Mechanisms of the biological effect of the Extremely-Low Frequency Electromagnetic Fields

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Abstract

Introduction: Since 1990s, studies of the effects of Extremely-Low Frequency Electromagnetic Fields (ELF_EMF) on biological systems have been conducted, including investigation of the effects of these fields on cancer cell apoptosis and induction of calcium uptake in osteoblasts. Besides, the influence of the Earth's magnetic field on bird navigation has also been discussed. Since different effects have been observed on biological systems, providing mechanisms for these effects has become an essential line of research in Biophysics; Two of the likely mechanisms are Ion Cyclotron Resonance (ICR) and Radical Pair Mechanism (RPM). However, the criticisms on the ICR mechanism leaves the RPM the most plausible one so far.

Methods: Investigations indicate the influence of the Earth's magnetic field on the birds navigation, and the models that justify this phenomenon, present the effect this field on singlet/triplet transition states in the cryptochrome, which is in the photoreceptor neurons of these birds. The effect of ELF_EMF on calcium flux was investigated by measuring the amount of fluorescence light by fluorescence microscopy. The effect of these fields on the apoptosis of cancer cells was also studied by flow cytometry.

Results and discussion: Despite all the efforts, it seems that there is no mechanism to explain the effects of these fields on biological systems. However, the radical pair mechanism seems to be much more efficient to explain the effects of these fields than the ion cyclotron resonance.

Conclusion: Various effects had been observed, particularly the dependence of apoptosis level of cancer cells on the frequency of the applied field. Presenting a convincing explanation of these phenomena can be huge breakthrough and paves the way for employing ELF_EMF as a selective treatment for solid cancer tumours.

ICR: Cellular effect due to weak magnetic fields tuned to calcium ion resonance

The ion-cyclotron-resonance (ICR) model, initiated by findings of Blackman et al. proposes that the transmembrane transport of biologically important ions such as Na+, K+, Mg2+ and Ca2+ can be enhanced when a constant (static) magnetic field *(Bc)* is superimposed on an alternating electric or magnetic (Bc) field at a distinct (resonance) frequency. The equation

$$f = \frac{qB_0}{2\pi m}$$

describes the relationship between the resonance frequency fR and characteristics of the ion (with q= the ion's charge and m = its mass) in the presence of a static magnetic field Bc .

In several observations, the influence of the magnetic field on biological systems has been observed.

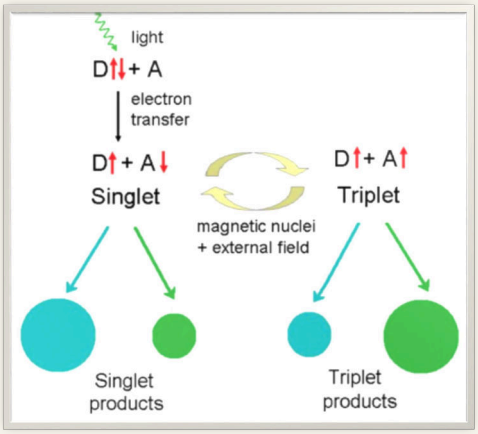
REFERENCE	FREQ Hz	DC FIELD μT	RATIO Hz/μT	EFFECT
Smith et al (1987)	16.0	20.9	0.765	Diatoms; motility
Liboff et al (1987)	14.3	21.0	0.68	Lymphocytes; Ca uptake
Rozek et al (1987)	14.3	20.9	0.68	Lymphocytes; channel blocking
Ross (1990)	100	130	0.77	Fibroblasts; proliferation
Rochev et al (1990)	16	20.9	0.765	Fibroblasts; proliferation
Lyle et al (1991)	13.6	16.5	0.82	Three cell lines; Ca uptake
Yost &Liburdy (1992)	16	23.4	0.68	Lymphocytes; mitogen activation
Horton et al (1993)	15.3	20	0.765	Neurons; differentiation
Ryaby et al (1993)	15.3	20	0.765	Chondrocytes; TGF β-inhibition
Fitzsimmons et al (1994)	15.3	20	0.765	Bone cells; IGF-II & DNA
Tofani et al (1995)	32	42	0.76	Lymphocytes; micronuclei
Blanchard et al (1997)	45	59	0.76	Neurites; outgrowth
Gaetani et al (2009)	7.65	10	0.765	Stem cells; differentiation
Ledda et al (2013)	7.65	10	0.765	Cancer cell line; differentiation

(Figure 1:*Reports of cellular effects due to weak magnetic fields some studies utilized isotopic calcium, Ca45, requiring a slightly smaller q/m ratio*)

Magnetic fields indeed couple to calcium ions in cells in ways that influence cell function

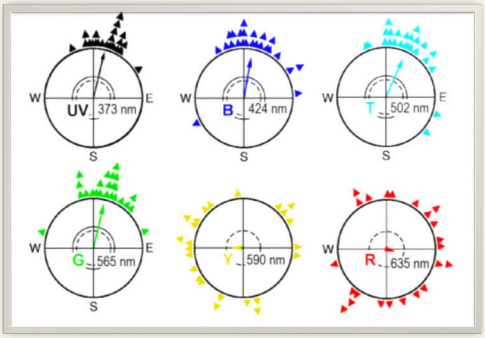
Light-induced electron transfer from a donor molecule to an acceptor create a Radical Pair

the influence of the Earth's magnetic field on bird navigation has also been discussed.
Singlet and triplet states, defined by the relative orientation of the electron spins, interconvert due to the combined effects of internal and external magnetic fields. Singlet and triplet radical pairs decay into singlet and triplet products respectively, with relative yields indicated by the sizes of the circles.



(Figure 2: Schematic of the radical-pair mechanism).

The center vector of each circle represents the average of the migration of birds under the Earth's magnetic field.



(Figure 3: Dependence of orientation of birds on the wavelength of ambient light.)

At wavelengths above 570 nm the orientation will be lost

ELF-EMF can induce the uptake of intracellular calcium level in osteoblast

[Ca2+]i fluorescence changes of five experimental groups were shown in one graph. Y-axis reflects the changes of [Ca2+]i concentration with arbitrary but uniform unit. The relative amplitudes of all the curves were comparable. EMFs of 0.8 mT, 50 and 60 Hz induced significant [Ca2+] increase.

Experimental setup of the Helmholtz coil configuration at the inverted fluorescence microscope

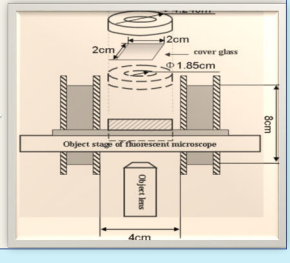
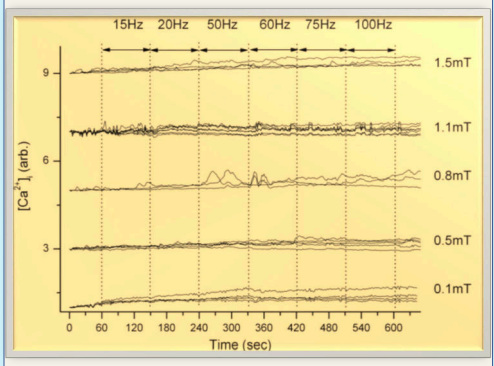
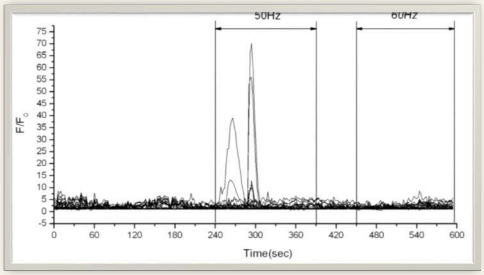


Fig.4 how the osteoblasts responded with [Ca2+]I upon exposure to the applied EMF at different flux densities and stimulation frequencies.



(Figure 4: [Ca2+]i fluorescence changes by flu-3 AM)
Four out of 10 cells appeared remarkable [Ca2+]i increase at 50 Hz stimulus

Calcium responses under EMF of 0.8 mT with the frequencies of 50 and 60 Hz



(Figure 2: [Ca2+]i responses under EMF of 0.8 mT with the frequencies of 50 and 60 Hz).

Four out of 10 cells appeared remarkable [Ca2+]i increase at 50 Hz stimulus

Conclusion

- Two of the likely mechanisms are Ion Cyclotron Resonance (ICR) and Radical Pair Mechanism (RPM).
- The criticisms on the ICR mechanism leaves the RPM the most plausible one so far.
- ELF_EMF can increase of intercellular calcium level.

Reference

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