On the function of DNA magnetism

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ABSTRACT

Although magnetism of DNA in strong fields is well established, it is not commonly considered magnetic in natural weak fields. SInce the behavior of strings of magnetic balls resembles some of DNA behaviors such as in replication and transcription, we hypothesize that DNA is magnetic and that DNA strands are magnetized in antiparallel orientation. We hypothesise that magnetism of DNA is based on ring currents of pi electrons in its bases. We hypothesize that ring currents are fueled by heat, enzymes or active forms of water. Accordingly, we proposed a helical model of magnetic lines in DNA. We also suggested a new way how the magnetic field in DNA may oscillate and that these oscillations will be sequence dependent. We suggest that collective oscillations of interspersed and periodic repetitive DNA sequences could contribute to electromagnetic communications between the cells and creation of Gurwitch morphogenic field. We suggest that primary cilium may be an antenna for sending and receiving electromagnetic oscillations by the genome.

While experimenting with magnetic balls we noticed that they prefer shapes familiar from biology: they self-organize in a globule or a string, Fig. [chain].

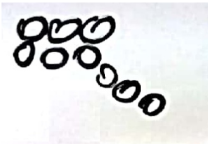

Fig. [chain]. Magnetic balls self-organize into strings.

The strings of magnetic balls when helped half-way, self-organize into circles, Fig. [circle].

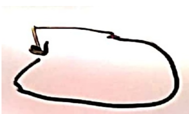

Fig. [CIRCLE] The strings of magnetic balls when helped half-way, self-organize into circles.

We also noticed that two strings of magnetic balls self-organize into a double-string with antiparallel orientation of the magnetic fields of the two strings in the double-string structure, Fig. [antiparallel]

Fig. [antiparallel] Two strings of magnetic balls self-organize into a double-string structure with antiparallel orientation of the magnetics fields.

We also observed other behaviors of magnetic balls which resemble behavior of DNA during replication, transcription, formation of telomere's loop, ligation and PCR. Also their behavior resembled the behavior of RNA forming loop structures, of growth and disassembly of microtubules and of formation of neural crest and neural tube.

Therefore we hypothesized that DNA, RNA, microtubules and cells forming neural tube and crest are naturally magnetised.

Magnetism of DNA is known to be formed in very strong magnetic fields around 1 to 16 Tesla via the induction of ring currents in the aromatic pi-electron rings of DNA bases (nucleotides, basepairs), Fig. [orientation]

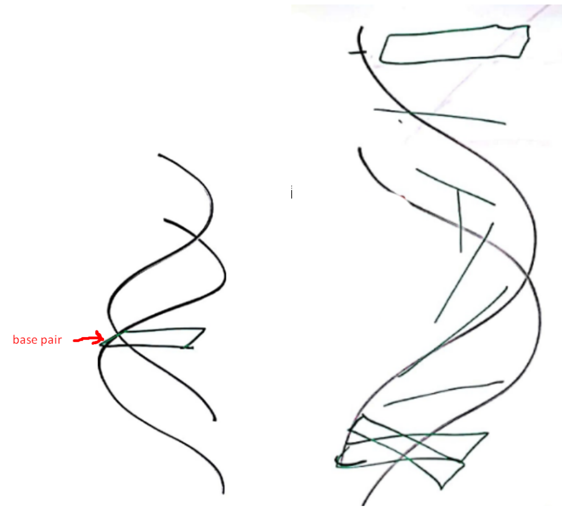

Fig. [orientation]. On the left: Basepairs are located inside the double helix of DNA, they are oriented nearly perpendicular to the helical axis. On the right: One turn of the natural DNA (B-form) has on average 10.5 basepairs, which are forming a twisted ladder with 360°/10.5=34° turn angle per basepair.

Ring currents are studied in aromatic compounds like benzol using Electron Spin Resonance (ESR) Spectroscopy, also called Electron Paramagnetic Resonance (EPR) Spectroscopy, Fig. [current].

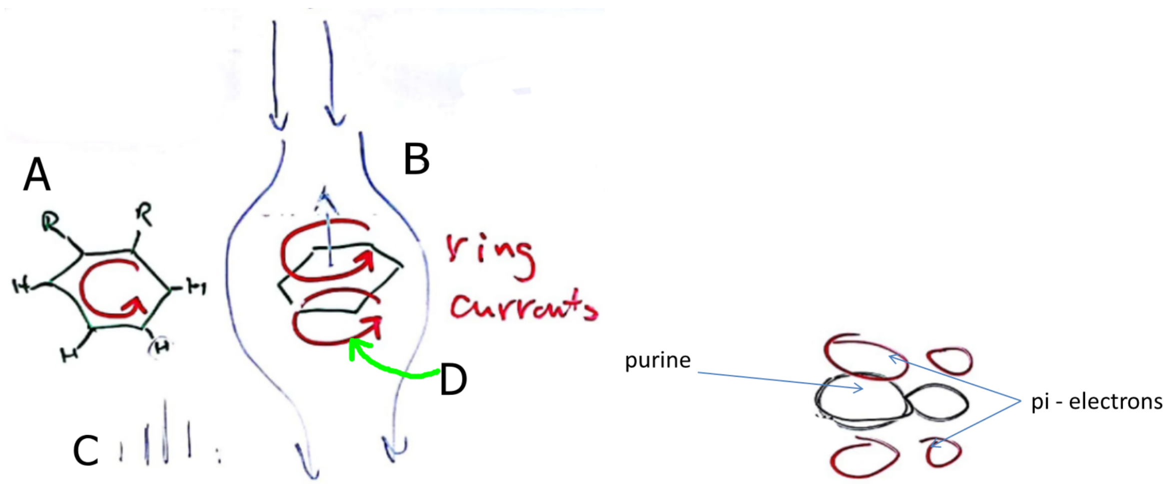

Fig. [current]. A. A bensol-based structure is shown with 4 hydrogens and two radicals. Ring current is in red. B. Ring currents are induced by a strong magnetic field (purple). They form a secondary magnetic field facing in the opposite direction of the incident magnetic field thus shielding the hydrogens from the incident magnetic field. This is affecting proton spin states and thus affecting the resulting Electron paramagnetic spectrum of these protons (C .) The pi-electron rings of aromatic molecular rings are located above and below the molecular ring, having about the same diameter and shifted about 17% of the diameter up and down (D).

Although, the ability of very strong magnetic fields to magnetize DNA is well known, we were not able to find any publications on the existence of magnetism of DNA in normal magnetic fields of modern Earth. Normally it is assumed that DNA is not magnetic since it belongs to the type of organic molecules which are normally not magnetic (more precisely, organic molecules and water are diamagnetic).

Nonetheless, since our modeling with magnetic beads illustrates that magnetism of DNA would explain its high efficiency in biochemical reactions, we hypothesize that it is magnetic. More specifically, based on the models with magnetic balls, we hypothesize that in life, single strands of DNA are ferromagnetic (retaining magnetic moment along the strand) and the double-stranded DNA is similar to in concept to an antiferromagnetic (where two strands oppose and cancel magnetism of each other).

It has also been observed by Blumenfeld that magnetic properties of DNA in strong field depend on the phase of cell cycle (Shnoll, 2011), the DNA extracted from pre-mitotic and mitotic cells was more magnetic in the strong field than in interphase. Therefore it is possible that the same DNA can exist in magnetized and unmagnetized states.

It is unclear from the literature how long does the DNA retain the ferromagnetic moment after it is removed from strong magnetic field. The ring currents induced by the magnetic field may fade very quickly or very slowly. This should be possible to measure by placing the DNA in the strong magnetic field, freezing it there, removing it and measuring the decay of the induced magnetic moment.

How possibly could ring currents (and accordingly magnetism) be fueled in DNA in nature? We suggest some possible driving forces for that: 1. heat motion, 2. Enzymes utilizing ATP energy and 3. A process fueled by deactivation of active forms of water.

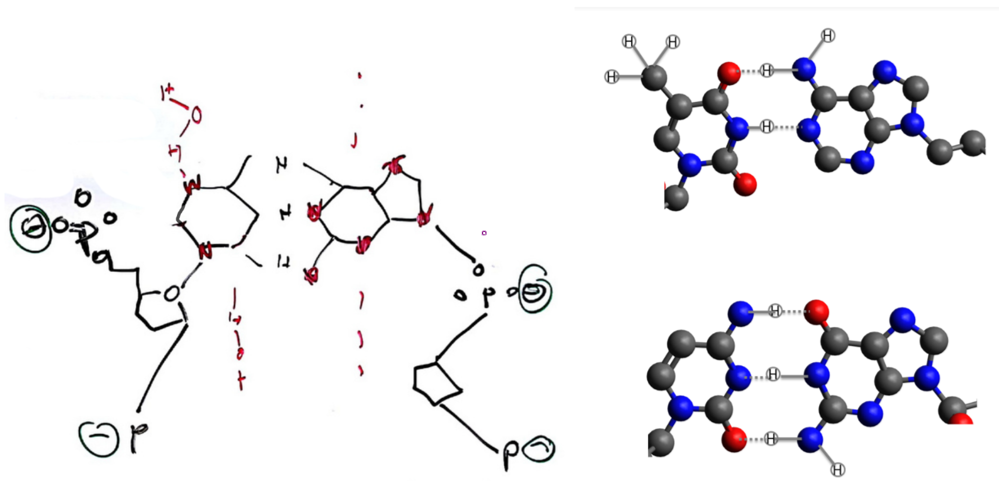

Fig. [nitrogens] A unit of the double helix - a DNA base pair with sugars and adjacent phosphates shown.

Note that nitrogen atoms are located asymmetrically in each of the bases.

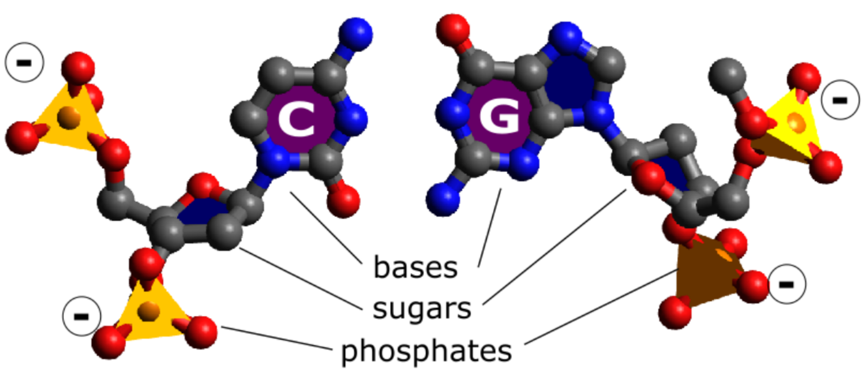

Fig. [phosphates]

Heat motion as a possible cause of ring currents

In the DNA, each pair of neutral bases are framed by negatively charged phosphates, Fig. [phosphates]. The bases are hydrophobic and form the base stack via stacking interaction which is largely due to the fact that the water pushes hydrophobic bases together. While the bases are stacked together, the phosphates which are covalently bound to them via sugars, repel each other due to their electrical charge. Therefore helical shape is most optimal for the DNA - it allows the bases to be stacked together and minimize their contact with water and it allows the phosphates to be as far as possible from each other.

We suggest that possibly heat motion is producing electromagnetic waves by shaking the 4 electrically charged phosphates and these waves could induce ring currents in the pi clouds of the bases. Since the bases are asymmetrical and anisotropic, ring currents in one direction may be prevail over the opposite direction.

Enzymes as a possible cause of ring currents

Many of key enzymes associated with DNA contain iron, usually as Fe-S (iron-sulphur) clusters. These are known to be exchanging electrons back and forth with DNA bases and thus to participate in sending and receiving electricity via the base stack. Also many of these enzymes are using the conversion of ATP to ADP as a source of energy. We suggest, that iron-containing enzymes the atoms of iron to create a magnetic moment and use the ATP energy to move over each of the two DNA strands and magnetise each of them in antiparallel direction, Fig [enzyme].

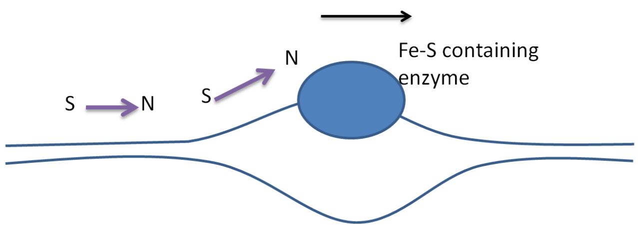

Fig. [enzyme]

Activated forms of water as a possible cause of ring currents.

Water constantly interacts with the nucleobases which have tautomeric forms, as shown on Fig. [tautomers].

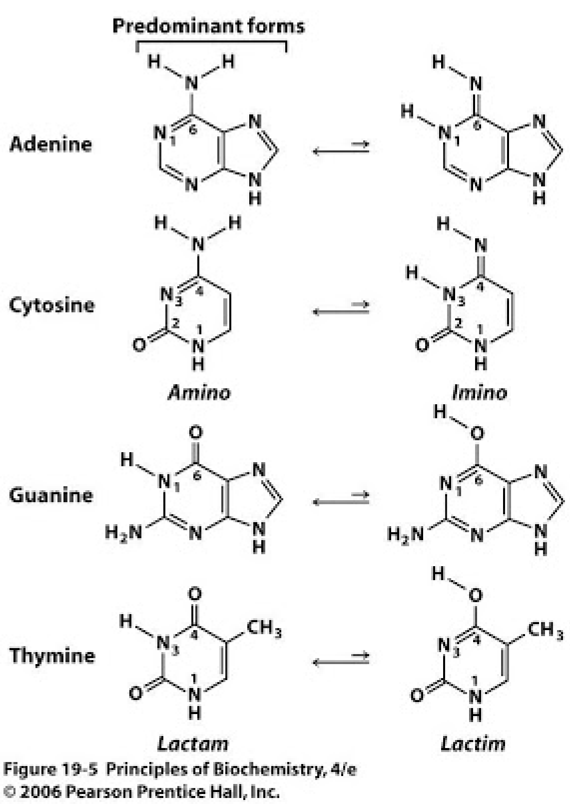

Fig. [tautomers].

Tautomeric forms of nucleobases likely coexist simultaneously in a state of quantum uncertainty, also called resonance form in chemistry. Tautomeric forms of bases involve water molecules which lands a proton to a base and takes it back, Fig. [water]. Possibly during this interaction, an activated form of water having a higher energetic state, can pass its energy to the base with the proton and thus fuel its ring current.

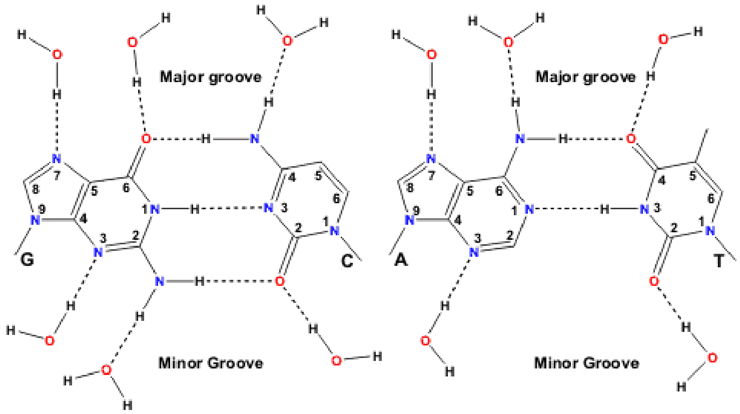

Fig. [water]

We know that DNA behaves as an insulated conductor - it passes electric charges via the base stack for a distance of thousands of bases without loss. How is it possible that water interacts with the bases (by participating in the formation of tautomeric forms) and yet, at the same time, the base stack is electrically insulated from the surrounding water? Our explanation is that the interaction of water with the bases happens in a different plane and different electron level than the electric conductivity of the base stack, Fig. [levels]

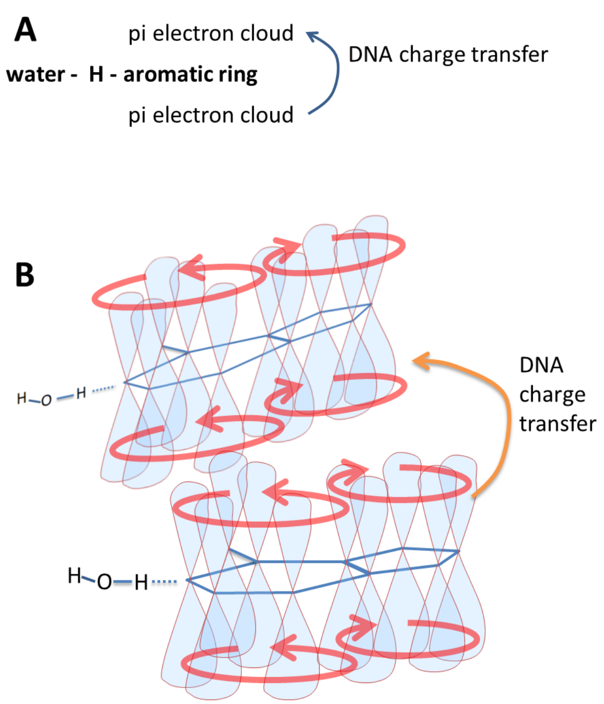

Fig. [levels]. DNA charge transfer and tautomeric interaction with water take place at different electron levels. A - schematic. B - same in 3D

Since purines have two fused molecular rings, it is interesting to consider possible directionality of ring currents and corresponding magnetic moments created by these currents. In the strong magnetic field, the ring currents induced by the incident field are spinning in the same direction, Fig. [directionality A], so that their magnetic moment is directed towards the incident magnetic field. This is known from shielding of covalently bound protons in EPR spectroscopy studies.

On the other hand, in the absence of strong magnetic field, this directionality (same direction) of the ring currents will be very unlikely, since their magnetic moments would repel each other. Yet, the opposite antiparallel directionality would be very favorable, since their magnetic moments would be attracted to each other and would close the magnetic loop.

Interestingly, since the two fused molecular rings of the pyrimidine, Fig. [directionality B], share two carbons and correspondingly, their two pi electrons, and since the all pi electrons of the purine are united in a unified cloud, it is likely that in the absence of strong magnetic field, the trajectory of the ring current will be of infinity sign shape, Fig. [directionality A and B]. This shape of ring current would also be stable since it would produce antiparallel magnetic moments attracted to each other.

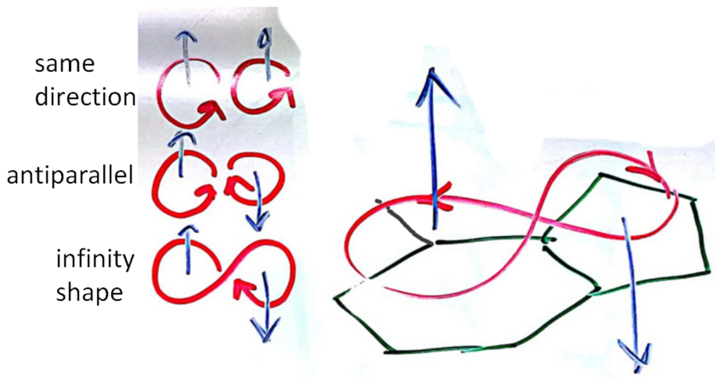

Fig. [directionality] Directionality of ring currents.

Next, it is important to understand the interaction of magnetic moments of ring currents in the base stack of the double helix. Since the structure of the base stack is also double-helical, it is easier to illustrate the interactions in the flattened image of the double helical base stack, Fig. [seq A]. The DNA sequence consists of double-ring purines (A, G) and single-ring pyrimidines (C and T), shown in red on Fig. [seq A].

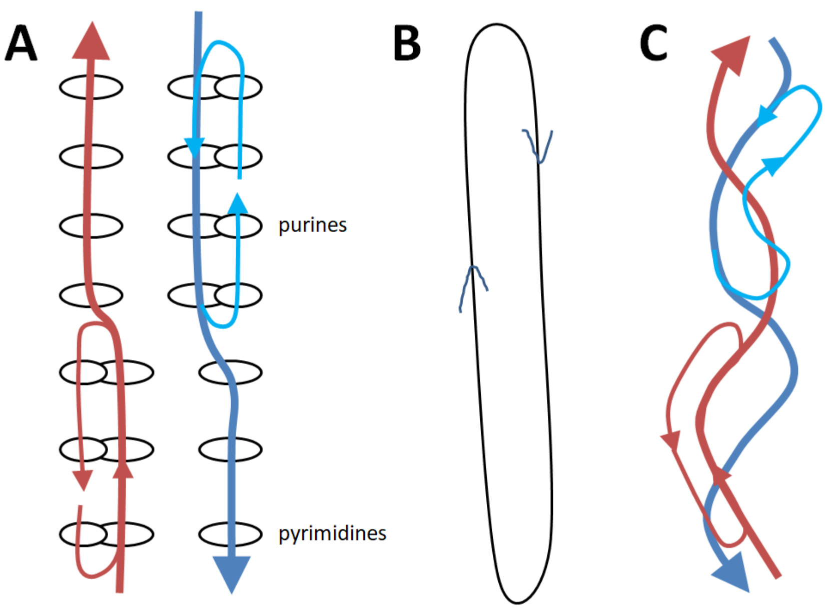

Fig. [seq]

The magnetic moments of the stacked bases in the absence of strong field, would have to coordinate with each other to maximize their attraction and minimize their repulsion. General antiparallel orientation of the magnetic moments of the two DNA strands is magnetically preferential as the moments of all bases will form a closed loop, Fig. [seq B]. Since the magnetic moments within each purine are also antiparallel, stretches of purines would have additional loops of magnetic moments as shown on Fig. [seq A]. Next, Fig. [seq C] is an illustration of double-helical shape of this structure, only the main magnetic contour is shown.

Oscillations

Importantly, the magnetic field of DNA doesn't have to be static, it may oscillate, especially due to its helical nature. The kinetic energy of the ring currents may transform into the potential energy of magnetic field and vice versa thus creating a classical electromagnetic oscillator as in LC circuits.

Sequence dependence

Note that the structure of the magnetic lines on Fig. [seq] is dependent on the nucleotide sequence of DNA. Therefore if the field is oscillating, there should emerge resonances between similar sequences in the genome. Moreover, there should emerge resonances between genomic sequences which have similar structure of the magnetic field. Therefore some resonating sequences might have different primary sequence but similar oscillation patterns. For example, possibly only Purine-Pyrimidine nature of bases is of importance for resonance, and not exact identity of A,G,C,T bases.

Function of resonances

Electromagnetic resonances may serve important biological functions. First, they may influence chromatin regulation and may be utilized by nature to control chromatin accessibility in such important events as replication and transcription. Importantly, we expect resonances between members of repetitive DNA sequences which comprise nearly half of the genome. Some of the sequences as Alu and LINE1 have million copies per cell and their resonances could have high quality factor just due to their high number of copies and high concentration in the nucleus. Also, the resonances between telomeric, centromeric and other periodic repeats might affect the function of telomeres, centromeres and chromosomes as a whole.

Lastly, the resonances might occur between individual cells and between tissues. Since every cell has nearly identical DNA sequence, and since the numbers of cells are large number in the body (about 30 trillion cells), the Q factor of the EM oscillations in the body would also be improved by the number and the concentration of the resonators. This idea of EM resonances in the body is meeting the predictions of the existence of a morphogenic field made by Gurwitch (Gurwitsch, 1922), nearly a hundred years ago. His theory is now being developed by Sheldrake (Sheldrake, 2009). The original idea and observations of Gurwitch were that the cells and tissues are producing an electromagnetic field that coordinates the development (morphogenesis) and the maintaining (morphostasis) of the shape of the body and the structure of the organs. That each cell is a transmitter and a receiver - communaly the cells create a morphogenic field and individually receive and follow the instructions from it. The modern idea of morphogenic field is that the DNA of the cells is creating the morphogenic field based on the genomic sequence and it receives and interprets the instructions from the morphogenic field according to the genomic program. In a way it is similar to each cell having a smartphone so it can tell its coordinate in the body and its needs and based on this to modify its behavior.

Therefore, modeling of magnetism of DNA may lead to understanding a new electromagnetic mechanisms by which genomic sequence controls morphogenesis. This may bring about novel therapeutic applications related to organ engineering and therapy of many disorders related to structure and shape of body and organs.

A connection between DNA and microtubules

The importance of aromatic heterocycles for conductivity is highlighted by Hameroff (Stuart Hameroff, 2008, 2002). This likely explains a similarity in conductivity in DNA and microtubules. Similarly to DNA which contains stacked aromatic bases, microtubules contain tryptophan and other aromatic aminoacids of periodically arranged tubulin (Stuart Hameroff, 2002) which is suggested provides conductivity and ability for electromagnetic resonance (Craddock, 2014; Stuart R Hameroff, 1994).Purines of DNA and tryptophan of tubulin have similar aromatic structures, Fig. [aromatics].

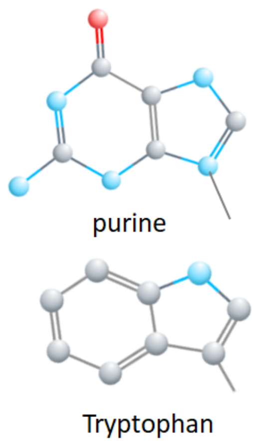

Fig. [aromatics]

Resonant EM oscillations in both DNA and microtubules were hypothesized to play a role in communication between cells. Primary cilium is a small structure (1-5 um, (Dummer, 2016)) in the cytoplasm near nucleus. Fig. [cilium].

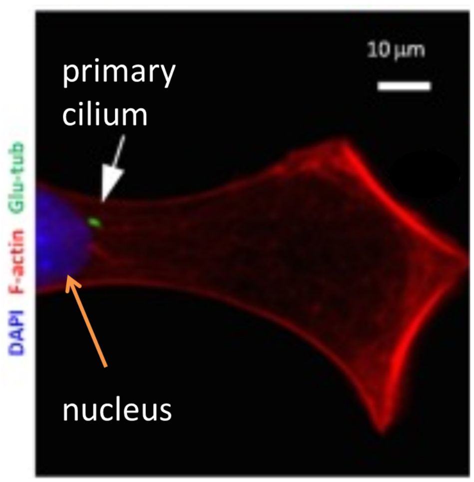

Fig. [cilium] Adapted from *(Veland, 2013)*

It is connected to one of the two centrioles. Both primary cilium and the centrioles contain cylindrically arranged microtubules, Fig. [connection]

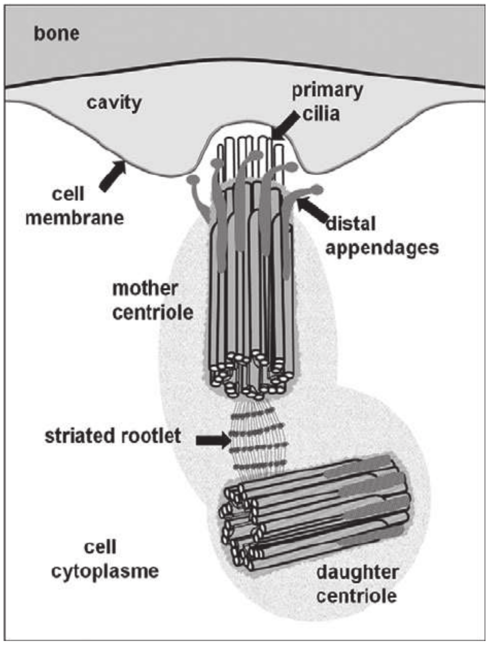

Fig. [connection]

We suggest that primary cilium is electrically connected to the DNA and serves as an antenna for the genome for sending and receiving EM signals and thus enabling communication between cells, creation of morphogenic field and receiving signals from it, Fig. [antenna].

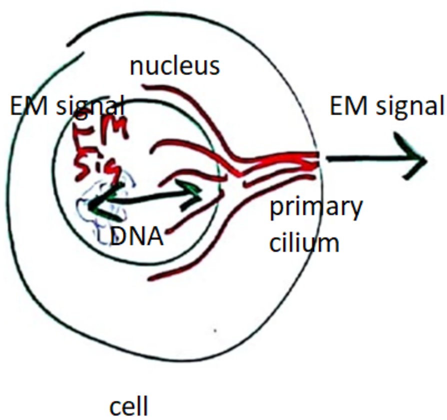

Fig. [antenna]

Author contributions

Main concepts and writing - MMR. MMR and OP - the idea of Fig. [antenna]. MMR, VG, OP, NZ, AM, AT - discussion of main ideas. EE - literature research.

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