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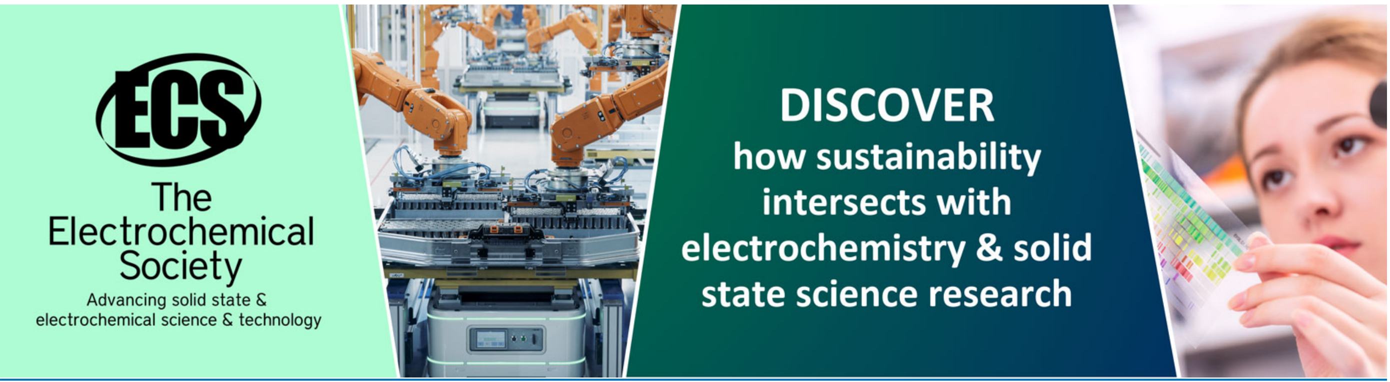

Physical model for effects of microwaves on nucleoids in living cells: role of carrier frequency, modulation and DC and AC magnetic field

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Abstract. The effect of static and alternating magnetic fields on the conformation of nucleoids in cells of different types is considered. The model of slow and nonuniform rotation of the charged DNA domain is used. An equation is obtained for the resonance frequencies of the alternating magnetic field.

1. Introduction

Exposures to radio-frequency (RF, 3 kHz–300 GHz) electromagnetic radiation or microwaves (MWs, 300 MHz–300 GHz) vary in many parameters: intensity (incident flux power density [PD], specific absorption rate [SAR]), wavelength/frequency, near field/far field, polarization (linear, circular), continuous wave (CW) and pulsed fields (which include variables such as pulse repetition rate, pulse width or duty cycle, pulse shape, and pulse to average power), modulation (amplitude, frequency, phase, complex), static magnetic field (SMF) and extremely low frequency (ELF) magnetic fields (MF) at the place of exposure, overall duration and intermittence of exposure (continuous, interrupted), and acute and chronic exposures.

Some physical models consider effects of both ELF MF and MW[1-13]. Binhi' s mechanism of quantum interference considers effects of magnetic field on distribution of probabilities of coordinate of charged particle or, in other words, on wave function of charged particle [1]. The effect is based on shift in the phase of wave function and appearance of nonlinear interference. This mechanism has especially interesting application for rotating charged particles like ions in the pockets of rotating proteins. Based on quantum-mechanical calculations stemming from this mechanism, ELF and MW can result, under specific parameters of these fields such as intensity and frequency, in a shift in kinetics of ion binding into the protein pockets, affecting activity of this protein and related biochemistry. Importantly, effective conditions of exposure include SMF at the place of exposure similar to the model of Matronchik and Belyaev, which is also based on EMF effects on phase [8].

It has previously been shown that MW and ELF MF at low intensities affect conformation of nucleoids in cells of different types [3]. Recent data have shown that MW from mobile phone affect nucleoids in human lymphocytes [4,5]. Effects of ELF MF depended significantly on collinear static MF. Experimental evidence has indicated that the MW effects have also been dependent on static and alternating MF at the location of exposure. The physical model has been developed to describe effects of weak static and alternating magnetic fields [6]. Recently, we presented the model of slow nonuniform rotation of the charged DNA domain for combined effects of microwaves, static and alternating magnetic fields [7-9].

2. Theoretical Model

The oscillation of the center of mass x, y, z of the charged nucleoid (DNA domain) in static MF $B_S = 60\,\mu T$, and high frequency electric modulated fields, $E(t) = E_0 Cos\left(\tilde{\omega} t\right) Sin(\omega t)$ is described as

$$m(t)\ddot{x} + kx = Q(t)(B_S \dot{y} + E\left(t\right)),\ m(t)\ddot{y} + ky = -Q(t)B_S \dot{x},\ m(t)\ddot{z} + kz = 0,$$

where k is elasticity coefficient, $Q(t)$ - a charge of nucleoid, $m(t)$ - its mass, E_0 - amplitude, ω - high frequency of an electric field and $\tilde{\omega}$ - low frequency of an electric field. The axis z is directed along vector of magnetic field and passes through a place of fastening of nucleoid, the axis x is directed along electric field. The mass and the charge of nucleoid slowly and periodically changes in due course as a result of interaction with proteins and ions. In the received solution there is a low-frequency resonance at $\tilde{\omega} = \Omega_0/2 + m\omega_q$, where $m = 0, \pm1, \pm2, \ldots$. In this case the radius of the center of mass increases in time under the law:

$$r_0\left(t\right) = \left(q_0 E_0 / 4\omega_0\right) J_m\left(\Omega_1 / 2\omega_q\right) t Cos\left(\omega t\right).$$

Such resonance growth of radius of the center of mass may affect binding of DNA with structural proteins and enzymes resulting in the experimentally observed effects.

Now let's write the equation oscillation of the center of mass x, y, z of the charged nucleoid (DNA domain) in alternating MF:

$$m(t)\ddot{x} + kx = Q(t)B_z\left(t\right)\dot{y},\ m(t)\ddot{y} + ky = -Q(t)B_z\left(t\right)\dot{x},\ m(t)\ddot{z} + kz = 0,$$

where $B_z\left(t\right) = B_S + B_A \operatorname{Cos}\omega_A t$, B_A - amplitude of alternating MF, ω_A - its frequency. We will assume that the specific charge of nucleoid undergoes harmonic oscillations with a set of natural frequencies $Q(t) / m(t) = \sum_{i=1}^{n} q_{0i}\left(1 + \operatorname{Cos}\omega_{qi} t\right)$. For the case of alternating magnetic field, the geomagnetic field B_g is replaced by $B_z\left(t\right)$. Then the phase of nucleoid oscillations changes by the value:

$$\Delta\Phi = \frac{B_S - B_g}{2} \sum_{i=1}^{n} q_{0i} \left(t + \frac{\operatorname{Sin}\omega_{qi} t}{\omega_{qi}} \right) + \frac{B_A}{2} \sum_{i=1}^{n} q_{0i} \left(\frac{\operatorname{Sin}\omega_A}{\omega_A} + \frac{\operatorname{Sin}\left(\omega_A - \omega_{qi}\right)t}{2\left(\omega_A - \omega_{qi}\right)} + \frac{\operatorname{Sin}\left(\omega_A + \omega_{qi}\right)t}{2\left(\omega_A + \omega_{qi}\right)} \right).$$

Accordingly, the maximum biological effect will be observed under the conditions:

$$\Delta\Phi\left(t\right) = \pi\left(1 + 2l\right), \quad d\left(\Delta\Phi\left(t\right)\right)/dt = 0$$

where l - integer. Resonance frequencies are obtained from these conditions.

3. Discussion

A number of subcellular organelles (membrane, mitotic spindle, nucleus, DNA-domain) or even a single molecule (protein, DNA) was considered as the target of interaction with non-thermal (NT) MW. Regardless of the target, one of the major problems in explaining NT MW effects is seen in the fact that the quantum of energy of an EMF with a frequency lower than a few THz in most cases is less than the average energy of thermal noise (kT constraint), providing limits for the effects of a single quantum [14]. However, the kT problem is based on assumption that primary absorption occurs by the atomic or molecular target under thermal equilibrium conditions in a single-quantum process. This assumption is not scientifically justified. In particular, besides atomic/molecular targets, relatively large particles with almost macroscopic magnetic moment, the so-called magnetite [1], or charged macromolecular DNA–

protein macrocomplexes such as nucleoids and nuclei [8] can be a sensitive target for NT MW effects. Moreover, even cell ensembles may be responsible for primary interaction with MW [15]. The interaction with EMF can be of multiple-quantum character and may develop in the absence of thermal equilibrium [10, 16, 17]. The kT problem has recently been challenged by Binhi and Rubin [16]. These authors stress that the notion of a *kT constraint* originates from statistical physics and is only applicable to systems near thermal equilibrium. In such systems, NT MW cannot change the mean energy of cellular structures or, more precisely, the vibration energy of their molecules stored in their degrees of freedom. Degrees of freedom characterize the ways in which a molecule or structure can move (vibrate, rotate, etc.). The energy absorbed by a degree of freedom from MW at certain frequency cannot be *stored* or accumulated at this frequency if this degree of freedom is coupled to other degrees strongly. Significant progress has been achieved in understanding the mechanisms for NT biological effects of MW. However, this understanding is not comprehensive. Thus, a variety of physical mechanisms may explain interaction of biosystems with NT MW and its important characteristics such as dependence on frequency, polarization, and modulation.

4. Conclusions

The predictions of this model are:
1. Amplitude of the electric field should be large enough to induce oscillations of nucleoids.
2. MW effects should be observed only at specific carrier frequencies.
3. Effects of MW should depend on modulation.
4. Effect should be observed at specific intensity flux densities of static and alternating MF.
5. Effect should be observed at resonance frequencies of alternating MF.
6. Model of the combined action of an alternating magnetic field and millimeter waves should be considered.

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