arXiv:1104.3113v1 [physics.bio-ph] 15 Apr 2011

Electromagnetic Signals from Bacterial DNA

A. Widom and J. Swain
Physics Department, Northeastern University, Boston MA USA

Y. N. Srivastava
Physics Department & INFN, University of Perugia, Perugia Italy

S. Sivasubramanian
Nanoscale Technology and High Rate Manufacturing Research Center
Northeastern University, Boston MA USA

Chemical reactions can be induced at a distance due to the propagation of electromagnetic signals during intermediate chemical stages. Although is is well known at optical frequencies, e.g. photosynthetic reactions, electromagnetic signals hold true for muck lower frequencies. In E. coli bacteria such electromagnetic signals can be generated by electric transitions between energy levels describing electrons moving around DNA loops. The electromagnetic signals between different bacteria within a community is a "wireless" version of intercellular communication found in bacterial communities connected by "nanowires". The wireless broadcasts can in principle be of both the AM and FM variety due to the magnetic flux periodicity in electron energy spectra in bacterial DNA orbital motions.

PACS numbers: 82.39.Pj and 82.35.Rs

I. INTRODUCTION

Biochemistry is most often described in terms of the short ranged molecular rearrangement interactions. However, it is clear that photo-induced biochemical reactions also exist. Photosynthesis constitutes an example of crucial biological importance. The photons which induce these chemical reactions can come from very distant sources (e.g. the sun). Chemical reactions can thereby be induced at at a distance due to the propagation of electromagnetic signals during intermediate reaction stages. It appears reasonable to investigate the biochemical possibilities of electromagnetic signals of frequencies slow on the scale of light signals. Evidence for such reactions has been previously reported[1] wherein the time dependence of electromagnetic signals were recorded to later be employed at will.

In two recent and important experiments[2, 3], it was shown that bacterial DNA macromolecules radiate electromagnetic signals which were monitored employing the voltage across an inductive pickup coil. The bacterial DNA within water was located in a test tube. The pickup coil was constructed with wires wrapped around the tube.

Our purpose is to theoretically discuss the biophysical sources of these electromagnetic signals. The sources are argued to be due to electronic transitions between energy levels of electrons moving around the bacterial DNA loops.

One may deduce the spectral properties of the electromagnetic signals via electromagnetic electromagnetic noise; i.e. by employing the fluctuation dissipation theorem[4]

$$S_V(\omega) = \left(\frac{k_B T_{\rm noise}}{\pi}\right) \Re e Z(\omega + i0^+), \tag{1}$$

wherein $T_{\rm noise}$ is the coil noise temperature and $Z(\zeta)$ is the coil impedance as a function of complex frequency $\zeta = \omega + i\sigma$. Eq.(1) is essential for the pickup coil method of detecting electromagnetic signals.

A. Low Frequency Noise

In the regime of very low frequency, say in the range 1 Hz $< (\omega/2\pi) <$ 20 Hz, spectral noise can appear from the electronic magnetic moment precession due to small magnetic fields. Even if the shielding of magnetic fields due to external sources were perfect, the thermal fluctuations of coil currents would still give rise to magnetic fields yielding low frequency noise signals. The value thermal magnetic fields B_T from thermal fluctuations is estimated in Sec.II.

B. High Frequency Noise

In the regime of higher frequencies, say in the interval 0.2 KHz $< (\omega/2\pi) <$ 5 KHz, there exists sharp peaks in the noise spectral function $S_V(\omega)$. It is worthy of note that the bacterial DNA molecule is in the shape of a loop. In what follows in Sec.III, we will model the coil noise spectra to the motion of nearly free electrons moving in a spatial loop of length L which includes the helix DNA coils. The elementary Scrödinger equation will be solved in Sec.III.

Fitting de Broglie electron waves on the loop, one finds the usual free electron quantum energy levels

$$E_n = \left(\frac{2\pi^2\hbar^2}{mL^2}\right) n^2, \qquad n = 0, \pm 1, \pm 2, \cdots. \tag{2}$$

The associated Bohr transition frequencies

$$\omega_n = \frac{E_{n+1} - E_n}{\hbar} = (2n+1)\varpi,$$
$$\varpi = \left(\frac{2\pi^2\hbar}{mL^2}\right), \tag{3}$$

should then appear as broadcast electromagnetic signals at ≈ 0.5 KHz, 1.0 KHz and 1.5 KHz in E. coli bacteria. This expectation is experimentally valid[2, 3].

C. Magnetic Moments

The orbital magnetic moment of an electron moving around a baterial DNA loop may be understood as follows: (i) The mean velocity of electrons moving about the loop determines the electronic mean current according to

$$I_n = \frac{ev_n}{L} = \frac{2\pi e\hbar n}{mL^2}\ , \quad n = 0, \pm 1, \pm 2, \cdots. \tag{4}$$

(ii) The magnetic moment $\mathbf{m}$ of a circulating current loop around a vector area $\mathbf{\Sigma}$ is given by $\mathbf{m} = I\mathbf{\Sigma}/c$; i.e. the mean magnetic moment is

$$\mathbf{m}_n = \frac{I_n\mathbf{\Sigma}}{c} = \left(\frac{\hbar e}{2mc}\right)\left[\frac{4\pi\mathbf{\Sigma}}{L^2}\right]n, \quad n = 0, \pm 1, \pm 2, \cdots. \tag{5}$$

If a magnetic field $\mathbf{B}$ is applied to the biological sample, then a magnetic flux

$$\Phi = \mathbf{B}\cdot\mathbf{\Sigma} \tag{6}$$

will thread through the bacterial DNA loop. The orbital electronic energy levels will then exhibit a flux periodicity; i.e. with flux quantum period

$$\Phi_0 = \frac{2\pi\hbar c}{|e|} \approx 4.13567 \times 10^{-7}\ \text{Gauss cm}^2,$$
$$\Phi_0 \approx 41.3567\ \text{Gauss micron}^2. \tag{7}$$

The periodicity of the energy levels is thereby

$$E_n(\Phi + \Phi_0) = E_n(\Phi). \tag{8}$$

Note that the magnetic flux quantum in Eq.(7) is *twice* the value found for superconducting loops wherein the charge value is the electron pairing value $q = 2e$.

As a consequence of Eq.(8). magnetic field noise must be very small to observe the KHz signals. In general, the magnetic flux threading the DNA loop, $\Phi = \mathbf{B}\cdot\mathbf{\Sigma}$, depends on how the vector area $\mathbf{\Sigma}$ is oriented with respect to the magnetic field $\mathbf{B}$. The sharp spectral lines would thereby be considerably broadened. The broadening is discussed in Sec.IV.

D. Bacterial Communication

There has been considerable interest in bacterial communities wherein a bacterium is connected to neighboring bacteria by means of *narrow nanowires*[5–7]. It is believed that the purpose of the nanowires is to allow for intercellular electronic communications. More advanced on the evolutionary scale are the more modern bacterial communities which are *wireless*. The electromagnetic signals sent from a bacterium to neighboring bacteria can be due to relatively low frequency electron level transitions within DNA.

II. MAGNETIC MOMENT PRECESSION

If a compact object with magnetic moment $\mathbf{m}$ is subject to a magnetic field $\mathbf{B}$, then a precession occurs,

$$\frac{d\mathbf{m}}{dt} = \gamma\mathbf{m}\times\mathbf{B}, \tag{9}$$

at a rotational angular velocity

$$2\pi\mathbf{f} \equiv \mathbf{\Omega} = -\gamma\mathbf{B}, \tag{10}$$

wherein γ is the gyromagnetic ratio. The gyromagnetic ratio associated with electronic charged current flows is given by

$$\gamma = \frac{e}{2mc} \approx -\frac{(8.7941\times 10^6)}{\text{Gauss sec}}. \tag{11}$$

Within a cylindrical water sample of volume V within an inductive pickup coil, one may employ the magnetic field equipartition theorem[4] in the form

$$\frac{V\overline{B^2}}{8\pi} = \frac{k_BT}{2}\ ,$$
$$B_T = \sqrt{\frac{4\pi k_BT}{V}}\ . \tag{12}$$

From Eqs.(10) and (12), one obtains a magnetic frequency, $2\pi f_T = |\gamma|B_T$, which serves as a lower bound for the magnetic noise frequency within the coil; Numerically,

$$f_T \approx 1.01\ \text{Hz}\ \sqrt{\left(\frac{\text{cm}^3}{V}\right)\left(\frac{T}{300\ ^{\text{o}}\text{K}}\right)}\quad \text{(orbital)},$$
$$f_T^{spin} \approx 2.02\ \text{Hz}\ \sqrt{\left(\frac{\text{cm}^3}{V}\right)\left(\frac{T}{300\ ^{\text{o}}\text{K}}\right)}\quad \text{(spin)}, \tag{13}$$

wherein the electron spin gyromagnetic ratio involves the factor $g \approx 2$. The above are consistent with the experimental value[2, 3] of ~ 7 Hz for diluted bacterial DNA samples in water. The magnetic field value in Eq.(12) is internal to the system and will hold true if *external* magnetic fields are sufficiently well *screened*.

III. ELECTRONS AND DNA LOOPS

Consider an electron which can move around a bacterial DNA loop including the windings of helices and along the ordered water layers within which the DNA is stored. A reasonable Hamiltonian model model for the electronic energy levels may then be written as

$$\begin{aligned} V(s+L) = V(s) \quad \text{and} \quad A(s+L) = A(s), \\ H = \frac{1}{2m}\left(-i\hbar\frac{d}{ds} - \frac{e}{c}A(s)\right)^2 + V(s), \end{aligned} \tag{14}$$

wherein allowed electron wave functions have a periodicity around the DNA loop

$$\psi(s+L) = \psi(s). \tag{15}$$

The vector potential tangent to the closed loop may be written as the periodic function

$$A(s) = \frac{\Phi}{L} + \sum_{n=1}^{\infty} A_n \cos\left(\frac{2\pi ns}{L} + \theta_n\right) \tag{16}$$

In virtue of the guage transformation

$$\begin{aligned} \chi(s) = -\sum_{n=1}^{\infty}\left(\frac{LA_n}{2\pi n}\right)\sin\left(\frac{2\pi ns}{L} + \theta_n\right), \\ A(s) \to A(s) + \frac{d\chi(s)}{ds}\ , \\ \psi(s) \to e^{(ie\chi(s)/\hbar c)}\psi(s), \end{aligned} \tag{17}$$

The Hamiltonian in Eq.(14) may be written with boundary conditions as

$$\begin{aligned} H = \frac{1}{2m}\left(-i\hbar\frac{d}{ds} - \frac{e\Phi}{cL}\right)^2 + V(s), \\ V(s+L) = V(s), \\ \psi(s+L) = \psi(s). \end{aligned} \tag{18}$$

For harmless E. Coli K-12 bacteria the loop length is $4,639,221$ *bp* or in absolute length units

$$\tilde{L} = 0.157733514 \text{ cm}. \tag{19}$$

If the mobile electron moving around the DNA in the ordered water layer, skips rungs around the helices, then the electron path around the DNA would be considerable shorter than in in Eq.(19) We find satisfactory agreement between the electron spectra and the observed pickup coil noise with the shorter length scale

$$L \approx 10^{-2} \text{ cm}, \tag{20}$$

yielding for zero magnetic flux and for uniform potential

$$E_n = \left(\frac{2\pi^2\hbar^2}{mL^2}\right)n^2, \quad n = 0, \pm1, \pm2, \pm3, \cdots. \tag{21}$$

In order to resolve the energy spectra, the magnetic field must be carefully screened.

IV. FLUX PERIODICITY

For the general spectral model in Eq.(18), the energy levels give rise to a magnetic flux periodicity as in Eq.(8). Different bacteria will exhibit different spectra depending on the orientation of the DNA loop vector area $\mathbf{\Sigma}$ with respect to the magnetic field $\mathbf{B}$. Flux periodicity exists in both the energy and the DNA loop current,

$$\begin{aligned} I(\Phi) = c\frac{dE(\Phi)}{d\Phi}, \\ E(\Phi + \Phi_0) = E(\Phi), \\ I(\Phi + \Phi_0) = I(\Phi). \end{aligned} \tag{22}$$

In addition, Faraday's law for the voltage around the DNA loop is given by

$$V = -\frac{1}{c}\frac{d\Phi}{dt}. \tag{23}$$

One thereby finds that a voltage uniform in time yield a current which alternates with time at a frequency

$$\omega_V = \frac{eV}{\hbar}\ . \tag{24}$$

The above implies modulated sidebands with the electronic spectral frequencies determined by the Faraday law voltage around the DNA loop. The resonance condition[8] is the voltage to frequency conversion

$$eV = n\hbar\omega, \quad n = 0, \pm1, \pm2, \pm3\cdots. \tag{25}$$

The wireless communications may thereby be transmitted for both AM and FM broadcast systems.

V. CONCLUSIONS

Although biochemical reactions are often described in terms of molecular contacts, electromagnetic signals can often be employed to allow chemical reaction control at a distance. The photosynthetic reactions are a classic case of chemical reaction control via electromagnetic signal propagation. T frequencies much less that optical there is a clear electromagnetic signal propagation in E. coli bacterial communities. We have probed a model wherein such signals are due to quantum electrnic transitions of electrons in orbital motion about DNA loops.

The electromagnetic signals between different bacteria within a community is a “wireless” version of intercellular communication found in bacterial communities connected by “nanowires”. The wireless broadcasts can in principle be of both the AM and FM variety due to the magnetic flux periodicity in electron energy spectra in bacterial DNA orbital motions. AM signals can arise from the Bohr transition frequencies between different electronic energy orbitals about the DNA loops. FM modulation signals can arise from the Faraday law voltage controlled signal modulation frequency in Eq.(24). There is considerable work required to extract the bioinformation contained in these electromagnetic signals.

[1] J. Benveniste, P. Jurgens, J. Aïssa, *Faseb Journal* **10 A**, 1479 (1996).

[2] L. Montagnier, J. Aïssa, S. Ferris, J-L. Montagnier and C. Lavallee, *Interdiscip. Sci. Comput. Life Sci.* **1**, 81 (2009).

[3] L. Montagnier, J. Aïssa, C. Lavallee, M. Mbamy, J. Varon and H. Chenal, *Interdiscip. Sci. Comput. Life Sci.* **1**, 245 (2009).

[4] L.D. Landau and E.M. Lifshitz, "Statistical Physics", Part I, 3rd Edition, Chapter XII, Pergamon Press, Oxford (1980).

[5] D. Ntarlagiannis, E.A. Atekwana, 3. Eric, A. Hill, and Yuri Gorby, *GeoPhys. Res. Lett.* **34**, L17305 (2007).

[6] M.Y. El-Naggar, Y.A. Gorby, W. Xia and K.H. Nealson, *Biophys. J. : Biophys. Letts.* L10 (2008).

[7] M.Y. El-Naggar, G. Wangerb, K.M. Leungc, T.D. Yuzvinskya, G. Southame, J. Yangc, W.M. Laud, K.H. Nealsonb and Y.A. Gorbyb *PNAS* **107**, 18127 (2010).

[8] E. Del Guidice, S. Doglia, M. Milani, C.W. Smoth and G. Vitiello, *Physica Scripta* **40**, 786 (1989).