MA 38: Magnetic Particles / Clusters & Biomagnetism

Time: Thursday 15:00–18:00 Location: H18

Invited Talk MA 38.1 Thu 15:00 H18
Liquid-mediated surface-surface interactions investigated by close-to-surface magnetic particle transport — •Rico Huhnstock, Yahya Shubbak, and Arno Ehresmann — Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel

Studying phenomena at the liquid-solid interface has tremendous significance for the physical, chemical, biological, and nanostructure sciences [1]. Experimental access to the underlying interactions is a nontrivial task, demonstrated for instance by the difficulties connected with performing atomic force microscopy measurements in liquids. In this talk, we propose a novel technique to inspect liquid-mediated surface-surface interactions based on guiding magnetic microparticles (MPs), surrounded by a quiescent fluid, along defined trajectories in the vicinity of a solid interface. The MP motion is induced by harnessing engineered magnetic stray field landscapes (MFLs) emerging from customized magnetic domain patterns imprinted into a topographically flat substrate. We will give an overview of the MFL fabrication process and discuss the influence of MP [2], liquid, and MFL [3] properties on the MP motion. Finally, we highlight, that the MP motion dynamics can be studied to identify changes in liquid-mediated DLVO interactions between surfaces of the MP and the underlying substrate.
[1] Chen *et al.* (2022), Advanced Materials Interfaces, 9(35):2201864.
[2] Huhnstock *et al.* (2021), Scientific Reports, 11(1):21794.
[3] Huhnstock *et al.* (2024), Small, 20(10):2305675.

MA 38.2 Thu 15:30 H18
Exploring iron nitrides: Insights from Mössbauer spectroscopy — •Lenka Kubíčková[1,2], Jaroslav Kohout[1], Tomáš Kmječ[1], Karel Knížek[2], Štefan Hricov[2,3], Ondřej Kaman[2], Yevhen Ablets[4], Robin Kidangan Paul[4], Stanislav Mráz[5], Jochen Schneider[5], Oliver Gutfleisch[4], and Imants Dirba[4] — [1]Faculty of Mathematics and Physics, Charles University, 180 00 Praha 8, Czechia — [2]FZU - Institute of Physics of the CAS, 162 00 Praha 6, Czechia — [3]Faculty of Science, Charles University, 128 00 Praha 2, Czechia — [4]Functional Materials, Institute of Materials Science, TU Darmstadt, 64287 Darmstadt, Germany — [5]Materials Chemistry, RWTH Aachen University, 52074 Aachen, Germany

Mössbauer spectroscopy, a powerful tool for probing the local electronic and magnetic properties of materials containing Mössbauer isotopes, will be employed to investigate selected examples of iron nitrides. First, we will show spectra of air-sensitive Fe_3N nanoparticles, which exhibit a high degree of structural disorder. Moreover, we will discuss formation of an oxide layer by their passivation, whose nature and extent is difficult to assess from other methods but is crucial for medical applications. Second, conversion-electron Mössbauer spectroscopy (CEMS) of $Fe_{4-x}Ge_xN$ (x = 0, 0.5 and 1) crystalline thin films allows us to determine not only the direction of magnetization in the film of the undoped phase, but also, together with the DFT calculations, position of the Ge atoms in the Fe_4N structure. Such local insights are valuable for designing and optimizing iron-based films, e.g., for their magnetic or thermoelectric applications.

MA 38.3 Thu 15:45 H18
Tunable magnetic behavior in $[CoFe_2O_4]_n$@Pt hybrid nanoparticles — •Joachim Landers[1], Moritz Raphael[2], Soma Salamon[1], Heiko Wende[1], and Annette Schmidt[2] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen — [2]Department of Chemistry, Institute of Physical Chemistry, University of Cologne

$[CoFe_2O_4]_n$@Pt hybrid nanoparticles were prepared by growing monodisperse $CoFe_2O_4$ (CFO) nanocubes epitaxially on the corners of 6 nm cubic Fe/Co-doped Pt seeds. The hybrid particles display a defined configurational order, in which the CFO cubes cover the corner positions, allowing the formation with a variable number n of CFO cubes in reproducible geometries. Thereby, the hybrid particles represent a system of tunable intraparticular magnetic dipolar interaction, acting in superposition to the high cubic magnetocrystalline anisotropy of the CFO nanocubes. This competition creates a complex temperature-dependence of the shape of the magnetic hysteresis curves, dependent on the size and number of attached CFO nanocubes. In the future, this could facilitate the production of high-anisotropy and -magnetization hybrid particles of widely controllable magnetic behavior. To analyze the acting mechanisms and resulting magnetic properties, in-field Mössbauer spectroscopy and different magnetometry protocols were employed. The experimental observations are compared to micromagnetic simulations utilizing MuMax3. Funding by the DFG projects SCHM1747/16-1 and LA5175/1-1 is gratefully acknowledged.

MA 38.4 Thu 16:00 H18
Inductive Heating of ZnFe Nanoparticles — •Esra Uz[1], Yohei Fujita[2], Marina Spasova[1], Tatiana Smaliarova[1], Ivan Tarasov[1], Michael Farle[1], Yuko Ichiyanagi[2], and Ulf Wiedwald[1] — [1]Universität Duisburg Essen — [2]Yokohama National University

Hyperthermia is a novel medical treatment that uses magnetic fields in combination with specially designed magnetic nanoparticles for the non-invasive elimination of pathological cells. The ZnFe nanoparticles (6-19 nm) have been chemically synthesized and analyzed with a focus on applications in magnetic hyperthermia. The structure and morphology of the nanoparticles have been investigated using X-ray diffraction (XRD) and transmission electron microscopy (TEM). The results confirm the cubic spinel structure of the nanoparticles. Vibrating sample magnetometry (VSM) revealed a ferromagnetic character of the 19 nm particles with a saturation magnetization of 79.8 Am*m/kg. The smaller particles, however, have shown superparamagnetic behavior. For two distinct particle sizes, 11 nm and 19 nm, agarose gel electrophoresis was applied to experimentally measure the heating power in an alternating magnetic field (100-250 kHz, 0-50 mT). For the specific loss power (SLP), determined by calorimetry, our experiments show a maximum value of 71 W/g at a frequency of 247 kHz and B = 40 mT. These findings demonstrate that ZnFe nanoparticles are a promising candidate for applications in the context of magnetic hyperthermia.

MA 38.5 Thu 16:15 H18
Simulation of Dynamics and Self-assembly of Magnetically Decorated Particles — •Maximilian Neumann, Sibylle Gemming, Oliver G. Schmidt, Daniil Karnaushenko, and Aaron Steinhäusser — TU Chemnitz, Chemnitz, Germany

Self-assembly allows for the aggregation of highly complex structures from simple components. Coupled with the highly tunable properties and susceptibility to external fields of magnetic particles this results in the potential to fashion systems with a plethora of applications. By decorating tubular particles with permanent magnets in specific patterns of up/down configuration we create different species of particles, whose behaviour is governed by a mix of attractive and repulsive interactions between individual magnets. This results in selective assembly between specific species, position and orientation. We show simulations of the interaction and dynamics of these particles with and without the influence of external fields and the surrounding medium.

MA 38.6 Thu 16:30 H18
Arranging dipoles on a ring to create homogenous fields — •Ingo Rehberg[1] and Peter Blümler[2] — [1]Experimental Physics, University of Bayreuth, D-95440 Bayreuth, Germany — [2]Institute of Physics, University of Mainz, 55128 Mainz, Germany

Homogeneous magnetic fields can be generated using appropriately arranged permanent magnets. Halbach rings serve as a prominent example of this approach [1], particularly effective when employing very long magnetic rods, often modelled as line dipoles. However, for shorter magnets, the optimal configuration of magnetic moments diverges from the traditional Halbach geometry [2]. In this talk, we present an experimental setup utilizing magnetic cubes and visualize the anticipated fields through an open-source animation of point dipole clusters [3].

[1] Peter Blümler and Helmut Soltner, Practical Concepts for Design, Construction and Application of Halbach Magnets in Magnetic Resonance. Appl. Magn. Reson. 54, 1701 (2023).
[2] Ingo Rehberg and Peter Blümler, submitted.
[3] Ingo Rehberg, From Concentric Halbach Rings to Tetraplex Cuts - Examine 540 Dipole Clusters with a Single Python Animation.

https://zenodo.org/records/11214206 (2024).

15 min. break

MA 38.7 Thu 17:00 H18

Quantum Mechanical Analysis of Complex Ferrimagnetic States in Iron Oxide Nanoparticles — •Valentína Berecová[1,2], Martin Friák[1], Naděžda Pizúrová[1], and Jana Pavlů[2] — [1]Inst. Phys. Mater., Czech Acad. Sci., Brno, Czech Republic — [2]Dept. Chem., Masaryk Uni., Brno, Czech Republic

Maghemite (γ-Fe_2O_3) is a biocompatible ferrimagnetic iron oxide that crystallizes in an inverse spinel lattice and can be viewed as magnetite (Fe_3O_4) with iron vacancies. Iron oxide nanoparticles related to maghemite have numerous applications in the biomedical field thanks to the combination of their magnetic properties, biocompatibility, low cytotoxicity and small size. Density functional theory calculations were employed to examine the local magnetic moments of individual atoms in two maghemite-related nanoparticles. Our calculations for the nanoparticles were inspired by bulk maghemite γ-Fe_2O_3, where tetrahedrally and octahedrally coordinated Fe sublattices have opposing orientations of local magnetic moments. Importantly, our results show that the nanoparticle surfaces create far more complex magnetic states compared to the magnetic ordering found in bulk. These complex magnetic states were described as "nested" ferrimagnetism, which is characterized by local magnetic moments of Fe atoms with mutually opposite orientations appearing even within each of the two (tetrahedral or octahedral) sublattices. Financial support from the Czech Academy of Sciences (*Praemium Academiae* of M.F.) is gratefully acknowledged. Computational resources were provided by the e-INFRA CZ project and IT4Innovations National Supercomputing Center.

MA 38.8 Thu 17:15 H18

Iron Nitride Magnetic Nanoparticles for Biomedical Applications — •Sayar Das[1], Yevhen Ablets[1], Lenka Kubíčková[2], Imants Dirba[1], and Oliver Gutfleisch[1] — [1]TU Darmstadt, Germany — [2]FZU, Praha, Czech Republic

With the urgent need for advanced materials in healthcare, magnetic nanoparticles (MNPs) have emerged to be helpful in versatile biomedical applications such as Hyperthermia for cancer treatment, contrast agents for Magnetic resonance Imaging, drug delivery, and others. For such applications, MNPs must be small in size and have high saturation magnetization (M_s) for better performance. Typically, iron oxide nanoparticles are used as they are inexpensive, chemically stable, and show low toxicity. Owing to the superior properties of iron nitride phases, it is considered a promising candidate over traditionally used iron oxides. This study systematically investigates the synthesis and characterization of iron nitride nanoparticles for intended biomedical applications. MNPs are synthesized via the thermal decomposition method using $Fe(CO)_5$ as a precursor, where nitriding is realized with ammonia as a carrier gas. Key findings demonstrate that surfactant-free synthesis yields ε-Fe_3N nanoparticles with M_s up to 122 Am^2/kg and a mean particle size of 14 nm. Synthesis with surfactants results in nanoparticles with higher yields and enhanced M_s. Moreover, using pure hydrogen as a reducing agent during synthesis significantly improves magnetic properties, with room temperature M_s reaching 162 Am^2/kg at a particle size of 15 nm, which is the highest M_s in iron nitride nanoparticles prepared by wet chemical routes up to date.

MA 38.9 Thu 17:30 H18

Magnetophoretic distinction of differently surface-functionalized magnetic microparticles by transport in a quiescent liquid — •Yahya Shubbak, Katharina Eichhorn, Nikolai Weidt, Arne Vereijken, Rico Huhnstock, and Arno Ehresmann — Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Strasse 40, 34132 Kassel, Germany

Magnetic particles (MPs) transported in a quiescent liquid close to the surface of a substrate with a periodic magnetic domain pattern is a promising Lab-on-a-chip technology for the detection of MP-bound analytes, even when their size is negligible compared to the MP size. As a proof of principle, we show an all-optical method to distinguish single MPs of the same nominal size that are surface-functionalized with two different chemical groups. More specifically, MPs measuring 2 micrometer in diameter with a polymer coating with only carboxyl end groups (COOH) or a mixture of carboxyl and amino (NH2) groups, respectively, have been studied. Harnessing a variation of liquid-mediated surface interaction forces in our close-to-substrate MP transport scheme, the different MP surface potentials lead to different magnetophoretic mobilities. Accordingly, transport of these MPs in double-distilled water showed a remarkable difference in the average velocity where the COOH MPs were almost twice as fast as the NH2 counterparts. A thorough investigation using external magnetic field pulses of varying durations revealed a significant distinction between both MP species using only moderate flux densities of a few mT.

MA 38.10 Thu 17:45 H18

Structural, magnetic properties and induction heating behavior studies of Mn doped cupper ferrite nanopowders synthesized using co-precipitation method — •Mahmoud Ismail[1] and Diaa EL-Rahman Rayan[2,3] — [1]Biophysics Branch and Physics Department, Faculty of Science, Al-Azhar University, Nasr City, Cairo, Egypt — [2]Central Metallurgical Research and Development Institute (CMRDI), P.O. Box: 87 Helwan, 11421, Egypt — [3]Department of Physics, Deraya University, New Minia, Minya, Egypt

In this research synthesizes nanocrystalline CuFe2O4 spinel structure using co-precipitation method. The pure copper ferrite is substituted by manganese MnxCu(1*x)Fe2O4 nanopowders (x from 0.0 to 1.0). XRD, HR-TEM, UV-visible-Spectrophotometer and vibrating sample magnetometer (VSM) are utilized in order to study the effect of variation of Mn2+ ions substitution and its impact on crystalline size, lattice parameters, microstructure and optical and magnetic properties of the formed nanopowders. Indeed, heating properties of the MnxCu(1-x)Fe2O4 nanoparticles in an alternating magnetic field at 160 kHz were estimated. The results reveal that the sonochemical method for polyethylene glycol (PEGylated) MnxCu(1-x)Fe2O4 nanoparticles with size 5 nm leads to pseudo-single domain with smallest loop area. Of note, it is clear that the specific heat rate SAR values were in the range from 104.5 to 302.0 W/g at different synthesis conditions. Finally, large SAR values are obtained within 10*15 min using low magnetic field, making Cu-Mn ferrite appropriate for hyperthermia treatment of cancer.