RF Interactions with Biological Molecules and Processes: Quantifying Thermal and Non-thermal Mechanisms

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Electromagnetic fields can have direct effects on mobile ions, atoms, and molecules within mechanis-m-specific constraints for field strength, temporal scale, and spatial dimensions. Threshold conditions for several mechanisms can be estimated from the field magnitude, frequency, and modulation that might satisfy criteria for biophysical interactions of potential physiological significance. The vast parameter space over which technological devices operate indicates the need for fundamental approaches that could apply to many of the established and speculative biophysical mechanisms.

Temperature is a fundamental parameter of biochemistry. It also is the most comprehensive and best-established measure for effects on whole organisms and small regions of tissue. "Microthermal" effects occurring over small distances and lasting brief times have been proposed as a way to focus heating at microscopic and molecular scales. However, thermal diffusion limits temperature changes over cellular dimensions to $\approx 10^{-12}\,K$, even for the extremes of exposure obtainable with common devices. For many years, laboratory reports of differences between the biological effects of CW vs. pulsed and amplitude-modulated RF have stimulated interest in modulation-dependent mechanisms. Heating, which is proportional to E^2 or H^2, is inherently non-linear and could be a basis for some demodulation of pulsed or amplitude modulation at low rates, but the controversial effects reported with definitively non-thermal exposures require other mechanisms, particularly above ≈ 1 to 10 MHz where nonlinearities of transmembrane ionic flux become insignificant [1–3]. The principles of thermodynamics show that various nonlinear interactions between a RF field and a biological system produce characteristic spectral signatures that could be detected by spectroscopy with exceptionally high sensitivity [4]. For example, for a proposed experiment, a detection sensitivity of -127 dBm in an experimental cavity corresponds to ≈ 10 to 100 photons/s/cell at a nonlinearly-produced 1^{st} harmonic [5]. This sensitivity suggests that if harmonic and other frequency signatures of nonlinearity are absent, the nonlinearities of biological matter are so weak that physiological effects are unlikely.

In general, phenomena reported at nonthermal power levels imply the existence of resonant absorption, such as in rhodopsin where a tuned response underlies the high photon efficiency of vision. Similarly, tuned absorption in the RF range would indicate greater sensitivity than thermal absorption, which occurs over a broad bandwidth. Quantitative models and experiment show that such resonances cannot occur below the low-infrared region, particularly because of damping by macromolecular collisions with water molecules [6].

Mechanisms that are inherently statistical, such as stochastically altered binding to DNA, allow estimates for the probability of consequences from the long-term accumulation of rare effects. Assuming an Arrhenius process, even integrating low probability events over years yields so few errors that it would be impossible to detect them against normal background errors.

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