Electromagnetic Environments and Health in Buildings

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CHAPTER 21

Theoretical and Experimental Evidences where Present Safety Standards Conflict with Reality

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21.1 INTRODUCTION

Why do some people feel unwell during a magnetic storm? Why is there a correlation between the level of electromagnetic background and the incidence of cancer [Portier *et al.*, 1998]? Why do so many medical centres use electromagnetic exposures to treat a wide variety of disorders in humans? People are continually immersed in electromagnetic fields both of natural and technological origin, such as those from power lines, domestic appliances, mobile phones. Human sense these fields, just as do other living beings. This fact is supported by an immense amount of scientific evidence [Bersani, 1999]. The World Health Organization now considers that enhanced electromagnetic contamination in occupational and residential areas is a stress factor for people.

At the same time, however, many authors note that the physical origins of the phenomenon are, as yet, unclear — the phenomena themselves often seeming paradoxical. This allows people to speculate about the safety aspect of EM radiation in ways that are not always compatible with science. In particular, manufacturers of widely used electrical appliances, such as cell phones, computers, and TVs continue to insist that their devices are safe, based solely on the fact that the radiation from such equipment is generally not intense enough to cause an adverse level of heating of biological tissues. At the same time, however, there are many experiments showing that weak and even hyperweak (*see below*) EM fields can influence living tissues, and even whole organisms. Generally, particularly in the case of time-dependent fields, such influences are characterized by "windows" in biological responses. Such findings undermine the philosophy on which existing EM safety standards are based — namely that EM fields can lead to biological effects only if they cause heating of biological tissues.

Both experimental findings and theoretical approaches indicate that EM fields — even when they are too weak to heat tissues — may result in a variety of different biological effects, some useful and some probably noxious. In this article, we show that hyperweak fields — even of intensities very much less than those emitted by cell phones — affect biology; thus it cannot longer be maintained that cell phone radiation cannot cause harmful biological effects. Accordingly, existent Western EM safety standards afford a totally inadequate level of protection, unlike those in Eastern Europe (and in the Russian Federation, in particular) which are much more stringent, having been developed with the benefit of experience with *non-thermal* biological effects, rather than solely heating. Here we will discuss in more detail the inadequacy of thermally-based guidelines, and study a new theoretical approach *via* which electromagnetic biocompatability might be realized.

21.2 DO BIOEFFECTS OF HYPERWEAK EM FIELDS EXIST?

Normally, biological systems dwell in the natural terrestrial magnetic field, the geomagnetic field, whose value varies with latitude, from approximately 40 μT at the Equator to 70 μT at the Poles. This provides a natural biological benchmark against which DC fields of technological origin can be compared. A magnetic induction of value B_0 = 50 μT is referred to in the scientific literature as "weak". Therefore, magnetic fields of strength $B \ll B_0$ — say below 1 μT — may be classed as hyperweak. There are good reasons to connect many biological effects of EM fields or magnetobiological effects[1] with the Zeeman and Stark effects at the atomic and molecular levels [Binhi *et al.*, 2000]. Since electric fields of the order of 100 V/m result in similar changes in the atomic structure as do magnetic fields of intensity B_0, we may take E_0 = 100 V/m as a natural benchmark, and consider electric fields below 1 V/m as hyperweak.

To characterize AC fields one may use their heating effect on biological tissues. In the ELF range this leads to approximately the same as given above for DC fields. Because thermal effects are directly proportional to EM frequency at frequencies of order 1 GHz, EM flux densities between 1–100 mW/cm^2 may be regarded as weak (causing the lowest discernible degree of tissue heating), and powers below 100 μW/cm^2 as hyperweak.

It is now necessary to consider whether such hyperweak EM fields can cause biological effects.

21.2.1 Experiments

Below, we list some of the results that confirm hyperweak EM fields can cause biological effects.

Early experimental evidence for biological detection of hyperweak signals, both magnetic (up to 1 nT) and electric (up to 0.1 mV/m), was given by Presman [Presman, 1970]. Bastian [Bastian, 1994] discussed the sensitivity of sharks and skates to electric fields as low as 0.5 μV/m. Peroxidase activity was changed from 9% to 72% after 3 h exposure to 8 Hz magnetic fields of magnitudes 0.02, 0.2, 1, and 2 nT. This was observed [Vladimirsky *et al.*, 1971] in measurements of

[1] The magnetobiological effect (MBE) is a generic term to designate any weak magnetic or electric field–dependence of any biological object.

biochemical parameters of neutrophils. Keeton, Larkin, and Windsor [Keeton *et al.*, 1974] reported that natural 100 nT geomagnetic fluctuations affect the orientation of pigeons. Delgado, Leal, *et al.* [Delgado *et al.* 1982] studied effects of 48 h exposure to pulsed magnetic fields on the growth of chicken embryos, statistically significant effects being found for ELF magnetic field of the order of 0.12 μT. Agadjanyan and Vlasova [Agadjanyan *et al.*, 1992] observed an effect of sinusoidal magnetic fields between 0.05–5 Hz, and approximately 100 nT on neuron spike activity in the cerebellum of mice; their experiments were made in a magnetically shielded room.

Jacobson, 1994, used hyperweak magnetic fields between 5 pT and 25 pT to treat epilepsy and Parkinson's disease. Application of a sinusoidal field to the human head was found to affect the pineal gland. Magnetic field stimulation induced changes in the production of melatonin, which is known to maintain anti-tumor activity. Work by Novikov and others, see for example [Fesenko, 1997], was devoted to investigation of policondensation of some amino-acids in aqueous solutions subjected to AC magnetic fields of about 20 nT in a geomagnetic-like static magnetic field. Effective frequencies were found to be of the order of a few Hz. Blank and Soo, 1996 researched Na, K-ATPase enzymatic activity on microsomes, and found that it appeared to depend on the 50 Hz magnetic field, the limit of susceptibility being 200–300 nT. Cell cultures of mouse epidermis grew twice as fast as the control when exposed to a 60 Hz, 1 μT magnetic field, superimposed on the background static laboratory field, [West *et al.*, 1996]. Akerstedt, Arnets, *et al.*, 1997, studied the effect of overnight exposure of human subjects to a 50 Hz, 1 μT magnetic field, it being found that such field significantly shortened the duration of the so-called "slow sleep".

Various scientific groups [Hyland *et al.*, 1999] showed that special microcrystalline solutions placed into small metal boxes appreciably reduced the risk of diseases arising from proximity to computer and TV monitors. It is likely that this protection is afforded by the magnetic field arising from precessing proton spins in water, the emitted field being in the pT range at half-meter distance.

There is much experimental data published by many investigators and reviewed by Binhi [Binhi *et al.*, 2000], in which electric fields were applied either externally — by capacitive or inductive coupling — or internally by direct coupling to electrodes. In all the cases, biological effects were observed for ELF electric fields ranging from 5 to 500 mV/m in magnitude.

Biological effects of hyperweak microwaves were also observed in several studies: 10^{-2} μW/cm^2 [Aarholt *et al.*, 1988], $5 \cdot 10^{-6}$ μW/cm^2 [Grundler *et al.*, 1992], 10^{-12} μW/cm^2 [Belyaev *et al.*, 1996], 10^{-12} μW/cm^2 [Kuznetsov *et al.*, 1997]. It is interesting to note that flux densities of the order of 10^{-10}–10^{-11} μW/cm^2 correspond to the thresholds of vision and hearing.

Some of these data are schematically depicted in Figure 1, which shows the domains of both the experimentally observed effects and various theoretical limits, and indicates the non-thermal physical nature of the effects.

21.2.2 Theory

To date, the physical nature of the biological sensitivity to weak and hyperweak EM fields remains unclear, although significant insight has recently been developed [Binhi, 2002]. A unified foundation is proposed which is claimed to account for the biological effects of EM fields. The interference of quantum states of ions and molecular groups explains many of the paradoxes surrounding the non-thermal action of EM fields. This theory is based on "primary" physical principles and agrees with experiments.

In many cases, biological effects display "windows" in biologically effective parameters of the fields. Most dramatic is the fact that relatively intense fields sometimes do not cause appreciable effect while smaller fields do. Linear resonant physical processes, as well as any kind of heating, cannot, of course, explain the existence of frequency windows.

It has been suggested [Binhi, 1997] that a nonlinear effect, involving the interference of quantum states of ions and molecules bound within some proteins — in particular, calcium and calmodulin — is a general molecular target for the external EM fields. The ion interference mechanism predicts multipeak biological effects in many cases: magnitude modulated magnetic fields, magnetic vacuum, pulsed magnetic fields [Binhi, 1998], weak AC electric fields, shift and splitting of MBE spectral peaks under the rotation of biological samples, combined action of different magnetic fields and magnetic noise, bioeffects of modulated microwaves. The consistency between theory and experiments indicates that what underlies the MBE is most likely the interference of ions.

In accordance to the ion-interference mechanism, the threshold field for biological responses to the ELF electric field falls into the range of hyperweak electric fields [Binhi *et al.*, 2000]. Ion interference mechanism applied to rotating biophysical structures, such as DNA-RNA fragments, provides a basis for understanding how weak EM fields affect biology [Binhi, 2000]. Of special interest is the existence of molecular gyroscopic degrees of freedom, because these degrees of freedom are not thermalised on biologically relevant time scales. Therefore, mechanisms that involve molecular gyroscopes can account for the biological effects of hyperweak EM fields [Binhi, 2002]. It is important to keep in mind that the possibility of the interference mechanism depends on the value of the local static magnetic field. Since this field varies in a complicated manner throughout the interior of modern buildings, the interference effect at the molecular level and consequently the biological endpoint, may not be reproducible in different places, even when all other EM fields are the same.

All living matter is built from the same molecular bricks — amino-acids and proteins. Despite their inherent differences they have very similar biophysical structures. Therefore, it is clear that the interference mechanism (a molecular physical theory) is equally applicable to biological systems having different levels of complexity. If an effect exists for one biological system at given EM fields, one may expect one for another biological system exposed to the same EM fields. The only condition for this is the presence in both systems the *same* molecular EM target.

Molecular mechanisms of biological sensitivity to EM fields are consistent with the fundamental quantum limit of sensitivity to electromagnetic radiation.

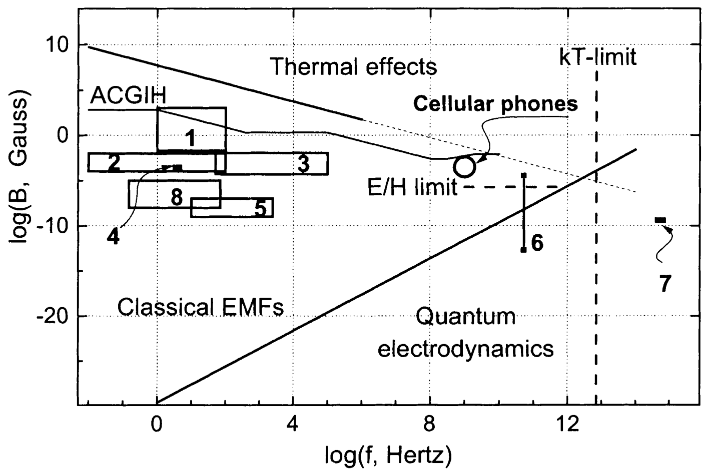

Figure 21.1 This figure illustrates various limits and areas of EMF biological effects as functions of two variables, EMF frequency f, in Hz, and amplitude B, in G = 100 μT. The large variation in both variables is chosen to show qualitatively different cases of the effects and theoretical approaches. A quantum of EMF with energy less than kT lies to the left of the dashed vertical line. This line defines a paradoxical area, wherein the biological effects are not possible from an orthodox viewpoint. The upper, diagonally downward directed line separates (very approximately) the domains of thermal and non-thermal EMF bioeffects. The lower, diagonally upward directed line is the QED limit. EMF must be described as a quantum system below this line. The step-inclined line is the ACGIH (see refs) – limit of safe levels of the EMF exposure. Areas marked by digits denote ranges of the parameters characterising: 1 — ELF EMFs used in most of magnetobiological experiments; 2 — EMFs produced by magnetic storms, which are known to correlate in time with a peaking of cardiac-vascular diseases; 3 — background EMFs produced by the variety of home appliances, video display terminals such as TV and computer monitors; 4 — MFs that affect some amino-acid solutions [Fesenko *et al.*, 1997]; 5 — MFs supposedly induced at 0.5 m from the TecnoAO units by VDT and cell phones EM radiation; 6 — EMFs below the quantum electrodynamics limit, which significantly affect cell cultures [Belyaev *et al.*, 1996]; 7 — limit of sensitivity of the human eye; 8 — magnetic fields used therapeutically to treat certain diseases. The open circle shows MF fields emitted by typical cellular phones.

Figure 21.1 shows several theoretical limits defining different mechanisms and descriptions of EMF bioeffects. The *kT* and thermal limits are well known, being used repeatedly in many scientific works on EMF standardization. The quantum electrodynamics limit, on the other hand, needs some comment.

The nature of the interaction between EM fields and a substance depends on whether the EMF can be treated classically, or whether its quantisation in photons has to be taken into account. Quantum electrodynamics gives the conditions for the validity of a classical description — namely, that the field must have a certain minimum intensity (*i.e.* amplitude), the value of which depends on frequency (as indicated by the lower, upwardly directed diagonal line in Figure 21.1). As can be seen, all "low frequency" effects except the hyperweak can be described within classical EMF approach.

However, this does not define a minimum EM field intensity that is detectable by a biological system. The natural constraint on the electromagnetic susceptibility of a biological reception, as well as any receiver of a physical nature, is given by the general laws of the quantum mechanics, which relates the minimal energy change, ε, and the time, t, required for its registration, according to $\varepsilon t > h$, where h is the Planck constant. For example, in order that an ELF EMF photon of frequency $f \sim \varepsilon / h$ to be registered by any system, including biological one, requires a time interval, t, of at least $1/f$.

At the same time, this relation does not set a lower limit of the susceptibility to EM fields. Apparently, there is no general theoretical constraint defining a lower limit for the intensity of EM fields capable of affecting a biological system. All physical constraints that have been suggested to date are based on specific primary mechanisms of the EM field signal transduction, and not on fundamental physical principles, which do *not* forbid biological hypersensitivity to EM fields. Only the microscopic design of a biological receptor and the time of its coherent interaction with EMF define the level of hypersensitivity in each specific case.

The indicated E/H limit shows the level of EM fields, in a plane wave approximation, below which atomic magnetic effects dominate electric ones. As is seen, such EM fields should be referred to as hyperweak fields. There are corresponding experimental observations [Belyaev *et al.*, 1996].

21.3 TOWARDS EM SAFETY STANDARDS

For a quantity of heat, Q, per unit mass of a biological tissue, the rate equation may be written as follows

$$dQ/dt = R + P - Q/\tau ,$$

where R is the heat input due to metabolic processes, P is the contribution from EM field absorption, and Q/τ is the heat loss on a time scale τ. In stationary regime, $dQ/dt = 0$, and we obtain a relation defining the heat increment corresponding to the growth of P: $\Delta Q = Q - Q_0 = P\tau$, where $Q_0 \equiv R\tau$ is a quantity of heat in the absence of the EM field. A heat increment ΔQ causes the temperature rise ΔT according to: $\Delta Q = c\ \Delta T$, where c is the specific heat capacity. It is then easy to find value of heat input, P_0, required to achieve a given temperature rise:

$$P_0 = c\ \Delta T/\tau .$$

For a biologically significant temperature rise of 0.1°C, a 1-minute relaxation time for biological tissue, and a specific heat capacity 1 J/g °C, we calculate P_0 of order 1 W/kg. This threshold quantity may be further linked to the so-called specific absorption rate (SAR)

$$SAR = \sigma E^2/\rho,$$

which shows the quantity of heat that is produced by alternating electric field, *E*, in a dielectric medium of electric conductivity σ and density ρ (we do not take into account the dielectric heating at the character frequency 2 GHz because it is two times less than Joule effect). If the SAR exceeds P_0, biological tissue will undergo a potentially dangerous degree of heating. It is impossible to analytically derive a relation between output power of a cell phone and SAR distribution in a user's head because of the very complicated field configuration in the near zone of an antenna due to non-uniform electric and dielectric properties of the head tissues. Numerous numerical results show that each Watt of the output power produces a SAR[2] value of the order of 1 W/kg. This value can, however, vary significantly depending on the type, orientation, and closeness of a cell phone to the human head. At the same time, the ICNIRP general public safety SAR threshold is 2 W/kg, at 935 MHz for localised exposure. Therefore, for example, a GSM 900–1800 MHz cell phone with an average output of 0.25 W is just within the recommended safety level, or just a little below it — see Figure 21.1.

There are similar data for the ELF range indicating the presence of ELF magnetic fields about 1–10 μT inside the head. This raises the hotly debated issue as to whether the present safety standards afford adequate protection against the emissions of cellular phones. In this regard, we would like to emphasize that both the existing EM safety standards (based solely on considerations of heating), and the current fixation with "fine-tuning" them, diverts public attention from the real problem of the bio-significance of non-thermal effects of this kind of radiation, which should, instead, be the centre of focus.

The real problem is that biological effects may be caused by hyperweak EM fields, far below those that can heat tissues. Most bioeffects of domestic appliances (which are confirmed in many scientific works) are not caused by EM heating, but rather by other, *resonance-like* physical processes that are still possible for much less intense EM fields. This well-known fact is a very dramatic one for manufacturers of devices that utilize EM fields. Therefore, in the interest of market growth, there are compelling reasons to suppress this knowledge, so that it does not become widely known.

Effecting simply a possible reduction of the output power of cell phones is not really a solution of the problem. It is easy to see that such attempt would be based, implicitly, on the direct proportionality between the EM power and subsequent biological effects. Whilst such proportionality indeed holds in the case EM heating

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[2] In order to ease connection with experimental data where EM fields were like a plane wave, we indicate that EM flux density at the surface of the head may constitute 1–100 mW/cm^2 per Watt of output power.

of biological tissues, it does not necessarily hold in the case on non-thermal effects. There are both theoretical and experimental grounds for *non-linear* power-dependences of MBEs, in which a reduction of the EM power may actually lead to the growth of a biological effect! This is why a totally different approach must be adopted if people are to be protected against cell phone radiation and other forms of sub-thermal EM environmental pollution. It follows that physical concepts other than those underlying thermal effects must be urgently studied at a fundamental level, so that they can ultimately be applied to the development of more comprehensive safety standards that incorporate the principle of electromagnetic biocompatibility.

21.3.1 Power Reduction

Researchers observed biological effects of very different EM fields that are distinct in frequency, amplitude, polarization, configuration, and so on. In addition, very different kinds of biological systems may be involved in the response to EM fields. Furthermore, many different endpoint parameters — physical, chemical, biological, and even social — are measured in such experiments. Is it possible to indicate some scales of the physical observables that could characterize EM bioeffects as a natural phenomenon? Because of the great variety of different cases, we may speak about such scales only in the sense of averaged values. Taking into account a lot of existing empirical data obtained under varying conditions, we may conclude "on average" that appreciable biological responses, say 10%, appear in a time period of 10 to 100 min as a consequence of exposure to ELF magnetic fields between 10 and 100 μT, or microwave EM fields at power densities between 10 to 100 $\mu W/cm^2$. Bioeffects of ELF electric fields, on the other hand, are generally less clear and decipherable.

Whilst exposure to these fields of these strengths does not necessarily cause bioeffects, bioeffects are, nevertheless, found at these intensities. It follows, in principle, that the common procedure of averaging over the whole ensemble of both positive and negative findings is unacceptable. From the viewpoint of a person who "caught" the EM field and got some associated disease, such averaging understandably seems amoral.

Can we use the above considerations to develop a new EM safety standard? Present EM safety standards make use of the notion of a "dose" of exposure to EM fields. The dose is the product of the field amplitude (or power) and the time of exposure. Indeed, many different safety levels can in this way be defined, according to the particular duration of exposure adopted — a minute, hour, and day[3]. Moreover, the greater the time interval, the lower can be the level. It is possible to consider the possibility of defining a "safe" dose as an upper limit (or threshold value) on the power-time product, which should not be exceeded during normal use of a particular device.[4]

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[3] There are a few or no EM safety standards related to month and year duration of exposure. By this, they renounce possibility of the long-term biological effects of the EM fields that is inconsistent with many experimental data on chronic EM exposure.

[4] Of course, the question is much more complicated, for example the EM frequency is an essential parameter of the EM safety standards. For clarity, we hold only main features of the question.

Despite the non-linearity of the physical processes underlying MBE, the notion of the dose is still a useful one, although it should be applied to or based on the above-mentioned biological effects rather than on heating effects. From the theoretical viewpoint, nonlinear molecular interference effects may be characterized by the dose, but only when all possible local static magnetic fields are averaged over, so that subject motion is taken into account.

Taking the above mean values for microwave power of 30 $\mu W/cm^2$ and time scale 30 min, we obtain a threshold dose about 10^3 $\mu W \cdot min/cm^2$. This value is significantly less, by between one and three orders of magnitude, than the thresholds suggested by the different specialist committees, and is likely to be better for human health. However, it would be much better if the averaging was done over a particular class of subjects, such as cell phone users, for example. The decrease of dose does not necessarily mean, however, that a particular individual is necessarily immune, particularly if the above time and space averaging is not realizable in that particular case. It thus becomes apparent that such "direct" methods cannot, in general, be considered to guarantee safety at an individual level.

21.3.2 Biological Protection

It was recently demonstrated that TecnoAO technology, based on hyperweak magnetic emission of a microcrystalline solution electromagnetically treated (International Patent, see references), offers an efficient protection against biological effects of the EM fields. Chicken embryos, which were exposed to computer/TV screens or the EM fields of cellular phones, showed an enhanced mortality rate, but in the presence of TecnoAO protective units (metal tubes or other forms filled with a special solution) the mortality rate or the status of the immune system of young adult chicken and of mice remained the *same* as in the control group [Youbicier-Simo *et al.*, 1996, 2000].

For humans exposed to VDU emissions in their workplace, epidemiological studies reveal a statistically significant improvement in the condition of 119 individuals one month after the VDUs had been protected by TecnoAO technology: specifically there was a 15% increase of stress resistance, and a 23% increase of concentration [Fillion-Robin *et al.*, 1996]. The portfolio of evidence obtained from controlled studies of the efficacy of TecnoAO technology makes it possible to conclude that that solution behaves as a source of signals that mitigated the adverse effect of device radiation on biological processes. The solution emits propagating physical field that affects biophysical targets. The signal is, in turn, transmitted to the cellular level, to organs and to the whole body. This implies that the saline solution supports a number of metastable states of differing biological activity [Binhi, 1991; Binhi, 1998b]. The solution acts as a re-emitter of radiation, which, however, modified in the low-frequency range. The solution within the TecnoAO is "charged" by a preliminary EM treatment, which transforms the solution into another metastable state, the re-emissions from which are characterised by the modified low-frequency EM spectrum that contains biologically significant information. In addition the EM fields, the solution may also radiate other physical agents of biological significance. Ultimately, the total emission targets particular biological structures preserving their integrity under irradiation from the device (cell phone, VDU), which, in turn, ensures that homeostasis is maintained.

Recently, the effect of exposure to cellular phone radiation on nitric oxide production by humans was observed [Fillion-Robin *et al.*, 2001]. An increase of nitric oxide concentration in exhaled air was found to be between 7 and 40% after two weeks intermittent exposure to GSM cell phone radiation. Endogenous nitric oxide plays an important role in a large number of biochemical processes in human body. The NO molecules are involved in the transmission of nervous impulses, regulation of vascular tension and the development of inflammation. Gaseous nitric oxide present in exhaled air is a bio-marker of inflammation processes in patients with respiratory diseases. Application of TecnoAO protective units during the following two-week exposure was found to return the NO concentration to the control level.

It is to be emphasized that TecnoAO technology protects at the biological level. It makes molecular targets of EM, such as ion-protein bonds, insensitive to EM fields, which could otherwise cause interference effects, resulting in abnormalities. Thus, this technology, which *compensates* harmful biological effects, rather than the EM field itself, implements the realization of electromagnetic biocompatibility.

21.4 CONCLUSION

Both published experiments results and recent theoretical advances show that EM fields may result in different biological effects, even if they are too weak cause any deleterious degree of heating. Present EM safety standards do not account this possibility. Therefore, in occupational and residential activities, people exposed to EM fields from industrial and domestic appliances, conform to existing safety standards, are *still vulnerable* to non-thermal biological effects having possible adverse consequences for human health.

The thermal effect of electromagnetic fields is the only factor that is currently used for the development of electromagnetic safety standards. There are, however, other influences — such as the molecular quantum interference, that can cause *non-thermal* biological effects that display resonance-like behavior. Levels of magnetic, electric, and microwave fields have been identified at which such non-thermal effects might be expected. These indicate that existing safety standards fail to provide adequate protection to the users of these devices.

New approaches to EM safety standards — based on the principle of electromagnetic biocompatibility — have been here proposed, from consideration of the *non-thermal* biological effects of EM fields of sub-thermal intensity.

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