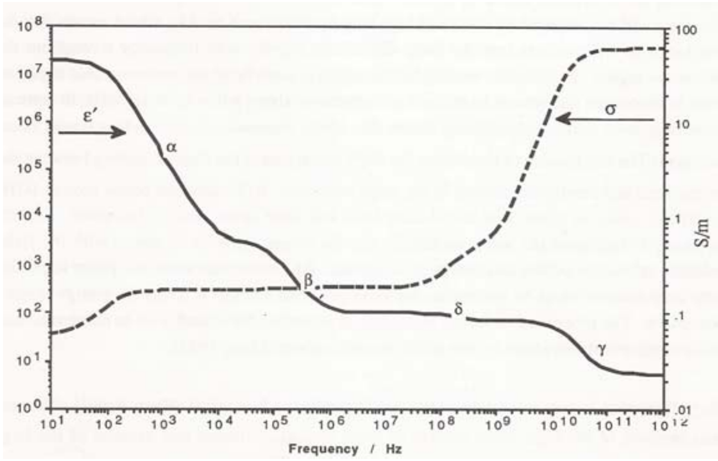

Fig. 1. Dielectric behavior of biological matter

γ dispersion

It is well known that g dispersion is due to the relaxation of water molecules. For pure water, the behavior of dispersion can be written as:

$$\varepsilon' = \varepsilon_\infty + \frac{\varepsilon_S - \varepsilon_\infty}{1+ \omega^2\tau^2}$$

$$\varepsilon'' = \frac{(\varepsilon_S - \varepsilon_\infty)\,\omega\tau}{1 + \omega^2\,\tau^2}$$

where the symbols are similar to the symbols in Figure 2.[Gardiol, 1981]

The pitch value of ε" occurs at a frequency ω_R, so that $\omega_R\ \tau$ is the unit, where τ is the duration of relaxation and it measures the duration in which the molecule spins within the electric field. It depends on the size of molecules and the nature of bond between the molecules.

For water at the temperature of the human body, τ has the value of several milliseconds. Dielectric losses, ε", measure the energy absorbed in a field cycle and the reason for its reduction at high frequencies is the lengths of cycles' reduction and not the reduction of energy absorption with the increase of frequency.[Gandhi, 1990] In a given constant electric field, the absorption necessary for a volume will take a shape similar to conductibility (Figure 1). Subsequently, from Figures 1 and 2 we can notice a substantial increase of energy absorption at a frequency higher than 1 GHz.

This implication refers to pure water, but the same behavior will be present in tissues with a large content of water, as the skin, which illustrates that the penetration of microwaves within the body is rapidly reduced with the frequency in the region of microwaves.[Popovici et al., 2007] As the heating in this region is superficial, the exposure levels recommended by the Manual of Protective Regulations can remain to frequencies over several hundred MHz, in contrast with inferior frequencies, where resonances and stable waves occur. The mechanism of interaction for g dispersion is the direct coupling between the electric field and dipole moment of water molecule. At frequencies less than 1

GHz, dipoles spin in the sense of the electric field and no energy is absorbed.[Gandhi, 1990]

As the frequency is increased, water molecules can no longer be oriented in the sense of the field, dielectric relaxation occurs and the energy is spread. At the molecular level, the phases delay is due to the time necessary to break the intermolecular hydrogen bond and the energy transfer will take place here.

γ dispersion is particularly important for relaxation, for the production of biological effects with thermal basis due to the high water content in most of the tissues and the contribution of water to the electric conductibility.

Heat produced within the water component is directed towards the biological macromolecules through conduction and convection and through the temperature increase experienced by the body. It is difficult to find a reason for which water molecules from the tissue behave in a manner opposite to equations (2) and (3) and it would be unlikely that subtle, micro-thermal or non thermal effect would occur in the exchange of water content.

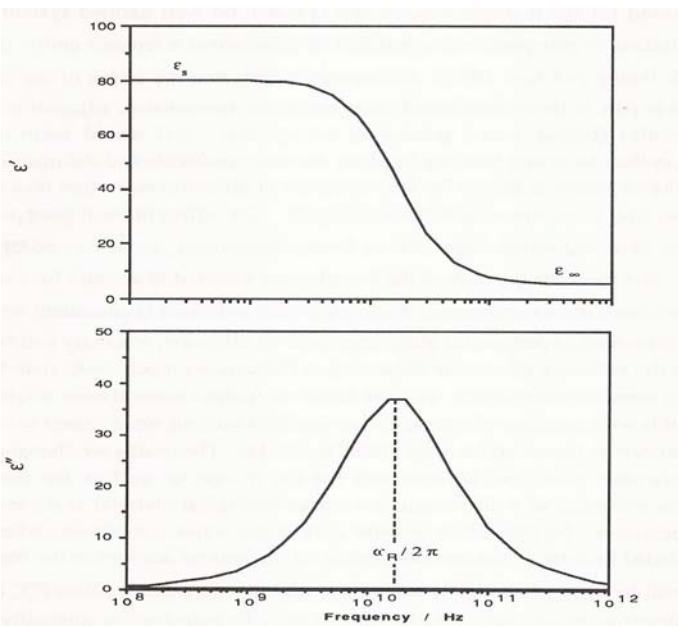

Fig. 2. Dielectric behavior of water at 20° C $_{\tau}$ = 9.3 ps;

Frequency of relaxation = wR/2p = 17 GHz

ε' Relative permeability ε'' Dielectric loss

ω Angular frequency (=2π x frequency)

ε_S Static relative permeability

ε_∞ Relative permeability of infinite frequency

δ dispersion

Figure 1 illustrates the presence of a small dispersion, having several hundred MHz, in the region. Although the magnitude of the tissue is small compared to 60 -70 for γ and several hundred for β, a thorough research of well defined systems, like pure proteins in water – based solutions , justifies its existence as a separate entity.[Metaxa, 1983]

In addition, the origin of δ dispersion is due, at least partially, to the orientation of water molecules immediately adjacent to biological macromolecules (water in the tissues) present

in the system. This fact seems to be reasonably, as the strong bond between water molecules and macromolecules will produce a higher limit to overcome the dielectric relaxation than the limit between two molecules from the liquid.[Gardiol, 1981]
The effect of the higher limit will be the change of water dispersion towards lower frequencies, as it can be noticed for d dispersion. Moreover, the water quantity necessary to the amplitude of d dispersion within the measurements of protein solutions is in agreement with the quantity provided by experimental techniques like diffusion, viscosity and NMR. Another supporting aspect for the existence of water dispersion at much lower frequencies compared to pure water are the measurements performed on frozen ocular tissues (Gabriel and Grant, 1985). Within this paper, the section retina, cornea and nucleus of lens were frozen at -9^0 C and their dielectric properties measured between 100 MHz – 10 GHz. The results are presented in Figure 3, where we can notice a clear dispersion in ε', both for frozen and cooled biological tissues.

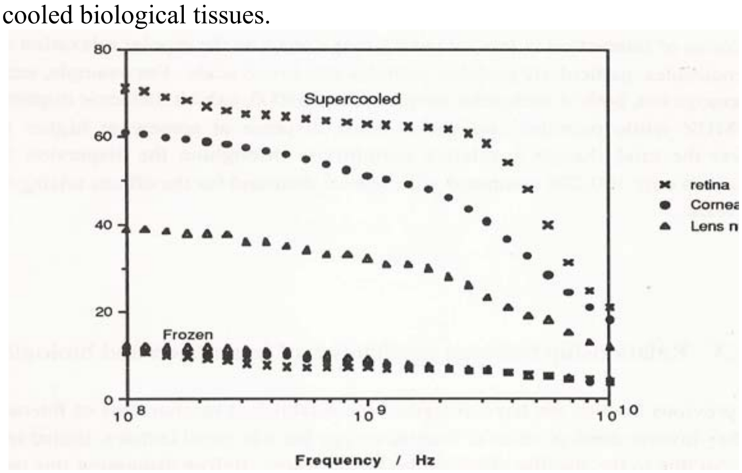

Figure 3. Permittivity of cooled or frozen ocular tissues

The existence of dispersion for a frozen biological matter at these frequencies is an indicative of dispersion in a part of water component; other mechanisms were excluded due to ion mobilization within the freezing process. The liberty of spinning regarding water molecules at temperatures under 0^0 C lead to its denomination: water that cannot freeze and it can be compared to water in tissues, also called hydration water.[El Harrous et al., 1997]
The presence of water within the tissues in the biological matters illustrates that the absorption of energy in a certain field will occur at frequencies of several hundred MHz, smaller than in the region where the absorption of pure water takes place. The presence of water from the tissues close to biological macromolecules can or cannot determine any deposit of selective energy.

β dispersion

Figure 1 illustrates a decrease in the relative permittivity for a typical biological tissue of several thousand to 60, as the frequency increases from several kHz to several tenth of MHz. This is due to the presence of a cellular membrane which behaves as a barrier against the movement of ions in the extra-cellular fluids, after the application of the electric field.
This accumulation of charge on the membrane surface imposes a delay of phases between the oscillations of the electric field and the production of answer, this being the necessary condition for dielectric dispersion and absorption.[Jones, 1987] The phenomenon can be mathematically described through the equations Maxwell – Wagner, its relationships within the biological tissue being previously described (Schwan 1975). In fact, the usage of

dielectric measurements for the study of cell behavior produced some particularly useful information in terms of cell parameters, as the membrane width.

However, in the current context, we will take into consideration the mechanism of interaction between the cells and the electric field applied, and there is no doubt that the Maxwell – Wagner effect is dominating in the interaction. Moreover, it usually implies the properties of tissues, the uniform production of thermal energy deposits in the environment. There is some evidence in terms of direct effect of the electric field on the cellular membrane, but the mechanism is not completely understood. Other forms of interaction within this range of frequencies are connected to dipolar relaxation of biological macromolecules, especially proteins, peptides and amino acids. For example, albumin and hemoglobin, both with a molecular weight of 68000, have a dielectric dispersion between 0.1 -10 MHz, while peptides and amino acids are dispersed at higher frequencies. However, the total exchange of relative permissibility of dispersion due to these molecules is of 100 – 200 compared to several thousand for the effects of cellular membranes.

The relationship between the mechanism of interaction and the biological effect

In the previous section, we described the established mechanisms of interaction. In all the cases, they involve the deposit of thermal energy, but it is possible to register the heating of a space due to the specific effect of water in the tissues. As 65 -70 % of the human body is water, the heating is present at frequencies over 1 GHz. The magnitude of water conductibility in the region 1 -10 GHz is another reason for which the pure water is dominant. The success registered at 2.45 GHz for the heating of food material is due to the heating of pure water.

Thus, we reaffirm that at frequencies over 1 GHz, the dielectric heating of pure water from the equations (2) – (3) is responsible for any biological effect or hazard on health that may occur through the exposure to microwaves.

At inferior frequencies, the effect of water hydration (water from tissues) is important. [Gandhi, 1990] We can discuss such a presumption in terms of hydrated macromolecules behavior as a sphere surrounded by a uniform water shell, Figure 4.

In a biological environment, the water shell within the tissues is filled with ions and all the hydrated particles in the environment with a significant concentration of free ions. At any frequency, we can calculate the quantity of energy absorbed in a water volume compared to the one in pure water. The size of this enhancement factor depends on the choice of values for ionic conductibility, but in some cases we can expect an enhancement factor of 2-3.

However, for a macromolecule surrounded by a hydration shell with a high ionic concentration, the enhancement factor can exceed 10. The strong points and the limits of this model, as well as the general approach were previously discussed (Grant, 1982), but all the evidences prove it is functional.

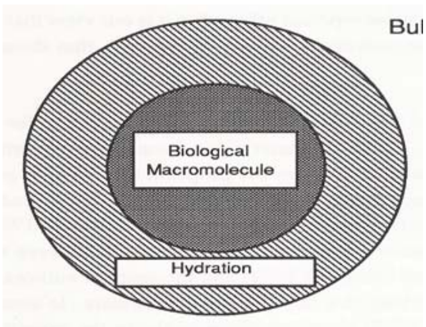

Fig. 4. Model of hydrated biological molecule

The practical implications of such a different heating can be the following. By definition, water in tissues consists of molecules that are more bounded to parent – macromolecules than the neighboring water molecules from the liquid. Thus, considering the system as the equivalent of one of the two springs coupled, we can state that for tissues, the deposit of energy from water communicates better with macromolecules than pure water.[Gardiol, 1981]

If this process takes place during a shorter period than the thermal equilibration processes, the macromolecule can suffer a change of configuration which would lead to the deterioration of the biological effect. The investigation of this type of micro-thermal effect must be discussed within further researches.

Beyond the possibility that water from tissues is responsible for a subtle mechanism, there is also the problem that any tissue with a larger amount of water would absorb more energy in the region 100 MHz – 1 GHz than we would expect. Such an example is the matter of lens, a tissue known to be vulnerable to microwaves.

These considerations can be extended to the heating and cooling of microwaves in general and we recently shown that a relative contribution corresponding to the production of heat in water increases as the concentration of solution increases. [Gardiol, 1981]

If we go back to β dispersion, we previously explained that the interaction with a field at frequencies in the range 0.1 -10 MHz is mainly due to the charging of cellular membrane, with some contribution of the relaxation of dipolar macromolecules.

Now we are interested to know if there is an effect on the cell due to direct action of the electrical field, and not an indirect effect due to the action of heating. Evidence can be presented within the experiments performed in vitro, which would illustrate the fact that certain different effects can occur, from the active and passive altered transport of ions through membranes to the promotion of cellular changes. Not everyone acknowledges the significance of these effects, but we can say that the analysis of direct action at the level of membrane must be a priority field of research.

Various other mechanisms were suggested in order to solve the problem regarding the interaction of radio frequencies and microwaves with biological matter, but none was experimentally verified in independent laboratories. One was the proposal that the circular DNA plasma would have other resonances at frequencies between 1 -10 GHz (Van Zandt, Kohli and Prohofsky, 1982) and there were measurements (Edwards, Davis, Saffer and Swicord, 1985) that supported this theory. However, other laboratories were not able to observe the effect (Gabriel, Grant, Tata, Brown, Gestblom and Noreland, 1989) and the initial authors acknowledged that this was due to experimental artifacts.

In another study connected to yeast cells, Grundler and Keilmann (1978) noticed some pitches of curves related to the growth rates of irradiations according to the frequency of microwaves between 41.6 – 42.1 GHz, these being theoretically supported by Frohlich (1980), using a model that implied the existence of metastasis conditions caused by the metabolic energy. However, the effect was never independently verified and the further experiments conducted by Furia, Hill and Gandhi (1986) were not able to prove it. Thus, it is necessary to eliminate the possibility of any absorption of resonances that occur in the biological matter at frequencies under several hundred or thousand GHz, where it can occur.

RESULTS AND DISCUSSION

Biological effect of radio frequencies and microwaves

There were many papers about the biological effects and the hazards on health through the exposure to radio frequencies and microwaves, as well as several guidelines. We consider that it is useless to repeat those studies and we will focus to resume the current situation and to indicate the further research fields.

The biological effects of radio frequencies and microwaves were discussed by several authors and the recent position is extremely well resumes by Gandhi and other 21 colleagues in this field (Gandhi, 1990). As a result of the important data basis establish in the last years, the International Commission on Non – Ionizing Radiation (INIRC) , which is a part of the International Radiation Protection Association (IRPA), drafted a Guidelines (INIRC, 1988), based on thermal effects. Many occidental countries produced their own Documents, which differ only in some minor aspects from the IRPA document. For eastern countries, the limits of exposure proposed are lower than for occidental countries, but the difference was continuously reduced from the first International Symposium from the scientific region in 1973 (Czerski, 1974). The exposure limits provided and included, for example, in GS11 document (1989) published by the National Radiological Protection of Great Britain , are illustrated in Figure 5.

As you can notice, there are three main regions of frequencies, under 10 MHz, 10 MHz-400MHz and over 400 MHz, corresponding to the three interaction means described in Section 2.1. The question asked is related to the major changes that must be executed, unlike the minor changes, at the magnitude of values and the shape of curve illustrated in Figure 5. The answer is related to the existence of an evidence for non thermal and micro-thermal effects.

In other words, is it correct to assume that thermal effects are the most important, or are there any other effects that have to be taken into consideration?

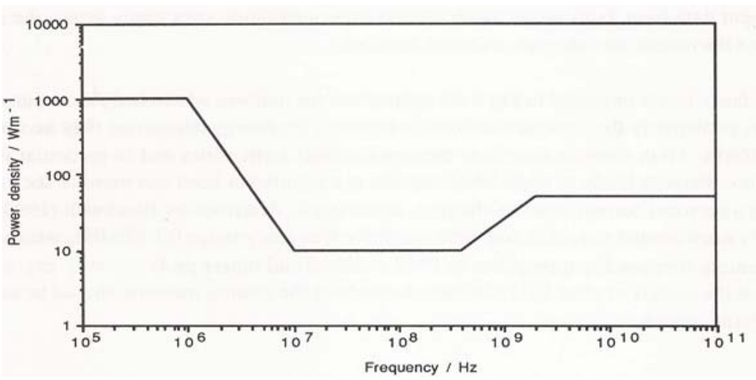

Fig. 5. Reference levels recommended below 100 kHz

The answer to this question is much more easily found for the region 1 MHz-300 GHz than for lower frequencies. At 50 Hz, 60 Hz and other ELF frequencies, there are many experimental effects reported, which, if they are correct, can be thermally explained. Moreover, the epidemiological analyses were conducted at 50 Hz and 60 Hz, some stating that the exposure at electric and magnetic fields increase the likelihood of cancer.[Gandhi, 1990]

The University of Oradea, is involved in researches regarding the influences of the microwaves about the biological, using equipments like in the Figure 6.[Popovici et al., 2007; Popovici et al., 2007]

Fig. 6. Microwave heating system

Fortunately, these statements were not supported by other independent analysis; if they were correct, their social and economic impact would be extremely serious. In the case of radio frequencies and microwaves, there were only a few verifiable data that could not be taken into consideration for a thermal mechanism. However, Smigielski, Szudzinski, and others (1982) stated that the guinea pigs treated with benzopyrene developed tumors more rapidly when they were exposed to 2.45 GHz microwaves than the other guinea pigs. The animals were exposed to powers of $48Wm^{-2}$, but these can be high enough for thermally induced stress under such experimental conditions and to tumors. In another study that involved rodents, conducted by Guy, Chou, Crowley and Krupp (1985), 100 guinea pigs were exposed to 2.45 GHz frequencies in order to produce a specific rate of absorption (SAR) in the range of 0.15 – 4W/kg. The comparison with 100 ordinary guinea pigs revealed a higher occurrence of maligns in the exposed group than within the control group. This occurrence was not higher than the one registered in the studies for the species of guinea pigs used in the experiment.[Grant, 1982]

If we go back to the experiments conducted in vitro, it is possible to notice the occurrence of a direct action of the electric field on the cellular membrane. Experimental evidences are resumed by Cleary in Gandhi (1990). Beyond the experimental data, we can also predict that the specific mechanisms of interaction may occur in some specific places on membranes and macromolecules, as we predicted above for the mediation effect of water from the tissues.[Krieger, 1980] We consider that these types of experiments conducted in vitro and the investigation regarding the occurrence of tumors for animals must be research fields followed at the frequencies of radio waves and microwaves. Due to the data basis established though experiments during the years, the current Guidelines are appropriate.

CONCLUSIONS

The levels presented in Figure 5 are adequate for the uniform absorption on the entire body, but in practice, especially for the individuals professionally exposed, the energy deposit can be non-uniform. High current can pass though the extremities of the body and especially though ankles. The individuals exposed to a significant level can monitor the values by wearing a device which measures the current. This device is worn on the ankle and operates at frequencies over 0.1 - 80 MHz that cover the operational frequencies adequate for PVC bonds and other individuals professionally exposed. In order to reduce the effects of RF fields, the electrode of the sealing device must be screened by a metallic shield.

It is very important to continue these studies, in order to prevent biological effect and to ask from the industry to respect new standards in electromagnetic influence security.

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