DRAFT - For the submission to Progress in Biophysics & Molecular Biology

# Biomagnetism of DNA

# A Possible Biological Function of DNA Magnetism

Vadim V. Guschin - L B

Oksana Polesskaya - U L,

Nelli Zyryanova - L B,

Alexey Tovmash - L B

Abraham Mara - L B

Elena Erdyneeva - L B

Max Myakishev-Rempel - B,L,V

Vadim V. Guschin, Oksana Polesskaya, Nelli Zyryanova,

Alexey Tovmash, Abraham Mara, Elena Erdyneeva, Max Myakishev-Rempel

B- Biophysics Research Institute of San Diego, San Diego, CA, USA

L- Localized Therapeutics, San Diego, CA, USA

V- Vaccine Research Institute of San Diego, San Diego, CA, USA

U- University of California -San Diego, San Diego, CA, USA

Contact MMR: max@localizedtherapeutics.com

**ABSTRACT**

- Magnetic **balls** resemble DNA.
- What is known of magnetic DNA In **strong** fields, In **weak** fields
- **Aromaticity** in weak fields may be responsible
- What is Magnetic may be **mono, single-stranded DNA** and RNA, double stranded, in vitro or in vivo.
- Ring currents may be driven by **enzymes, heat -** phosphorus rocking**, water**
- **Ways to test - Direct measurements, Behaviors, Nanoparticles and dyes**

- **Kinetics and specificity.**
- **Physical differences from Stacking - Hydrogen bonding and Electrostatic interactions.**
- **Microtubules and other bio structures**

Some of magnetic properties of DNA has been previously studied (Berashevich, 2008; Buchachenko, 2013; Mizoguchi, 2008, 2016; Nakamae, 2005; Nikiforov, 2017; White, 2012; Yung, 2015), reviewed in (Mizoguchi, 2016). It has suggested that nucleotides in DNA behave like magnets in DNA replication and the shortening of the telomere (Rojeab, 2013). Here we expand this idea using magnetic balls as a model.

Magnetic balls have recently become a popular toy. They are usually of 5mm diameter and sold as an assembled cube of 216 balls. While making DNA structures with these balls, we noticed strikingly recognizable behaviors of DNA and RNA strings.

**MAGNETIC BALLS BEHAVE SIMILARLY TO DNA AND RNA STRINGS**

1. Globule - strings, sheets, hollow surfaces like cones and cylinders, random globules but not into orderly solids.
2. Single strands
    a. Have polarity.
    b. Prefer looping into a circle, the ends of the string are attracted to each other.
    c. Form hairpin structures,
    d. Form clover leaf structures
3. Double strands -
    a. are antiparallel.
    b. Loop into a circle
        i. While retaining polarity - each strand will loop to itself but not to another strand. Even after several twists of the double helix.
        ii. Close into a circle with blunt or sticky ends.The ends are attracted to each other.
4. Primer annealing
    a. The primer anneals in proper orientation (antiparallel)
5. Primer extension
6. Transcription bubble
7. Replication bubble
8. Shape of the bubble
9. Telomere looping
10. Forming a nucleosome structure.
11. Forming a nucleosomal solenoid structure.

**DNA MAGNETISM IN THE LITERATURE**

Textbook types of magnetism include diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism, ferrimagnetism and antiferromagnetism. Diamagnetic substances repel magnets, paramagnetic substances become magnetic only while in the magnetic field, ferromagnetic substances are stable magnets, antiferromagnetic substances have layers of ferromagnetic units facing and canceling each other and ferrimagnetic substances have layers of ferromagnetic units facing and partly canceling each other. The known magnetic behavior of DNA depends many factors and doesn't fall into the above textbook subtypes especially because these subtypes usually describe solid inorganic substances with small molecular units. DNA is a long organic polymer, heavily ionized, it's natural environment is physiological, in well buffered salt-protein solution, the negative charges of DNA are balanced by hydrated sodium and magnesium ions, DNA is packed on positively charged histone octamers. Internal structure of DNA is complex, DNA is electrically conductive and semiconductive and has in its core a unique double helical base stack structure composed of single and fuzed double aromatic heterocycles with a unified system of pi-electron clouds.

- **DNA MAGNETISM IN STRONG MAGNETIC FIELDS**

Best studied is DNA magnetism in electron paramagnetic resonance (EPR) spectroscopy experiments (Arter, 1976; Giessner-Prettre, 1976). EPR is similar to nuclear magnetic resonance (NMR), except, EPR studies splitting of electron spins while NMR studies splitting of nuclear spins. There are many papers published on EPR spectroscopy of DNA: Pubmed search shows 274 hits for the search of "DNA" and "EPR spectroscopy" in the title or abstract. In these experiments, the DNA is often a dried or dissolved oligonucleotide subjected to a strong magnetic field from 1 to 16 Tesla. This magnetic field induces so called ring currents in aromatic DNA bases as it does in any aromatic structures. The mechanism of the induction of the ring currents is quantum (Fox, 2010; Rai, 2012) and can simplistically be explained that the external magnetic field preferentially slows down ring currents in one direction over another due to the right hand rule. This secondary magnetic field created by the ring current blocks immediately adjacent hydrogens from the initial field thus affecting splitting of their spins and this produces unique spectral signatures. This phenomenon is utilized by the EPR spectroscopy for analytical purposes.

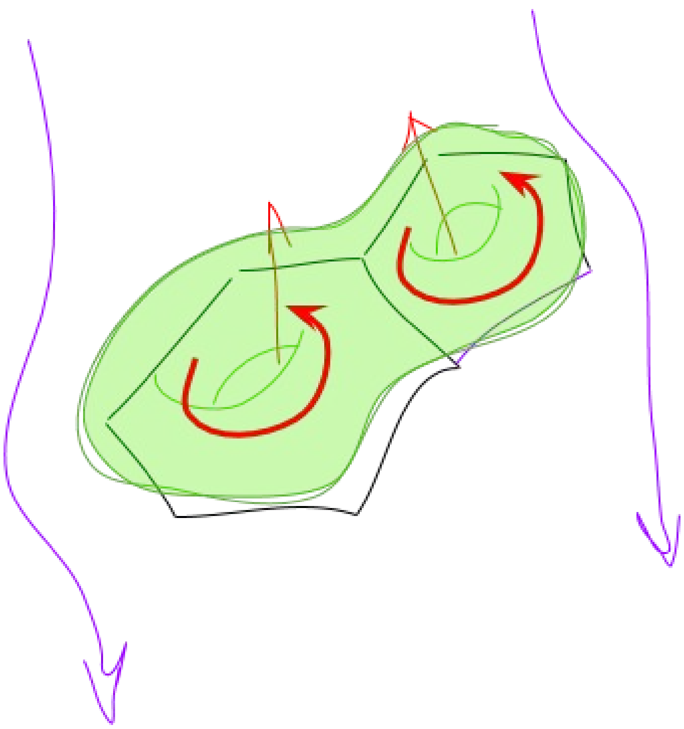
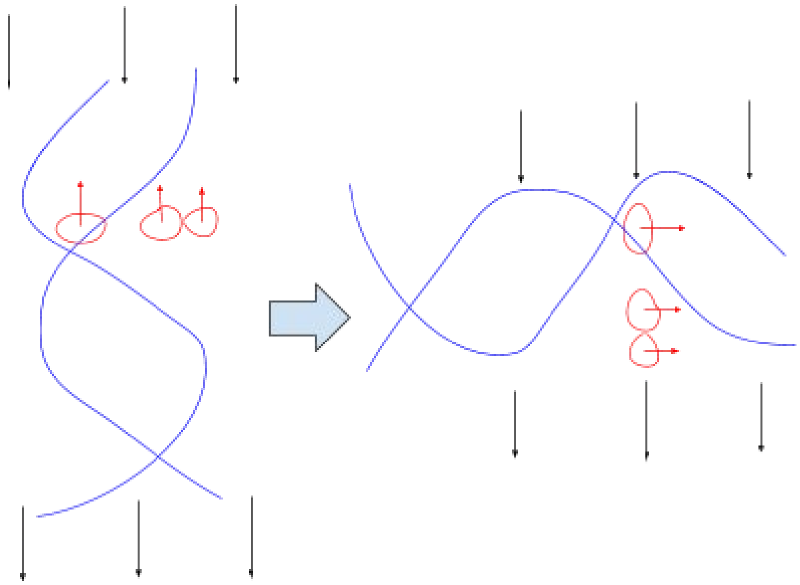


Fig. [RCU]. An example of ring currents in a purine induced by a strong magnetic field.

When a strong magnetic field is applied to the DNA in solution, the DNA turns perpendicular to the incident field. This was reported to have been utilized for orienting and drying DNA molecules in parallel orientation.



The reason the DNA turns perpendicular to the strong incident field, is that the induced fields in DNA bases strive to flip over and  align their field in the same direction as the incident field, but if they flip over, the effect would reverse. So the best position for them is to align the rings along the incident lines. Accordingly, the DNA axis will be aligned perpendicular to the incident field (Alam, 1990). Yet, the fact that DNA double helices align parallel to each other is likely to their magnetic interaction with each other.

The first report on the magnetism of DNA was made based on electron paramagnetic resonance (EPR). At that time, Bliumenfeld (Bliumenfeld, 1959) was exploring free radical products induced by high energy irradiation on the nucleic acids where unirradiated, bare DNA was used as the control specimen. Surprisingly, they found (Fig. 47) that the bare DNA induced huge EPR signals centered at the near zero magnetic field. At the same time, clear ferromagnetic responses were also noticed in the magnetization measurements. The same phenomena were subsequently observed for RNA and bacteriophages.(Müller, 1961)

Strong magnetic field inhibits growth of cancer tumors (Tatarov, 2011), likely because it interferes with DNA replication.

**DNA MAGNETISM IN NATURAL WEAK MAGNETIC FIELDS**

While the magnetism of DNA induced by strong magnetic fields is well established, it is normally assumed that DNA is not magnetic in normal (weak) magnetic fields of Earth and technological environment. Yet, there are a few tens of experimental papers which investigate the magnetism of DNA in weak magnetic fields.

Many of those study dry DNA or DNA in other nonphysiological conditions, and barely any of the papers experimentally test the magnetism of DNA in water solutions with salt and temperature conditions close to physiological.

Water is moderately diamagnetic, XXXX

A real chinese mess (Wang, 2011)

A real russian mess (Irkhin, 2017)

A real Adnan Y. Rojeab mess (Rojeab, 2013)

- What is known of magnetic DNA In **strong** fields, In **weak** fields
- **Aromaticity** in weak fields may be responsible
- What is Magnetic may be **mono, single-stranded DNA** and RNA, double stranded, in vitro or in vivo.
- Ring currents may be driven by **enzymes, heat** - phosphorus rocking**, water**
- **Ways to test - Direct measurements, Behaviors, Nanoparticles and dyes**

Proposed experiments - nanoparticles as was used for magnetic nanoparticles that were aligned along the DNA strands and visualized - (Kinsella, 2008; Liu, 2017; Pershina, 2014)

- **Kinetics and specificity.**
- **Physical differences from Stacking - Hydrogen bonding and Electrostatic interactions.**
- **Microtubules and other bio structures**

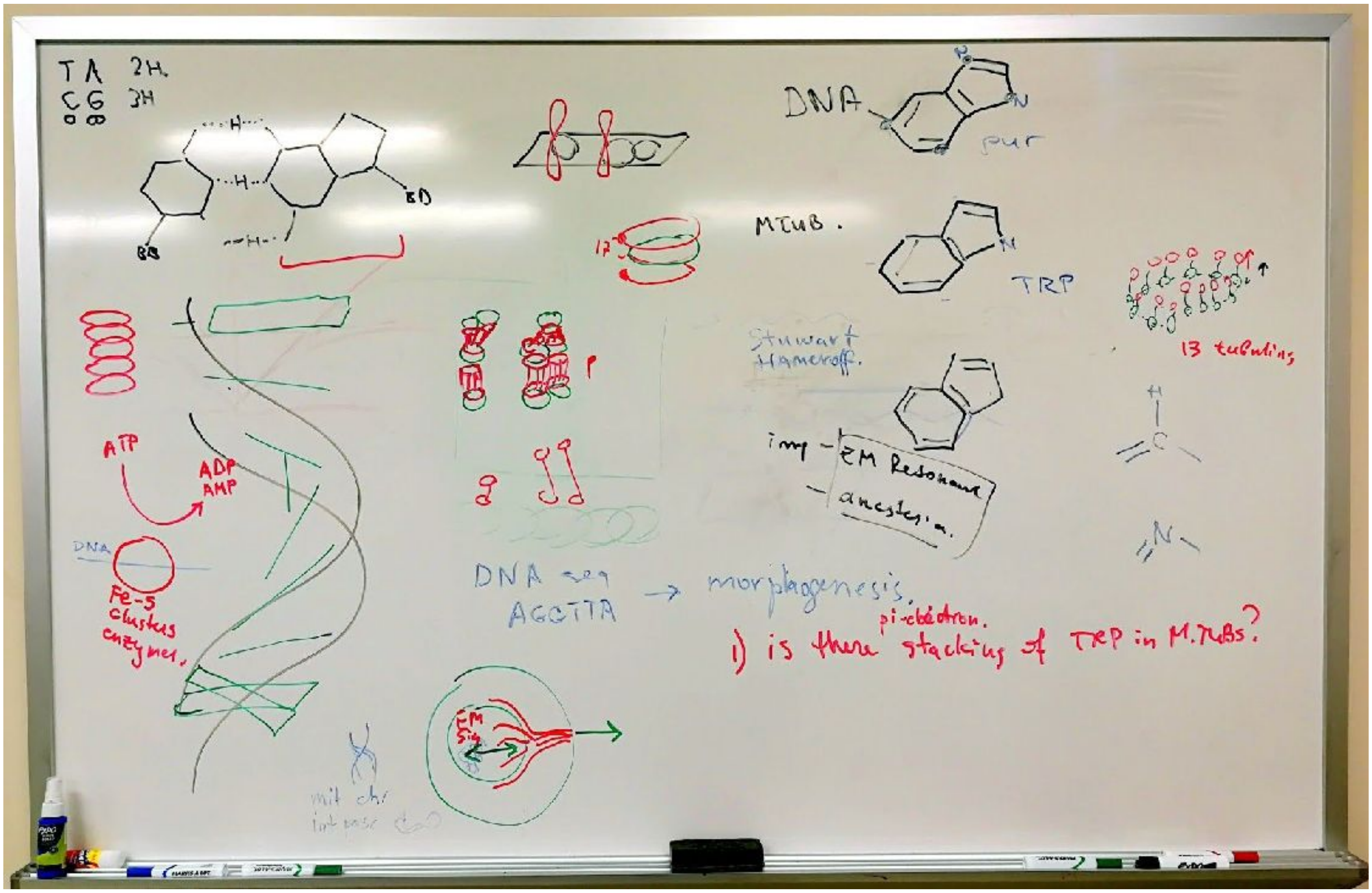
==============================

**OTHER BIOLOGICAL STRUCTURES**

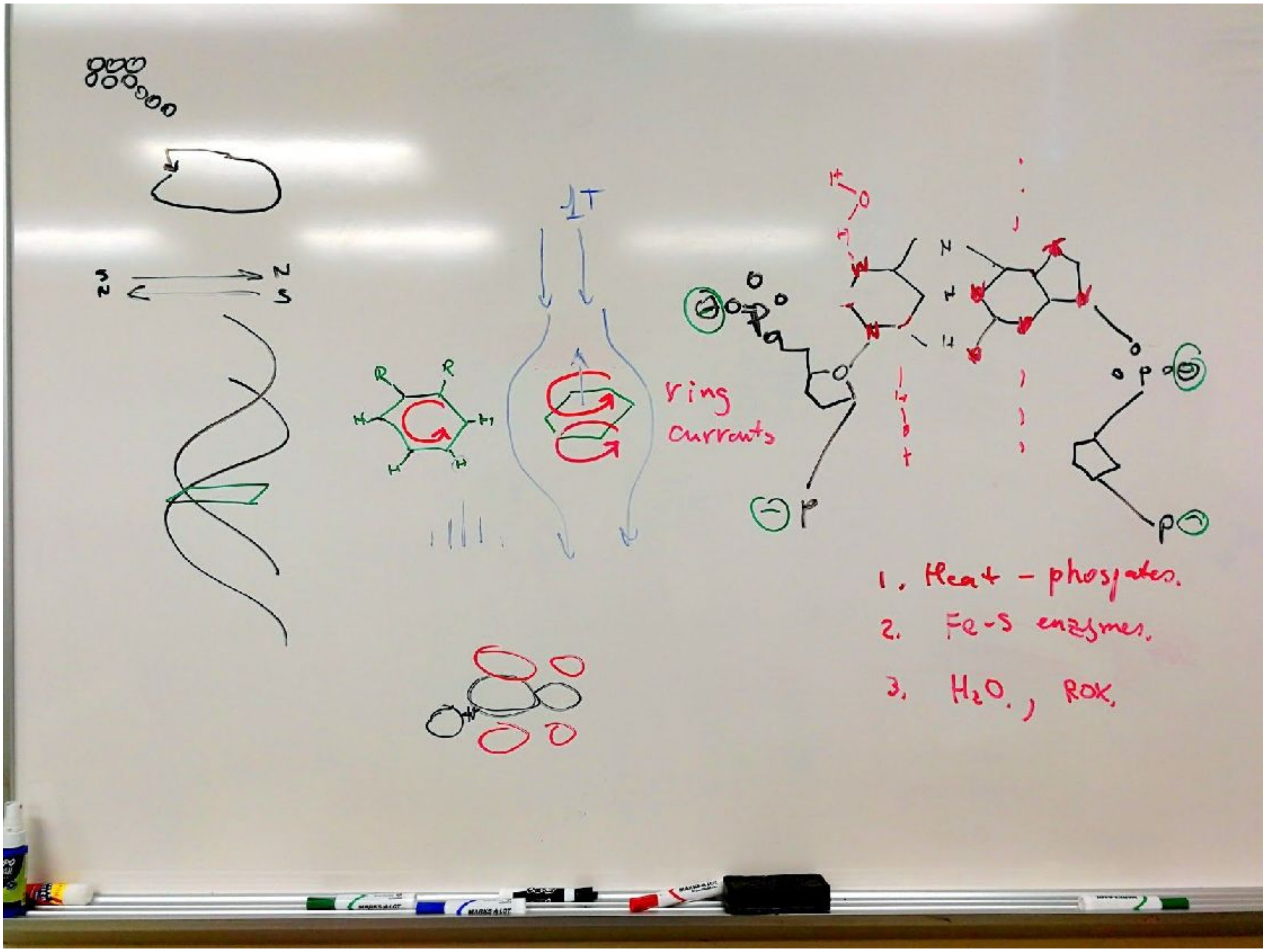
In addition to DNA, assemblies of magnetic balls resemble other biological structures such as microtubules (FIG), strings of cells (FIG), cones, cylinders made of proteins (FIG) or cells (FIG), neural crest (FIG) and proteins (FIG).

Magnetic balls exceptionally well self-assemble into microtubule-like structures. Magnetic balls self-assemble into honeycomb sheet which easily warps into a cylinder resembling formation of a neural tube.
Self-assembled conical structures of magnetic balls resemble some of plant structures.

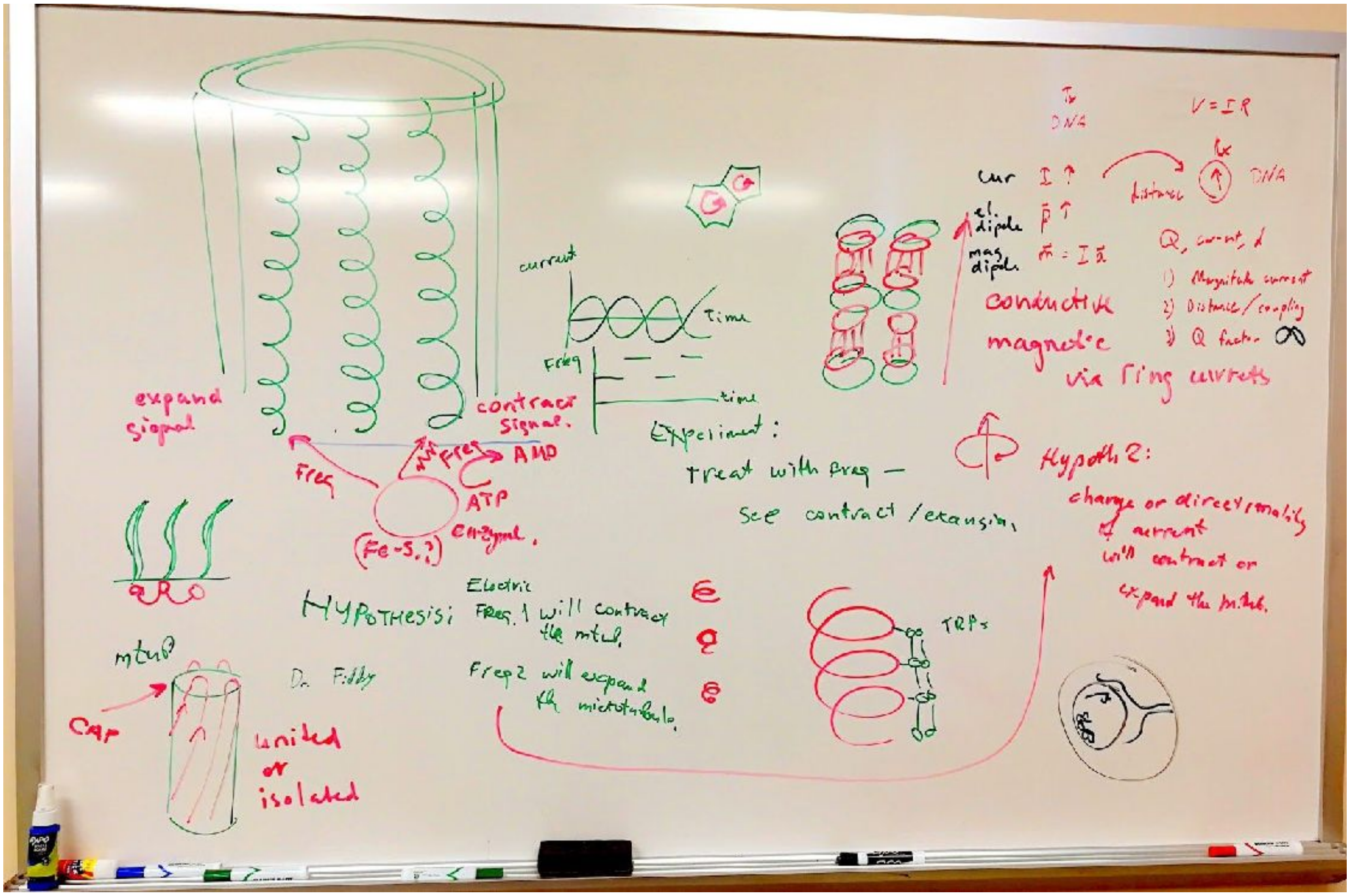
Magnetic properties of some of cell types (Zborowski, 2007)



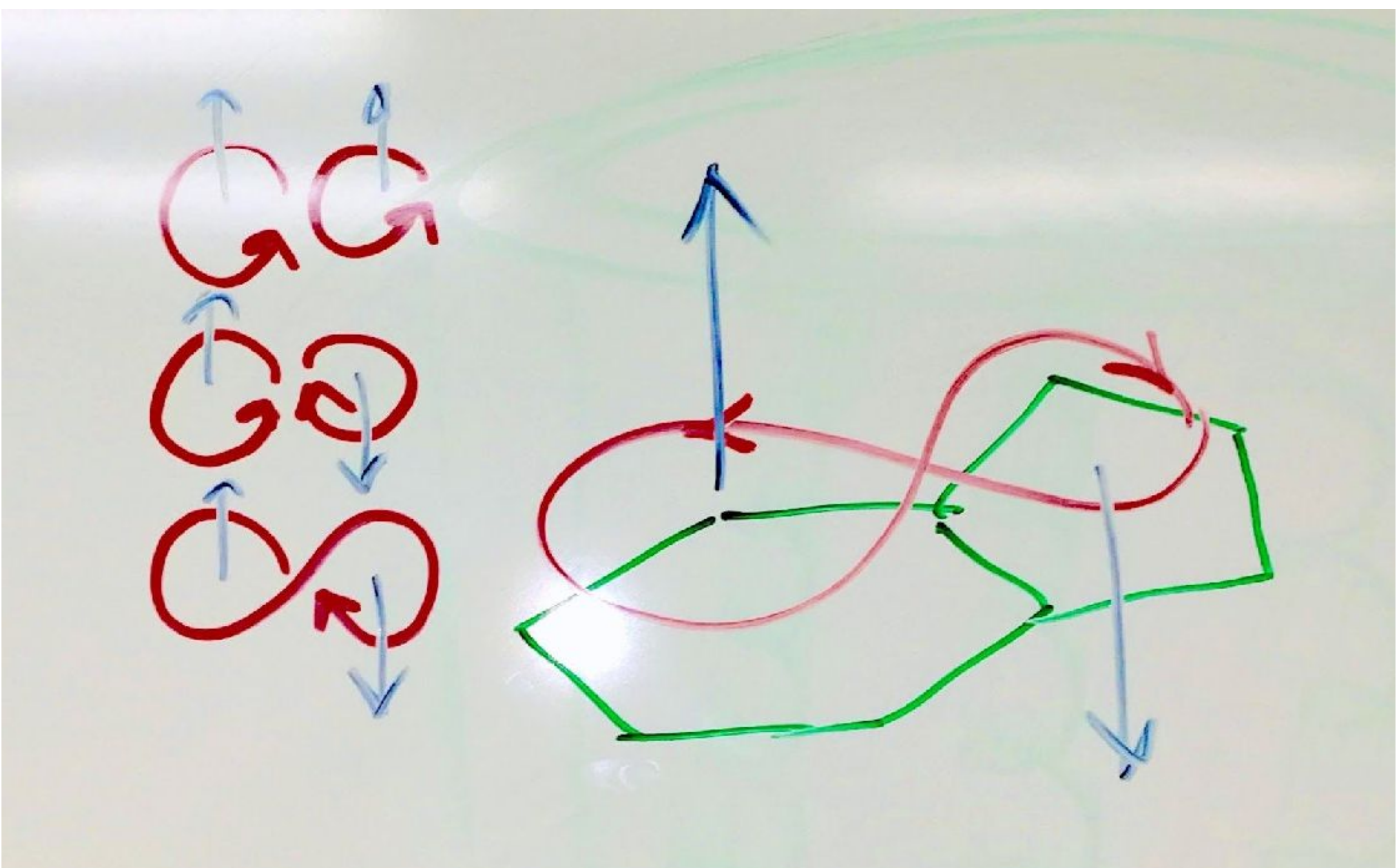
TA 2H.
CG 3H
DNA
pur
MTUB.
TRP
Stuwart Hameroff.
13 tubulins
ATP
ADP
AMP
DNA
Fe-S clusters enzymes.
imp - EM Resonance
- anesthesia.
DNA seq
AGCTTA → morphogenesis.
1) is there pi-electron. stacking of TRP in M.TUBs?

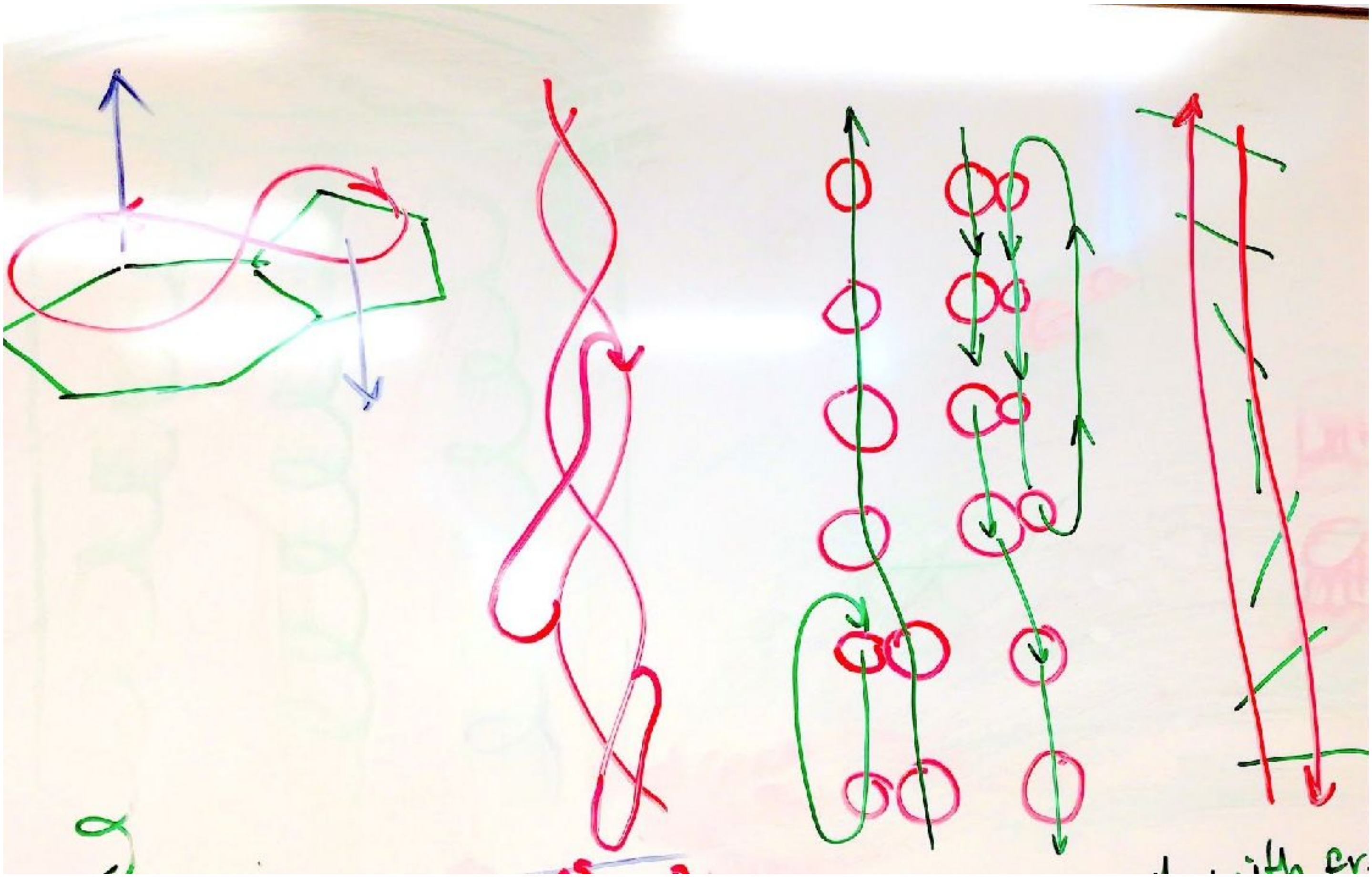


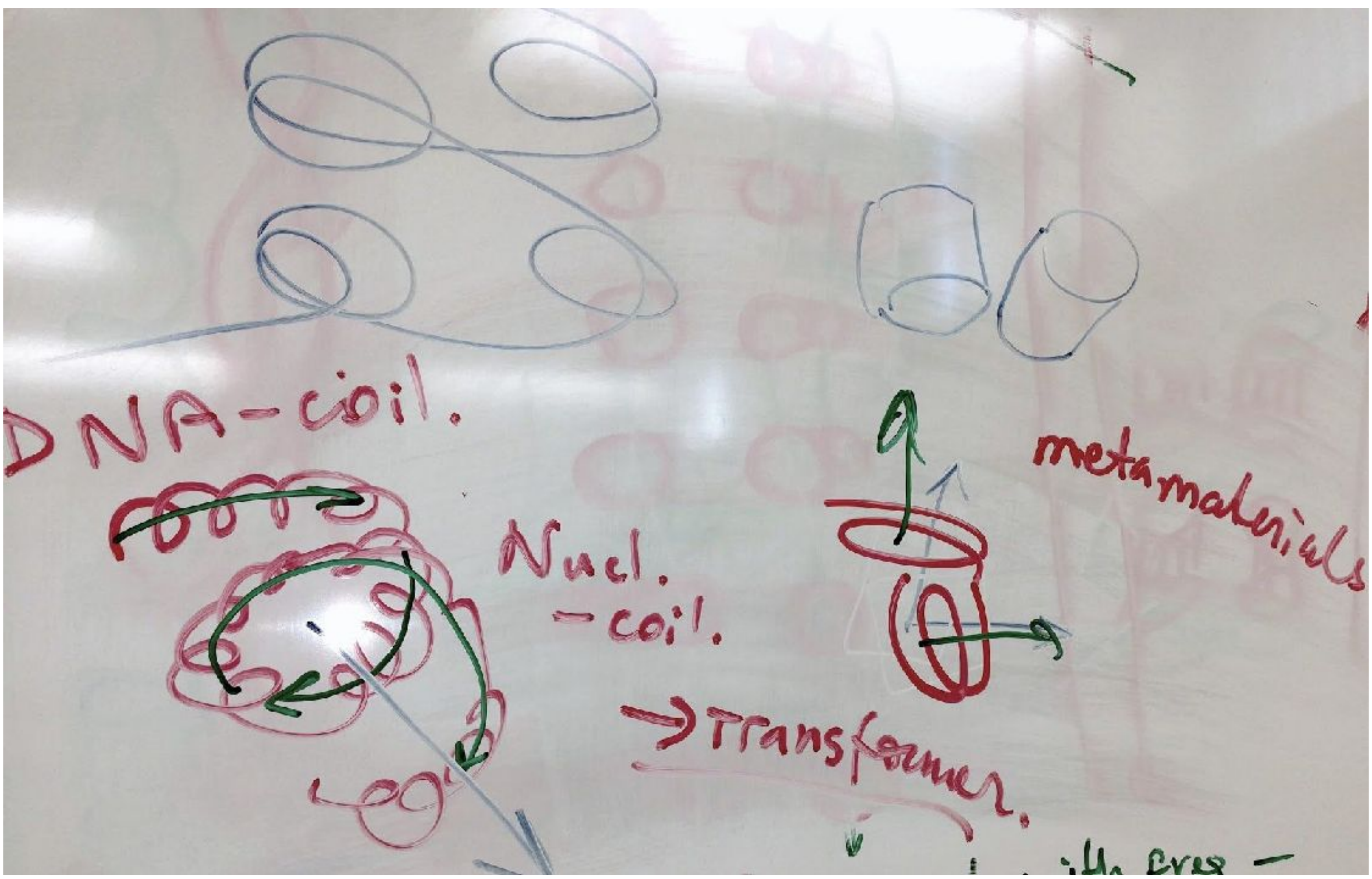
1T
ring
currents
1. Heat - phospates.
2. Fe-S enzymes.
3. $H_2O$., ROX.



expand signal
contract signal
Freq
AMP
ATP
(Fe-S, ?)
enzyme
current
time
Freq
time
Experiment:
Treat with freq —
See contract / expansion
HYPOTHESIS: Electric Freq. 1 will contract the mtub.
Freq 2 will expand the microtubule.
mtub
CAP
Dr. Fiddy
united or isolated
TRPs
Hypoth 2:
change or directionality of current will contract or expand the mtub.
V = IR
DNA
cur
el. dipole
mag. dipole
distance
Q, current, d
1) Magnitude current
2) Distance / coupling
3) Q factor
conductive
magnetic
via ring currents




DNA-coil.
Nucl.
-coil.
→Transformer.
metamaterials

**EXTRAS**

Magnetic forces direct this process making many steps of above mentioned assemblies error-proof and attracting the ends of matching structures and repelling unmatching structures.

Also behavior of magnetic balls resembles self-assembly of living structures since (unlike atoms in crystals) magnetic balls resist being shaped into orderly solids and prefer self assemblage into linear, sheet, tubular and conical structures. This strikingly distinguishes them from non-magnetic balls and from atomic structures of inorganic crystals.

Based on these observations, I hypothesize that DNA, chromatin, microtubules and tissues are magnetic and their corresponding units are magnetic.

I also hypothesize that the magnetic properties of those are created by heat-fueled spinning electron pi-orbitals of asymmetrical aromatic heterocycles such as purines and tryptophan.

**REFERENCES**

1. Magnetic properties of DNA (Mizoguchi, 2008).
2. Magnetic properties of DNA (Berashevich, 2008),
3. Magnetic nucleotide models (Yung, 2015),
4. DNA resembles a magnet(White, 2012),
5. Creating magnetic composite nanomaterials with DNA (Nikiforov, 2017)

Alam, T. M., & Drobny, G. (1990). Magnetic ordering in synthetic oligonucleotides. A deuterium nuclear magnetic resonance investigation. *The Journal of Chemical Physics*, *92*(11), 6840–6846.

Arter, D. B., & Schmidt, P. G. (1976). Ring current shielding effects in nucleic acid double helices. *Nucleic Acids Research*, *3*(6), 1437–1447.

Berashevich, J., & Chakraborty, T. (2008). How the surrounding water changes the electronic and magnetic properties of DNA. *The Journal of Physical Chemistry. B*, *112*(44), 14083–14089.

Bliumenfeld, L. A. (1959). Anomalous magnetic properties of nucleic acids. *Biofizika*, *4*, 515–520.

Buchachenko, A. L., Orlov, A. P., Kuznetsov, D. A., & Breslavskaya, N. N. (2013). Magnetic isotope and magnetic field effects on the DNA synthesis. *Nucleic Acids Research*, *41*(17), 8300–8307.

Fox, R. F. (2010). Aromatic Ring Currents. Retrieved February 26, 2018, from http://www.fefox.com/ARTICLES/AromaticRingCurrents.pdf

Giessner-Prettre, C., Pullman, B., Borer, P. N., & Kan, L. S. (1976). Ring-current effects in the nmr of nucleic acids: A graphical approach. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/bip.1976.360151114/full

Irkhin, V. Y., & Nikiforov, V. N. (2017). Quantum effects and magnetism in the spatially distributed DNA molecules. *Journal of Magnetism and Magnetic Materials*. http://doi.org/10.1016/j.jmmm.2017.08.087

Kinsella, J. M., & Ivanisevic, A. (2008). Magnetotransport of One-Dimensional Chains of CoFe2O4 Nanoparticles Ordered along DNA. *Journal of Physical Chemistry C*, *112*(9), 3191–3193.

Liu, C.-H., Tsao, M.-H., Sahoo, S. L., & Wu, W.-C. (2017). Magnetic nanoparticles with fluorescence and affinity for DNA sensing and nucleus staining. *RSC Advances*, *7*(10), 5937–5947.

Mizoguchi, K. (2008). Physical properties of natural DNA and metal ion inserted M-DNA. In *Proc. SPIE* (Vol. 7040, pp. 1–9).

Mizoguchi, K., & Sakamoto, H. (2016). *DNA Engineering: Properties and Applications*. Pan Stanford Publishing.

Müller, A., Hotz, G., & Zimmer, K. G. (1961). Electron spin resonances in bacteriophage: Alive, dead, and irradiated. *Biochemical and Biophysical Research Communications*, *4*(3), 214–217.

Nakamae, S., Cazayous, M., Sacuto, A., Monod, P., & Bouchiat, H. (2005). Intrinsic low temperature paramagnetism in B-DNA. *Physical Review Letters*, *94*(24), 248102.

Nikiforov, V. N., Koksharov, Y. A., & Irkhin, V. Y. (2017). Magnetic properties of “doped” DNA. *Journal of Magnetism and Magnetic Materials*. http://doi.org/10.1016/j.jmmm.2017.09.008

Pershina, A. G., Sazonov, A. E., & Filimonov, V. D. (2014). Magnetic nanoparticles–DNA interactions: design and applications of nanobiohybrid systems. *Russian Chemical Reviews*, *83*(4), 299.

Rai, D., Hod, O., & Nitzan, A. (2012). Magnetic fields effects on the electronic conduction properties of molecular ring structures. *Physical Review. B, Condensed Matter*, *85*(15), 155440.

Rojeab, A. Y. (2013). Magnetic Properties Govern the Processes of DNA Replication and the Shortening of the Telomere. In *Proceedings of World Academy of Science, Engineering and Technology* (p. 1342). World Academy of Science, Engineering and Technology (WASET).

Tatarov, I., Panda, A., Petkov, D., Kolappaswamy, K., Thompson, K., Kavirayani, A., … DeTolla, L. J. (2011).

Effect of magnetic fields on tumor growth and viability. *Comparative Medicine*, *61*(4), 339–345.

Wang, Y. J., Cheng, J., Yue, X. F., & Liu, D. S. (2011). The Magnetism of DNA Molecular Materials. In *Advanced Materials Research* (Vol. 306, pp. 46–49). Trans Tech Publ.

White, M. (2012, March 21). How DNA is like a Magnet. Retrieved January 22, 2018, from https://thefinchandpea.com/2012/03/21/how-dna-is-like-a-magnet/

Yung, S. B., & Primm, T. P. (2015). Nucleotide Manipulatives to Illustrate the Central Dogma. *Journal of Microbiology & Biology Education: JMBE*, *16*(2), 274–277.

Zborowski, M. (2007). Magnetophoresis. In *Laboratory Techniques in Biochemistry and Molecular Biology* (Vol. 32, pp. 105–118). Elsevier.