Reply to Comment on “Behavior of Charged Particles in a Biological Cell Exposed to AC-DC Electromagnetic Fields” and on “Comparison Between Two Models of Interaction Between Electric and Magnetic Fields and Proteins in Cell Membranes”

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In order to produce a field of 10 mV/m in a deep tissue at 50 Hz, external fields of about 800–1000 kV/m are needed. According to Dimbylow (2005), an external vertical electric field of 1 kV/m results in an induced electric field in the human body; for example, 2.7 mV/m in skin, 1.85 mV/m in muscle, 1.6 mV/m in liver, and 0.5 mV/m in gray matter. The question of what external magnetic field of 50 Hz is necessary to produce an induced electric field in the body is more complicated since the induced electric field increases linearly with distance from the central axis of a body. A 50-Hz magnetic field of 1 mT would give an internal electric field at 10 cm from the central axis of a human body of 1.6 mV/m according to Maxwell’s third equation. Thus, it can be concluded that very strong external electrical or magnetic fields are needed at 50 Hz in order to obtain an internal electric fields on the order of 1 mV/m.

We do not rule out the possibility that electric fields have a direct impact on biological matter, we only conclude that very strong external electric and magnetic fields are needed to obtain the required induced electric fields. We do acknowledge the statement by Panagopoulos et al. (2002) that the coherent action of more than one ion can increase the sensitivity of the proposed model (Halgamuge et al. 2009).

We do not quite understand how weak magnetic fields can influence voltage gating of an ion channel as described by the authors in their comment article. It is stated there that the magnetic field will exert a force on the moving ions in the channel, but if the purpose of the magnetic field is opening the channel, it is still closed when the magnetic field is applied and ions are only moving by Brownian motion in all directions, and no systematic displacement of ions will occur in the vicinity of the voltage sensing unit of the channel protein.

The assumption made by the authors that an environmental external magnetic field can induce electric fields in the body on the order of 1 V/m must be considered unrealistic. As is shown above, a 50-Hz magnetic field on the order of 1 T is needed in order to induce an electric field on the order of 1 V/m.

The authors claim that the free ion forced-vibration theory also can explain biological effects caused by low-frequency amplitude modulated microwaves. However, it is unclear to
us how the modulation would change the interaction between the high frequency carrier wave and the ions in the vicinity of the voltage sensing unit of the channel protein.

The problem of how extremely weak signals that are much weaker than the thermal noise in a biological tissue can be detected by the living cell has been discussed for decades and several solutions have been proposed. It is beyond the scope of this comment article to discuss the signal-to-noise problem in detail. In theory, very weak regular signals can be detected in the presence of a strong noise signal if some integration over time process is active, or if the biological system is “tuned” to the frequency of signals presented. In this respect, we agree with the authors. A valid interaction model should state how the signal-to-noise problem is solved by the biological “detector.”

The ion parametric resonance (IPR) model, proposed by Lednev in 1991, predicts that biological effects can be expected under the combined action of static and time-varying magnetic fields at certain frequencies. We thank the authors for pointing out the printing error in Halgamuge et al. (2009: 1476, third paragraph). Indeed the resonance frequency is determined by the strength of the static magnetic field only, not the combined strength of the AC+DC magnetic field.

In the original version of the IPR model, radiation from the Zeeman-splitted excited states to the ground state of the ion in its potential well was considered. Not, as the authors state, transitions between two Zeeman levels, 10^{-13} eV apart. The photons from the decaying states were considered to be in the infrared region. In a later interpretation, polarization of the ion orbit of the excited ion was considered sufficient for causing a biological effect (Lednev, 1996). For a discussion see Engström (1996). The lifetime of the ion in its excited state must be quite long (>0.1 s) in order for the widths of the Zeeman energy states to be sufficiently narrow. The statement by Engström: “I cannot provide satisfying answers or justifications to all issues raised” is directed to the objections that Adair (1992) raised against the original version of Lednev’s theory. He then describes the conditions necessary for the model in order to make it plausible.

Lednev’s theory was meant to describe the change in enzymatic activation of enzymes by calmodulin. We generalized Lednev’s ideas and hypothesized that any protein might change its conformational state when it binds ions at certain sensitive sites. We could have stated this clearer in the article (Halgamuge et al., 2009). One of the authors of this article has studied calcium channels in vesicles of highly purified plasma membranes and found that the ion flux through the channels could be modified under the conditions predicted by Lednev (although with a modification as described by Blackman (Bauréus Koch et al., 2003; Blackman et al., 1994). Bauréus Koch et al. (2003) detected changes in calcium flux at resonance frequencies as predicted by the IPR theory. It is not clear how these results could be explained by the forced-vibration theory, considering the high viscosity of the medium that eliminates resonant displacement (Halgamuge and Abeyrathne, 2011).

At least, it can be concluded that the quest for a realistic model, that can explain observed modifications of biological activity, is still open.

References
Lednev, V.V. (1991). Possible mechanism for the influence of weak magnetic fields on biological systems. Bioelectromagnetics 12, 71.