Plenary Talk PLV I Mon 8:30 H1

Seeing dents in the atom — •Franz Giessibl — Exp. and Appl. Phys., University of Regensburg, 93053 Regensburg, Germany

Explaining the emission spectra of atoms was a giant early success of quantum mechanics. Directly seeing atoms remained elusive, though. When Binnig and Rohrer imaged the atoms of the silicon 7x7 reconstructed surface with the scanning tunneling microscope (STM), it came as a surprise. STM relies on a quantum effect, electron tunneling. In 1986, Binnig, Gerber and Quate introduced atomic force microscopy (AFM), a method that also images samples by probing it with, ideally, the single front atom of a sharp tip. Feynman quoted the atomic hypothesis (attracting each other when they are a little distance apart, but repelling upon being squeezed into one another) in chapter 1 of his Lectures on Physics. The AFM uses exactly those forces between atoms to create images line by line. The force sensor needs to probe forces small enough such that neither the tips front atom nor the sample are displaced. AFM passed its acid test when it resolved the silicon 7x7 surface in a non-contact mode using the frequency shift of an oscillating cantilever. The qPlus sensor, a self-sensing quartz cantilever oscillating at sub-A amplitudes resolves molecules with a CO tip. Today, AFM even resolves structures within single atoms. The quantum corral, introduced by Crommie, Lutz and Eigler in 1993, was revisited by AFM, showing that this 2D artificial atom interacts similar with AFM tips as a natural atom. A qPlus sensor with a metal tip reunites STM with AFM and it enables us to do surface science of insulators on the atomic level.

Plenary Talk PLV II Mon 14:00 H1

High-power semiconductor lasers based on Hermitian and non-Hermitian control in photonic crystals — •Susumu Noda — Department of Electronic Science and Engineering, Kyoto University, Kyoto 615-8510, Japan

Realizing single-mode, high-power, high-beam-quality semiconductor lasers, which rival (or even replace) bulky gas and solid-state lasers, is one of the ultimate goals of photonics and laser physics. Conventional high-power semiconductor lasers, however, inevitably suffer from poor beam quality owing to the onset of many-mode oscillation. In this conference, I will review the recent progress, in which these challenges have been surmounted by developing large-scale photonic-crystal surface-emitting lasers (PCSELs) with controlled Hermitian and non-Hermitian couplings inside the photonic crystal. A CW output power exceeding 50W with purely single-mode oscillation and an exceptionally narrow divergence of 0.05°has been achieved for PCSELs with a diameter of 3mm. The brightness, a figure of merit encapsulating both output power and beam quality, exceeds 1GWcm-2sr-1, which is over ten times larger than those of conventional semiconductor lasers and rivals those of existing bulky lasers. I will also discuss our recent efforts towards realizing even 1-kW-class PCSELs with expanded resonant diameters of 10mm and finely tuned Hermitian and non-Hermitian couplings. Such PCSELs are expected to replace conventional, bulkier lasers in the near future. Finally, I will refer to the high functionalities of PCSELs including the emission of arbitrary beam patterns, and high-peak-power short-pulse generation.

Plenary Talk PLV III Mon 14:00 H2

Physics informed artificial intelligence and data-driven design of materials — •Jörg Neugebauer — MPI für Nachhaltige Materialien, Düsseldorf, Germany

Recent advances in materials science have introduced novel compositionally and structurally complex materials, opening up a vast configuration space for discovery. These innovative materials promise to revolutionize industries related to energy storage, transportation, and medicine. However, traditional methodologies fall short in dealing with the high-dimensional configuration spaces involved. This presentation addresses the application of physics-informed artificial intelligence (PIAI) and data-driven strategies as an emerging solution. PIAI uses physical laws and advanced simulation techniques to improve the predictability of AI models, while automated digital workflows facilitate efficient exploration and material discovery. This synergy accelerates the design pipeline and effectively supports navigation of the newly opened vast material space. Real-world case studies will illustrate the potential of these methodologies.

Plenary Talk PLV IV Tue 8:30 H1

Some new aspects of unconventional superconductivity in layered materials — •Irina Grigorieva — University of Manchester, Manchester, UK

I will overview our recent work on layered superconductors where signatures of unconventional superconductivity are revealed or sometimes promoted by their response to magnetic fields. Magnetic correlations and superconductivity are usually antagonistic. However, in some situations external magnetic fields can be helpful in bringing to light new superconducting properties. One example is magnetic field induced multiphase superconductivity in an anisotropic superconductor with strong spin-orbit coupling, PdBi2. Another is an unconventional response of surface superconductivity to the applied magnetic field due to the presence of topological surface states in In2Bi. Yet another is proximity superconductivity surviving in the quantum Hall regime in Josephson junctions based on twisted bilayer graphene. I will discuss the underlying mechanisms and their relation to unconventional topology of these materials.

Plenary Talk PLV V Wed 8:30 H1

Ultrafast magnetism- terra incognita beyond the classical approximations — •Alexey Kimel — Radboud University, Nijmegen, The Netherlands

While the conventionally accepted Curie-Neumann's principle states that "the symmetries of the causes are to be found in the effects" [1], in ultrafast magnetism the principle fails and magnetization dynamics becomes counter-intuitive. We will demonstrate that ultrafast (sub-100 ps) heating with the help of ultrashort laser pulses causes magnetization reversal without any magnetic fields [2], laser-induced spin dynamics is strongly non-linear, where new channels of spin-lattice interaction open-up [3,4], the principle of superposition fails i.e. 1+1>2 [5] and the approximation of macrospin is no longer adequate [6].

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[2] T.A. Ostler et al, Ultrafast heating as a sufficient stimulus for magnetization reversal in a ferrimagnet, Nature-Communications 3, 666 (2012).
[3] E. A. Mashkovich et al, THz light driven coupling of antiferromagnetic spins to lattice, Science 374, 1608-1611 (2021).
[4] T. W. J. Metzger et al, Magnon-phonon Fermi resonance in antiferromagnetic CoF2, Nature Communications 15, 5472 (2024).
[5] T. G. H. Blank et al, Empowering control of antiferromagnetic spins by THz spin coherence, Phys. Rev. Lett. 131, 096701 (2023).
[6] F. Formisano et al, Coherent THz spin dynamics in antiferromagnets beyond the approximation of the Neel vector, APL Mater. 12, 011105 (2024).

Plenary Talk PLV VI Wed 14:00 H1

Topological spin-textures – from domain walls to Hopfions: Current innovations and future challenges — •Stefan Blügel — Peter Grünberg Institute, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Topological spin- and magnetization textures, generally associated with Skyrmions, is a very exciting, timely and multidisciplinary field, where mathematicians, theoretical and computational physicists meet with experts on film and multilayer growth, on high-resolution magnetization and electronic structure characterization, transport and dynamics, and on device concepts and devices in order to integrate these particles into the field of spintronics. It is very fascinating to observe that simple spin models, which can be determined for real materials by density functional theory calculations, lead to micromagnetic equations whose solutions are localized topological textures in an homogeneous solid, which can now be studied by experimental methods, e.g. by means of quantitative off-axis electron holography or x-ray ptychography. Drawing a line between the first solitary wave discovered by John Scott Russel and Heisenberg's question of how countable particles can appear in continuous fields, I will give an elementary overview of the field, introduce the core objects and the primary interactions, discuss their nonlinear behavior which can be useful for neuromorphic spintronics, discuss their electric detection and magnetic hopfions, a new type of solitonic structure in three dimensions shaped as bounded knots, and their recent discovery stabilized by a skyrmion filament.

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Plenary Talk PLV VII Wed 14:00 H2

Variance sum rule for dissipative systems — •Felix Ritort — Small Biosystems Lab, Condensed Matter Physics Department, University of Barcelona, C/ Marti i Franques, 1, 08028 Barcelona (Spain)

Nonequilibrium pervades nature, from the expanding universe to climate dynamics, living cells, and molecular machines. Key to nonequilibrium states is the entropy production rate σ at which energy is dissipated to the environment. Despite its importance, σ remains challenging to measure, especially in nanoscale systems with limited access to microscopic variables. I present a recently introduced variance sum rule for displacement and force variances that permits measuring σ by constraining energetics through modeling [1,2]. We apply it to measure the first heat map of human red blood cells in experiments with laser optical tweezers and ultrafast life-imaging microscopy. The variance sum rule sets a new resource for energy inference in nonequilibrium systems [3], from measuring entropy production in active and living matter to identifying hidden sources of energy and dissipation.

[1] Di Terlizzi, I., Gironella, M., Herráez-Aguilar, D., Betz, T., Monroy, F., Baiesi, M., & Ritort, F. (2024). Variance sum rule for entropy production. Science, 383(6686), 971-976. [2] Di Terlizzi, I., Baiesi, M., & Ritort, F. (2024). Variance sum rule: proofs and solvable models. New Journal of Physics, 26, 063013. [3] Roldán, É. (2024). Thermodynamic probes of life. Science, 383(6686), 952-953.

Plenary Talk PLV VIII Thu 8:30 H1

Learning how biomolecules move and undergo chemical reactions — •Frauke Gräter — Max Planck Institute for Polymer Research, Mainz, Germany

Life is biochemistry in action. While molecular simulations of systems as complex as whole cells are now within reach, predicting chemical reactivity on relevant time and length scales remains a challenge. I will present our recent work towards bringing action * here: chemistry * to classical atomistic simulations and molecular design through machine learning.

We substitute costly quantum mechanical calculations with a graph neural network-based emulator which predicts reaction rates without explicitly modelling the reaction. To deal with the chemistries arising from the such reactions, we have developed a framework to parametrize a classical force field. GRAPPA leverages graph attention, is highly accurate, and can be easily fine-tuned. Our ML-based simulations can predict cascades of chemical reactions amidst the 'jiggling and wiggling' of biomolecules at an efficiency close to classical simulations.

Finally, I will demonstrate how we harness a flow-matching model based on geometric algebra and trained on Molecular Dynamics simulations to design novel proteins with tailored flexibilities. Our method generates conformational ensembles of unseen proteins without the need to run costly Molecular Dynamics simulations, and paves the way for generating novel proteins with biochemical functions that rely on molecular motions.

Plenary Talk PLV IX Thu 14:00 H1

Tunable Ultrafast Dynamics of Antiferromagnetic Vortices in Nanoscale Dots — •Jelena Klinovaja[1], Ji Zho[1], Even Thingstad[1], Se Kwon Kim[2], and Daniel Loss[1] — [1]Department of Physics University of Basel Klingelbergstrasse 82 4056 Basel, Switzerland — [2]Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 34141, Republic of Korea

Topological vortex textures in magnetic disks have garnered great attention due to their interesting physics and diverse applications. However, up to now, the vortex state has mainly been studied in microsize ferromagnetic disks, which have oscillation frequencies confined to the GHz range. We propose an experimentally feasible ultrasmall and ultrafast vortex state in an antiferromagnetic nanodot surrounded by a heavy metal, which is further harnessed to construct a highly tunable vortex network. We theoretically demonstrate that, interestingly, the interfacial Dzyaloshinskii-Moriya interaction (iDMI) induced by the heavy metal at the boundary of the dot acts as an effective chemical potential for the vortices in the interior. Mimicking the creation of a superfluid vortex by rotation, we show that a magnetic vortex state can be stabilized by this iDMI. Subjecting the system to an electric current can trigger vortex oscillations via spin-transfer torque, which reside in the THz regime and can be further modulated by external magnetic fields. Coherent coupling between vortices in different nanodisks can be achieved via an antiferromagnetic link. Remarkably, this interaction depends on the vortex polarity and topological charge and is also exceptionally tunable through the vortex resonance frequency.

Plenary Talk PLV X Thu 14:00 H2

Process-directed formation of nonequilibrium structures in copolymer materials — •Marcus Müller — Georg-August-Universität, Göttingen, Germany

Macromolecular systems often become trapped in metastable structures rather than reaching true equilibrium, offering opportunities to fabricate structures with unique properties. Process-directed structure formation refers to reproducibly trapping the kinetics of structure transformation into a desired (meta)stable target structure after a quench of the thermodynamic state, such as solvent evaporation or light-stimulated chemical conversions. This strategy leverages several unique advantages of copolymer systems, including a comprehensive knowledge of equilibrium properties and a clear separation of timescales between the quench of thermodynamic variables, the system's spontaneous relaxation toward the nearest metastable structure, and its thermally activated escape toward equilibrium. Both highly coarse-grained particle-based and continuum models will be discussed, highlighting challenges for quantitatively predicting copolymer material processing at the molecular scale.

Plenary Talk PLV XI Fri 8:30 H1

Exploring correlated phases and topology in van der Waals platforms — •Roser Valenti — Institute of Theoretical Physics, Goethe University Frankfurt

In recent years a plethora of new correlated states have been observed by stacking, twisting and straining two dimensional van der Waals materials of different kind. Some prominent examples are twisted bilayer graphene, bilayer heterostructures of graphene with the spin-orbit assisted Mott insulator α-RuCl3 -a candidate for Kitaev spin physics-, or bilayer heterostructures of the Mott insulator 1T-TaS2 with the metal 1H-TaS2. Unique to these bilayer structures is the possible emergence of phases not foreseable from the single layers alone, such as heavy fermions, Kondo insulators, quantum spin liquids, correlated metals, or topological superconductors.

In this talk I will discuss the microscopic modelling of such heterostructures by a combination of first-principles calculations, effective-model considerations, many-body techniques and statistical/ machine learning methods and will present exemplary cases on the emerging correlated electronic and magnetic properties[1-5] and will compare with experimental results.

[1] Rai et al. PRX 14, 031045 (2024)
[2] Crippa et al. Nature Communications 15, 1357 (2024)
[3] Akram et al. Nano Letters 24, 890 (2024)
[4] Hu et al. PRL 131, 166501 (2023)
[5] Yang et al. Nature Materials 22, 50 (2023)