

Intrinsic Electromagnetic Fields and Atom-Field Coupling in Living Cells

Masroor H. S. Bukhari and Z. H. Shah

Abstract—The possibility of intrinsic electromagnetic fields within living cells and their resonant self-interaction and interaction with ambient electromagnetic fields is suggested on the basis of a theoretical and experimental study. It is reported that intrinsic electromagnetic fields are produced in the form of radio-frequency and infra-red photons within atoms (which may be coupled or uncoupled) in cellular structures, such as the cell cytoskeleton and plasma membrane. A model is presented for the interaction of these photons among themselves or with atoms under a dipole-dipole coupling, induced by single-photon or two-photon processes. This resonance is manifested by conspicuous field amplification and it is argued that it is possible for these resonant photons to undergo tunnelling in the form of evanescent waves to a short range (of a few nanometers to micrometres). This effect, suggested as a resonant photon tunnelling mechanism in this report, may enable these fields to act as intracellular signal communication devices and as bridges between macromolecules or cellular structures in the cell cytoskeleton, organelles or membrane. A brief overview of an experimental technique and a review of some preliminary results are presented, in the detection of these fields produced in living cell membranes under physiological conditions.

Keywords—bioelectromagnetism, cell membrane, evanescent waves, photon tunnelling, resonance

I. INTRODUCTION

INTRINSIC cellular oscillations, electric currents and local field potentials constitute some of the exciting and important areas of cellular electrical activity [1], since the early work in last century by Lund [2], Loeb [3], Becker [4], Pohl [5], Liboff [6] and Burr [7, 8], among others. Some reports have cited cellular electric noise in various kinds of cultured cells [9, 10]. Frohlich [11] and Pokorny *et. al.* [12] have reported observations of endogenous electromagnetic fields from microtubules in cytoskeleton [13]. Aday [14] has outlined detailed rationale and mechanisms for interactions of low-level external electromagnetic fields with living systems.

The existence of intrinsic electric currents, cellular oscillations and endogenous local field potentials originated in living cells and their effects on cell physiology and pathology are all physical phenomena observed with living organisms.

M.H.S.B. is with the Department of Biophysics and Laboratory of Interdisciplinary Physical Science, Dow University of Health Sciences, Karachi-74200, Pakistan (Tel: ++92-21-99215754, Fax: ++92-21-99215758, e-mail:masroor.bukhari@duhs.edu.pk)

Z.H.S. is with the Department of Biophysics and Laboratory of Interdisciplinary Physical Science, Dow University of Health Sciences, Karachi-74200, Pakistan (e-mail:zbukhari@gmail.com)

A suggestion is made here that living cells give rise to intrinsic electromagnetic fields and these fields can interact with neighbouring atoms under physiological conditions (i.e. in favourable temperature-pressure conditions and under aerobic respiration).

This rationale and the proposed model is built upon the possibilities of resonance induced between single-photons and uncoupled atoms [15] or induced among two-photon processes and coupled atoms [16], using techniques in quantum mechanics.

Studies have reported non-thermal channel noise [17], in the range of a few GHz owing to processes taking place at a very high cyclic frequency, such as changes in conformational states of cellular proteins or rotations of ATP synthase in the mitochondrial outer membrane.

II. A THEORETICAL MODEL

Ignoring the negligible magnetic field component of the electromagnetic field, the electric field, \mathcal{E} , is taken as as:

$$E(\vec{r}, t) = \vec{r} \cdot \exp(-i\omega_y t) + c.c.$$

Under this, the n-photon absorption, by an ensemble of n-atoms under a $(\mathbf{d}\cdot\mathbf{d})_n$ interaction-induced resonance shall take place at the summed frequency;

$$2\pi\omega_1 + 2\pi\omega_2 + 2\pi\omega_3 + \dots + 2\pi\omega_n = \sum_{i=1}^n 2\pi\omega_i$$

Under a simple harmonic oscillator model, the total energy of the photons interacting with the ensemble of atoms within the macromolecules is given by;

$$E = \frac{1}{2} \sum_{i=1}^n \hbar v_{\zeta}$$

The model is illustrated with the help of Figure 1A and 1B.

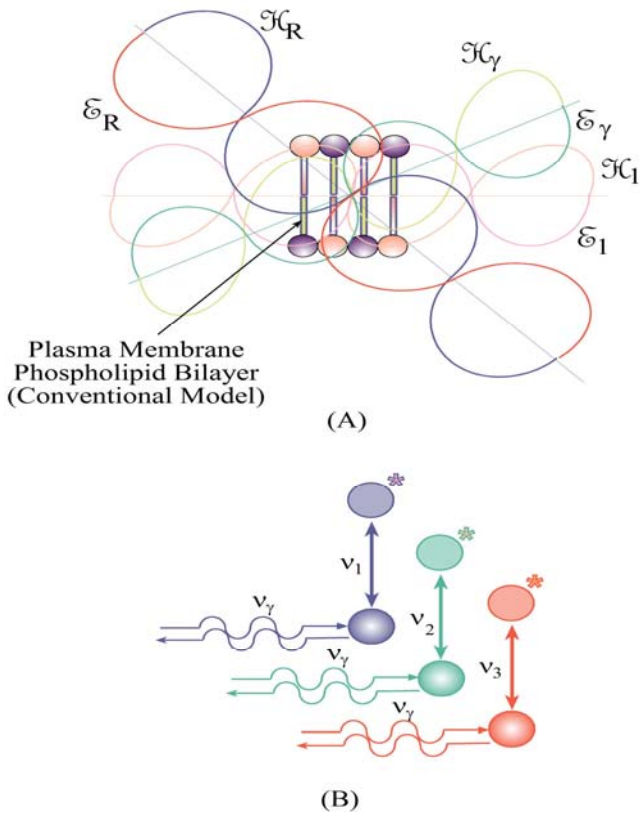


Fig. 1 Interaction of the E_1 and H_1 field vectors in the intrinsic electromagnetic field within plasma membrane. Figure 1B: Resonant absorption of an incident photon with frequency ν_γ induces the atom with a normal mode ν_1 (equal to ν_γ) to undergo transition to a higher (excited state) energy level

The collective Hamiltonian \hat{H} [18] for the ensemble of n n -level atoms interacting with an ambient field of frequency ν_γ is then defined as;

$$\hat{H} = H_0 + H_{d-d} + H_{int}$$

Which gives the total Hamiltonian for the field and atom system in a form;

$$\hat{H} = \sum_{i=1}^2 [\Delta_i S_i^z + g_i S_i^+ + V S_i^+ S_j^- + h.c.]$$

Which is to a careful approximation, the total energy contained in the photon-atom system within an ensemble of atoms in a living cell macromolecule.

An important and pertinent effect possible here as a result of the resonance among the fields is the quantum mechanical resonant tunnelling (QMR) [18] of photons. Although resonant tunnelling of matter waves (such as electrons) is a well-established quantum mechanical effect, whereby particles can surmount potential barriers under resonant tunnelling (if there is a non-vanishing quantum mechanical probability for

this to occur), this mechanism has also been cited for photons as well, in the form of evanescent waves. Photons can be transmitted through barriers under this effect when the dimensions of barriers are smaller than the photon wavelengths. The radiative transfer by means of photon tunnelling can result in both information and energy transfer (both of which can be important in cell biophysics and neuroscience).

Figure 2 depicts a cartoon of the proposed Tunnelling Photon Resonance (TPR) effect taking place in the atoms within the plasma membrane bilayer on interaction with external electromagnetic fields.

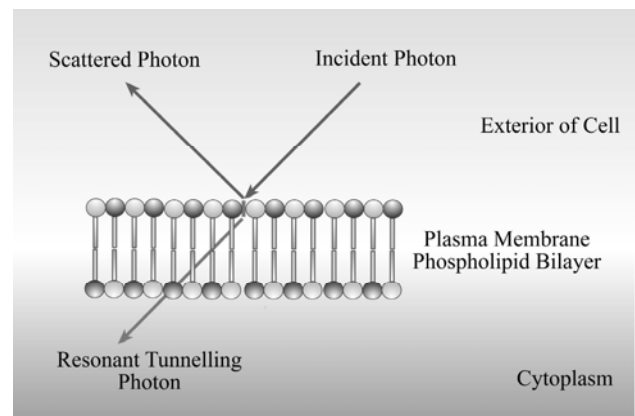


Fig. 2 A cartoon of the Tunnelling Photon Resonance (TPR) effect suggested here, whereby an incident photon (RF or IR) may get scattered from the atoms in the plasma membrane phospholipid bilayer, however by the virtue of a non-vanishing probability of quantum mechanical resonant tunnelling, it can traverse the bilayer structure (within the fraction of a micron) and interact with the structures in the cytoplasm within the interior of the cell

III. AN EXPERIMENTAL STUDY

The experiments reported here were based on a wild-type yeast (*Saccharomyces cerevisiae*) cell model. Yeast was used in an autoclaved YPD (1% yeast extract, 2% peptone, and 2% dextrose) medium. Inocula were grown at 29°C with agitation (160 rpm) in YPD broth up to 3.3 mg d.w./ml. Detailed materials and methods of growing, preparation and study of the cells can be found in an earlier study [17]. All experiments were carried out at room temperature, which was maintained at 20.5°C.

A specialized low-current low-noise preamplifier was developed for this study, the details of which are documented earlier [19]. Amplifier was operated on batteries to optimize isolation from mains noise and eliminate any possible effects of mains power or electromagnetic interference (EMI) on cellular signals. A HP spectrum analyzer 8525B (Hewlett-Packard) was employed as analysis workstation for the purpose of amplifier testing as well as recording of intrinsic cellular response. Signals were obtained from cells using a microelectrode made of 99.99% pure gold wire. The input sensing probe wire was kept very short (<3 cm) and pre-amplifier was mounted on the probe to minimize signal pick-

up from surroundings of the sample holder (details of the experiment are reported in an earlier study [17] where a similar experiment was carried out). In the second phase of the study, a cell bioreactor was used with an array of microelectrode antennae mounted in a cell suspension chamber in aerobic conditions. An overview of the setup is illustrated in Figure 3.

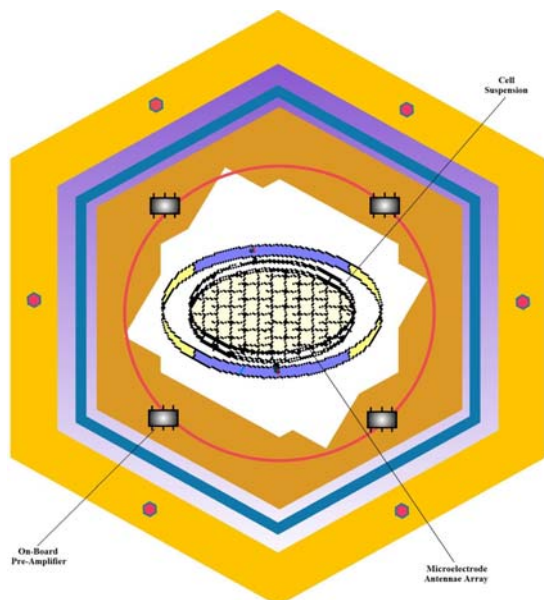


Fig. 3 An overview of an experimental bioreactor in which aerobic and active yeast cells were suspended

IV. RESULTS

The study led to some encouraging results, although preliminary.

Figure 4 illustrates a summary plot taken from the experiments carried out with respiring aerobic cells of *Saccharomyces cerevisiae* in physiological conditions.

Intrinsic electromagnetic activity from the cells studied is noted in the Low-Frequency (LF) region of the electromagnetic spectrum. There are a number of significant peaks seen around 110Hz, 300Hz, 600Hz and 1150Hz.

Therefore, it is concluded that actively respiring aerobic cells in the best state of metabolism do possess intrinsic electromagnetic fields in the LF region. Their detection beyond the cells (stretching to a distance of a fraction of millimetres between the cells and probe) illustrates that it may be from resonant tunnelling photons.

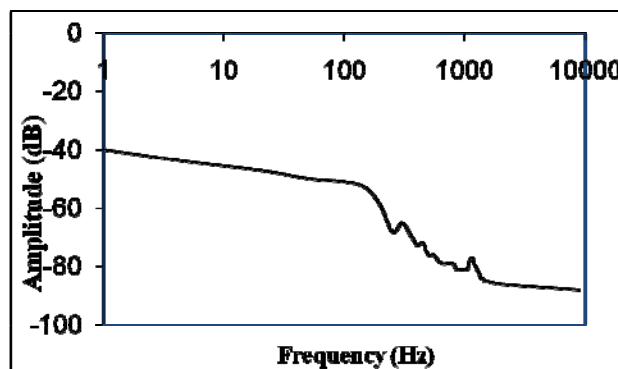


Fig. 4 A summary plot (log-linear) of intrinsic electrical field coupling and amplification seen from cultured yeast cells after recordings from numerous viable cell batches under aerobic conditions. Cellular response is seen in the region spanning frequencies from 110Hz to 1500Hz, with a number of significant peaks conspicuously identified beyond the noise level

V. DISCUSSION

McLeod et al. have suggested a mechanism for interactions of ELF fields with living tissue [20]. They proposed that cell-field interactions may take place through the action of electric polarization forces, developing at the cell surface. Moreover, these ELF field interactions with cells and tissues are identified at intensities far below the 1 mV/cm limit, implying that the interaction mechanisms do not depend on the transmembrane potentials. They have further cited a possibility that intrinsic electrical resonances may exist within cells, and may lead to a linear form of the interaction, with the field-cell interaction to be strongly frequency dependent. In the same study, the cells and tissues were reported to demonstrate increased sensitivity to external fields in the 10-100Hz frequency range. Finally, the degree of cellular response to driving electric fields had correlations with the cell size and shape.

This study may have possible implications on higher processes in brain, such as cognitive science, consciousness and learning, where the RF communications may serve pivotal communicative roles and in forming bridges between disparate or disconnected neurons and neuronal nuclei.

The intrinsic electromagnetic fields and their resonant interactions may possibly have some correlations with pathology, as various pathological conditions imposed on cells or experienced by them significantly affect overall cellular activity, processes and metabolism. For instance, since, the neoplastic cells (i.e. malignant cancer cells) have higher and more vigorous metabolism, as demonstrated by higher consumption of energy, in principle, they may give rise to fields with slightly higher frequencies. A study may be undertaken to assess this reasoning, as it may have profound implications on diagnostics. Efficient and low-cost biosensing assays may be developed exploiting this rationale which may probe the intrinsic fields produced in the isolated cells from a sample of patient's tissue.

This report presents a few preliminary but important suggestions which warrant further investigation, which if undertaken, could advance our knowledge on the fundamental processes in cell physiology and pathology.

ACKNOWLEDGMENT

This work was supported by the Dow University of Health Sciences, Karachi, under a faculty grant, in addition to support by the Higher Education Commission of Pakistan under TTS and SFHP programs. Author wishes to thank the Dow University and Higher Education Commission for their valuable support. Personal support from the Vice Chancellor, Dow University of Health Sciences, Prof. Masood Hameed Khan, is appreciated.

REFERENCES

- [1] T. H. Bullock, "Signals and signs in the nervous system: The dynamic anatomy of electrical activity is probably information-rich", *Proc. Nat. Acad. Sci. USA* 94 (1997) 1
- [2] E. J. Lund, *Bioelectric Fields and Growth*, The University of Texas Press, Austin, 1947.
- [3] J. Loeb and R. Beutner, "The source of the current of injury" *Science* 35 (1912) 970
- [4] R. O. Becker, "The significance of bioelectric potentials" *Bioelectrochem. Bioenergetics* 1 (1974) 187
- [5] H. A. Pohl *et al.*, "Life cycle alterations of the micro-dielectrophoretic effects of cells" *J Biol Phys* 9 (1981) 133
- [6] A. R. Liboff, "Geomagnetic cyclotron resonance in living cells" *J. Biol. Physics* 13 (1985) 99; A. R. Liboff, "The electromagnetic field as a biological variable", In A. H. Frey (ed.) *On the Nature of Electromagnetic Field Interactions*, (Austin: R.G. Landis, 1994); A. R. Liboff, "Evolution and the change in electromagnetic state" *Electro- and Magnetobiology* 15 (1996) 245
- [7] H. S. Burr and F. S. C. Northrup "The electro-dynamic theory of life" *Q. Rev. Biol.* 10 (1935) 322
- [8] H. S. Burr, *The Fields of Life* (New York: Ballantine Books, 1972)
- [9] E. A. Blair and J. A. Erlanger "A comparison of the characteristics of axons through their individual electric responses" *Am. J. Physiol.* 106 (1933) 524
- [10] P. N. Steinmetz *et al.* "Subthreshold voltage noise due to channel fluctuations in active neuronal membranes" *J. Comput. Neurosci.* 9 (2000) 133; J. A. White *et al.* "Channel noise in neurons" *Trends Neurosci.* 23 (2000) 131; M. C. Van Rossum, B. J. O'Brien and R. G. Smith "Effects of noise on the spike timing precision of retinal ganglion cells" *J. Neurophysiol.* 89 (2003) 2406
- [11] H. Fröhlich "The extraordinary dielectric properties of biological materials and the action of enzymes" *Proc. Nat. Acad. Sci. USA* 72 (1975) 4211; H. Fröhlich "The biological effects of microwaves and related questions" , *Advances in Electronics and Electron Physics*, 53 (1981) 85
- [12] J. Pokorný *et al.*, "Frohlich electromagnetic radiation from human leukocytes: implications for leukocyte adherence inhibition test" *J. Theor. Biol.* 102 (1983) 295
- [13] J. Pokorný, J. Hašek, and F. Jelinek, "Electromagnetic Field of Microtubules: Effects on Transfer of Mass Particles and Electrons", *J. Biol. Physics* 31 (2005) 501
- [14] W. R. Adey, "Interaction Mechanisms of Low-Level Electromagnetic Fields in Living Systems", Ed. Norden B. and Ramel K. (Oxford University Press, Oxford, 1992)
- [15] Y. Gontier, "Atom-atom correlations induced by resonant coupling with a laser field" *Phys. Rev. A*, 59 (1999) 4747; *ibid* 31 (1985) 279; *ibid* 55 (1997) 2397
- [16] G. V. Varada and G. S. Agarwal, "Two-photon resonance induced by the dipole-dipole interaction" *Phys. Rev. A*, 45, 6721 (1992); F. Varsanyi and G. H. Dieke, *Phys. Rev. Lett.* 7 (1961) 442; G. V. Varada and G. S. Agarwal, *Phys. Rev. A* 45 (1992) 45
- [17] M. H. S. Bukhari and J. H. Miller, Jr., "Measurement of Intrinsic Physiological Membrane Noise in Living Cells" *Electromagnet. Biol. Med.* 29 (2010) 36
- [18] C. Itzykson and J-C. Zuber, *Quantum Field Theory* (McGraw-Hill, 1990)
- [19] M. H. S. Bukhari, J. H. Miller, Jr., and Z. H. Shah, "A weak current amperometric technique in physiological and bioelectromagnetic measurements" *J. Pak. Sci. Ind. Res.* 52 (2009) 91
- [20] K. J. McLeod, C. T. Rubin, H. J. Donahue and F. Guilak, "On the mechanism of extremely low frequency electric field interactions with living tissue", *Proc. IEEE Conference* (IEEE Press, 1992), pp. 65-6