Magnetic Interfaces and Nanostructures Division
Room 203A - Session MI+BI-ThA

Interdisciplinary Magnetism

Moderator: Markus Donath, Westfälische Wilhelms-Universität Münster, Germany

2:40pm **MI+BI-ThA2 Chiral Induced Spin Selectivity in Molecular Bond Dissociation***, **Richard Rosenberg**,* Argonne National Laboratory

Since nearly all biological compounds are homochiral, any model of the origin of life must be able to incorporate a mechanism that could lead to preferential chirality. Since chiral molecules have a certain handedness, many researchers have investigated the possible influence of circularly polarized UV photons and longitudinal spin-polarized electrons in creating an enantiomeric excess.[1-3] However, in general the demonstrated effects have been small and/or on the order of the experimental error. Previously we demonstrated [4] that chiral-selective chemistry occurs when X-rays irradiate a chiral molecule bound to a magnetic substrate and suggested that a previously unappreciated source may play a role in chiral-selective chemistry: low-energy (0-20 eV) spin-polarized secondary electrons, produced by photon, electron, or ion irradiation. In the present work, we explore a possible alternative mechanism based on the chiral induced spin selectivity (CISS) effect [5] which suggests that the lifetime of an excited electron in a chiral molecule bound to a magnetic substrate should depend on the magnetization direction of the substrate. To investigate this possibility, we examined the photon-stimulated desorption yield of hydrogen ions from D- and L-Hystidine bound to a magnetized cobalt film. The data indicates differences in the N K edge spectra of the H^+ ion yield depending on the substrate magnetization direction. These results suggest a possible CISS effect on the excited state lifetime of the dissociative state. Such a mechanism would be applicable to any process that leads to an excited electron in a dissociative state of a chiral molecule bound to a magnetic substrate. Iron is one of the most common elements and many iron compounds are magnetic, so such a mechanism could be applicable in a wide range of prebiotic environments.

The work performed at the Advanced Photon Source was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under contract No. DE-AC02-06CH11357.

REFERENCES

[1] M. Avalos *et al.*, Chem. Rev. **98**, 2391 (1998).

[2] W. A. Bonner, Orig. Life Evol. Biosph. **25**, 175 (1995).

[3] P. Ehrenfreund *et al.*, Rep. Prog. Phys. **65**, 1427 (2002).

[4] R.A. Rosenberg, M. Abu Haija and P.J. Ryan, Phys. Rev. Lett., **101**, 178301 (2008).

[5] S. G. Ray, S. S. Daube, G. Leitus, Z. Vager, R. Naaman, Phys. Rev. Lett. **96**, 036101 (2006).

3:00pm **MI+BI-ThA3 The Chiral Induced Spin Selectivity Effect- From Spintronics to Controlling Chemistry***, **Ron Naaman**,* Weizmann Institute of Science, Israel **INVITED**

Spin based properties, applications, and devices are commonly related to magnetic effects and to magnetic materials. However, we found that chiral organic molecules can act as spin filters for photoelectrons transmission, [i] in electron transfer, [ii] and in electron transport. [iii]

The new effect, termed Chiral Induced Spin Selectivity (CISS), [iv] enables new type of spintronics, [v] has interesting implications in Biology, [vi] varying from allowing long-range electron transfer, controlling multiple electrons reactions, and in enantio-recognition.

The effect and its various applications and implications will be discussed.

[i] Göhler, B.; Hamelbeck, V.; Markus, T.Z.; Kettner, M.; Hanne, G.F.; Vager, Z.; Naaman, R.; Zacharias, H. Science 2011, 331, 894.

[ii] Mishra, D.; Markus, T.Z.; Naaman, R.; Kettner, M.; Göhler, B.; Zacharias, H.; Friedman, N.; Sheves, M.; Fontanesi, C. PNAS, 2013, 110, 14872 .

[iii] Xie, Z.; Markus, T. Z.; Cohen, S. R.; Vager, Z.; Gutierrez, R.; Naaman, R. Nano Letters, 2011, 11, 4652.

[iv] a) Naaman, R.; Waldeck, D.H. J. Phys. Chem. Lett. (feature) 2012, 3, 2178. b) Naaman, R.; Waldeck, D. H. Ann. Rev. Phys. Chem. 2015, 66, 263.

[v] Michaeli K., Varade V. , Naaman R., Waldeck D., J. Physics: Condensed Matter, 29, 103002 (2017).

[vi] Michaeli, K.; Kantor-Uriel, N.; Naaman, R.; Waldeck, D. H. Chem. Soc. Rev. 2016, 45, 6478.

4:00pm **MI+BI-ThA6 Multifunctional Ferromagnetic Disks for Life Sciences Applications***, **Elena Rozhkova**, V. Novosad,* Argonne National Laboratory **INVITED**

The impact of modern nanomaterials and engineered architectures on biological modulation, bioanalytical techniques, and healthcare technologies can hardly be overestimated. Magnetic nanomaterials are attractive for life sciences applications because they can be detected and operated remotely, biological barriers-free, using external magnetic field. Using top-down micro-/nano-fabrication techniques allows for production of monodisperse magnetic particles of virtually any composition and shape, with tunable magnetic properties. Such particles have been exploited as multi-spectral MRI contrast enhancement labels, for *in vitro* detection of molecular markers and cell sorting. This talk will summarize successful applications of lithographically defined disk-shaped particles composed of ferromagnetic $Fe_{20}Ni_{80}$ permalloy core for biomedical applications in both low- and high frequency magnetic field regimes as mediators of biological mechanotrasduction, as delivery vehicles, contrast agents and ultrasensitive detection labels. Advanced synchrotron imaging was used to visualize interaction of engineered nanomagnetic hybrids with living systems and study their chemical stability at subcellular, cellular and 3D multicellular levels.

E. A. Rozhkova, V. Novosad, D.-H. Kim, J. Pearson, R. Divan, T. Rajh, S. D. Bader, *J App Physics* 105 (7): 07B306 (2009)

D-H Kim, E. A. Rozhkova, I. V. Ulasov, S. D. Bader, T. Rajh, M. S. Lesniak, V. Novosad, *Nature Materials* 9 (2): 165-171 (2010)

D.H.Kim, P. Karavayev, E.A. Rozhkova, J. Pearson, S.D. Bader, V. Novosad, *J Mater Chem* 21, 8422-8426 (2011)

E. A. Rozhkova, *Advanced Materials,* 23, H136–H150 (2011)

E.A. Vitol, V. Novosad and E.A. Rozhkova, *Nanomedicine,* 7(10), 1611-1624 (2012)

M. Nikitin, A. Orlov, I. Sokolov, A. Minakov, P. Nikitin, J. Ding, S.D. Bader, E.A. Rozhkova, V. Novosad, In Press (2018)

4:40pm **MI+BI-ThA8 Magnetic Nanoparticles in Biomedicine: Recent Developments in Imaging, Diagnostics and Therapy***, **Kannan Krishnan**,* University of Washington **INVITED**

The Néel relaxation of magnetic nanoparticles (MNP), subject to alternating magnetic fields in solution, depends exponentially on their core diameter while the complementary Brownian relaxation mechanism depends critically on their hydrodynamic volume [1]. Recent developments [2] in the synthesis of highly monodisperse and phase-pure magnetite nanoparticles allows for reproducible control of the former in biological environments, enabling novel imaging [3,4] and spectroscopic modalities, under ac excitations such as magnetic particle imaging/spectroscopy (MPI/MPS) with superior resolution and sensitivity [5]. [8] .

Magnetic Particle Imaging (MPI) is an emerging, tracer-based, whole-body medical imaging technology with high image contrast (no tissue background) and sensitivity (~250 nm Fe) to an optimized tracer consisting of an iron-oxide nanoparticle core and a biofunctionalized shell. MPI is linearly quantitative with tracer concentration and has zero tissue depth attenuation. MPI is also safe, uses no ionizing radiation and clinically approved tracers. MPI is also the first biomedical imaging technique that truly depends on nanoscale materials properties; in particular, their response to alternating magnetic fields in a true biological environment needs to be optimized.

In this talk, I will introduce the underlying physics of MPI, the alternative approaches to image reconstruction, and describe recent results in the development of our highly optimized and functionalized nanoparticle tracers for MPI. I will then present state-of-the-art imaging results of preclinical *in vivo* MPI experiments of cardiovascular (blood-pool) imaging [6], stroke [7], GI bleeding [8], and cancer [9] using rodent models. I will also discuss a related diagnostic method using magnetic relaxation and illustrate its use for detecting specific protease cancer markers in solution [10]. If time permits, I will introduce therapeutic applications of magnetic nanoparticles [11].

[1] Kannan M. Krishnan, *IEEE Trans. Mag.* 46, 2523 (2010)

[2] S. J. Kemp, R.M. Ferguson, A. P. Khandhar and Kannan M. Krishnan, *RSC Advances*, 6, 77452 (2016).

[3] B. Gleich & J. Weizenecker, *Nature* 435, 1214 (2005).

[4] R.M. Ferguson, et al, *IEEE Trans. Med. Imag*. 34, 1077 (2015)

[5] M. Graeser et al, *Scientific Reports*, 7, 6872 (2017)

[6] A. Khandhar et al, *Nanoscale* 9,1299 (2017)

[7] P. Ludewig et al, ACS Nano *11, 10480 (2017)*

[8] E. Y. Yu et al, *ACS Nano* 11, 12067 (2017

[9] H. Arami et al, *Nanoscale* 9, 18723 (2017)

[10] S. Gandhi, H. Arami and Kannan M. Krishnan, *Nanoletters* 16, 3668 (2016)

[11] This work was supported by NIH grants 1RO1EB013689-01, 1R41EB013520-01, 2R42-EB013520-02A1 and 1R24-MH109085 .

Author Index

Bold page numbers indicate presenter