DY 24: Focus Session: Broken Symmetries in Statistical Physics - Dynamics of Odd Systems

In recent years, the effect of broken microscopic symmetries on emergent mesoscopic and macroscopic behavior has gained significant attention in non-equilibrium statistical physics. For example, breaking Newton's third law leads to so-called "non-reciprocal interactions" among species and gives rise to odd transport coefficients. These are primarily investigated in active systems. However, even with Newton's third law valid, odd transport can emerge, and even in equilibrium systems. In both cases, many novel phenomena have been reported over the last years, such as asymmetric clustering, oscillatory phase behavior, crowding-enhanced diffusion in in- and out-of-equilibrium systems, as well as off-diagonal correlation functions, topologically protected edge flows, and many more. With this symposium, we bring together the communities working on odd transport systems in the context of (non)equilibrium statistical physics, to stimulate discussions about the physical background and implications of such broken symmetries in transport-related phenomena.

Organized by Erik Kalz (Potsdam), Ralf Metzler (Potsdam), and Abhinav Sharma (Augsburg)

Time: Wednesday 15:00–18:30 Location: H43

Invited Talk DY 24.1 Wed 15:00 H43

Dynamics of odd and chiral active systems — •Hartmut Löwen — Heinrich-Heine-Universität Düsseldorf

After a brief introduction into "odd" systems characterized by odd viscosity, odd elasticity or odd diffusivity, we focus on *odd diffusive dynamics*. For normal diffusive systems, repulsive interactions typically reduce the dynamics as signalled by a reduction of the long-time self-diffusion coefficient. Contrarily, in odd-diffusive systems, collisions can enhance the self-diffusion due to a mutual rolling effect. We further address *active chiral particles* which break the discrete left-right symmetry in their motion. Examples include spinners, circle swimmers and particles moving on helical trajectories. We explore phase separation, glassy dynamics as well as crystallization and polymerisation in these chiral systems. New phenomena absent for achiral objects are observed including active surfactants, rotating crystallites, self-wrapping of chiral polymers and a hammering effect in supercooled fluids. Also the realization of such odd systems in granular or colloidal experiments is discussed.

DY 24.2 Wed 15:30 H43

A route from force to velocity autocorrelation in overdamped odd dynamic and its applications to the study of diffusion — Filippo Faedi and •Abhinav Sharma — University of Augsburg, Augsburg, Germany

In this work we present a derivation of the relation between the velocity and force autocorrelation in over-damped dynamic starting from the underdamped Langevin equation. Time reversal symmetries are used to simplify the noise force autocorrelation and this procedure can be applied both in the presence and in the absence of magnetic field. Thanks to these relation we can prove that off diagonal element of the force autocorrelation matrix contribute to the self diffusion coefficient in the presence of a magnetic field. In addition the result is applied to study the dynamics of two odd dimers with same and opposite charges.

DY 24.3 Wed 15:45 H43

A model collective system made of spinning micro-disks: from fundamentals to microrobot swarms — •Gaurav Gardi — Max Planck Institute fort Intelligent Systems, Stuttgart, Germany

Collective systems such as bird flocks and fish schools in nature and colloidal and robotic artificial collectives, display order in their spatiotemporal patterns. Although they are inherently out-of-equilibrium systems, the order in their patterns may share similarities with well-understood phases of matter in equilibrium and thus may be characterized by similar metrics. These phases also contain information, which is embedded in their spatiotemporal structures and can be quantified by information entropy. Although order and information are connected fundamentally in thermodynamics, their relation in collective systems is seldom explored. Here we combine the approaches of statistical mechanics and information sciences to demonstrate the order and the information in the phases of a two-dimensional (2D) small-scale robotic collective system consisting of hundreds of spinning micro-disks at the air-water interface. We design and control the balances of local interaction forces between micro-disks so that distinct globally ordered phases emerge. We relate the order and information in the global phases using concepts from statistical physics and information theory. Lastly, we design experiments to demonstrate the diverse self-organised behaviours of our system and its ability to transition to non-reciprocal regime. Overall, this talk highlights our system's capability to act as an adaptable and versatile model system for dynamic self-organisation and for development of versatile microrobot collectives.

DY 24.4 Wed 16:00 H43

Active pattern formation emergent from single-species nonreciprocity — Zhi-Feng Huang[1], •Michael te Vrugt[2], Jonas Mayer Martins[3], Raphael Wittkowski[3,4], and Hartmut Löwen[5] — [1]Department of Physics and Astronomy, Wayne State University, Detroit, Michigan 48201, USA — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany — [3]Institut für Theoretische Physik, Universität Münster, 48149 Münster, Germany — [4]Center for Soft Nanoscience, Universität Münster, 48149 Münster, Germany — [5]Institut für Theoretische Physik II: Weiche Materie, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany

Nonreciprocal interactions violating Newton's third law are common in a plethora of nonequilibrium situations ranging from predator-prey systems to the swarming of birds and effective colloidal interactions under flow. Here (arXiv:2404.10093), we systematically derive a field theory for the basic case of a single-component system breaking the *actio* and *reactio* equality of force within the same species from the microscopic particle dynamics, leading to a generic continuum model termed *Active Model N*. One particular new characteristic pattern found in this model is an interwoven self-knitting "yarn" structure with a unique feature of simultaneous development of micro- and bulk phase separations. The growth dynamics of a "ball-of-wool" active droplet towards these self-knitted yarn or branched states exhibits a crossover between different scaling behaviors.

DY 24.5 Wed 16:15 H43

Dance of odd-diffusive particles: A Fourier approach — •Amelie Langer[1], Abhinav Sharma[2,3], Ralf Metzler[4], and Erik Kalz[4] — [1]University of Heidelberg — [2]University of Augsburg — [3]IPF Dresden — [4]University of Potsdam

Odd-diffusive systems are characterized by transverse responses and exhibit unconventional behaviors in interacting systems. To address the dynamical interparticle rearrangements in a minimal system, we here exactly solve the problem of two hard disklike interacting odd-diffusing particles. We calculate the probability density function (PDF) of the interacting particles in the Fourier-Laplace domain and find that oddness rotates all modes except the zeroth, resembling a mutual rolling of interacting odd particles. We show that only the first Fourier mode of the PDF, the polarization, enters the calculation of the force autocorrelation function (FACF) for generic systems with central-force interactions. An analysis of the polarization as a function of time reveals that the relative rotation angle between interacting particles overshoots before relaxation, thereby rationalizing the recently observed oscillating FACF in odd-diffusive systems. — [Langer et al., Phys. Rev. Res. 6, 043036 (2024)]

DY 24.6 Wed 16:30 H43

Odd mobility in interacting particle systems — •Erik Kalz[1], Shashank Ravichandir[2], Johannes Birkenmeier[1], Ralf Metzler[1], and Abhinav Sharma[2,3] — [1]University of Potsdam —

[2]IPF, Dresden — [3]University of Augsburg

Colloidal mobility characterises the response of an overdamped particle to an external drift. We present a many-body theory where the diffusion of particles is modelled in the presence of interactions with other colloids. A tracer particle therefore can respond to its own applied force as well as to the external drift of the host particles, an effect transferred via particle-particle interactions. We examine these direct and transferred mobilities in the context of odd systems and show that they display qualitatively different behaviours. Odd systems are characterized by a transverse — Hall-like response which occurs in addition to the ordinary, parallel response. We show that both components, the parallel and transverse are drastically altered by particle-particle interactions up to a complete reversal for each component. Our findings are validated by Brownian dynamics simulations.

Invited Talk DY 24.7 Wed 16:45 H43

Odd dynamics and universal flows of passive objects in a chiral active fluid — •Cory Hargus[1], Federico Ghimenti[1,2], Julien Tailleur[1,3], and Frédéric van Wijland[1] — [1]Laboratoire Matière et Systèmes Complexes (MSC), Université Paris Cité & CNRS (UMR 7057), 75013 Paris, France — [2]Department of Applied Physics, Stanford University, 348 Via Pueblo, Stanford, CA 94305, United States of America — [3]Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, United States of America

A passive object submerged in a chiral active fluid is imbued with odd diffusivity, odd mobility, and rotational ratchet motion. We show how these different effects are interrelated, obtaining a Langevin equation for a sufficiently heavy object, and how they are determined by the symmetry properties of the object, as well as its size and mass. Finally, spontaneous flows of the chiral active fluid around the object are understood through a multipole expansion, and connected through odd diffusion to equations of state involving only bulk fluid properties.

DY 24.8 Wed 17:15 H43

Vortex formation and odd viscosity in a chiral active fluid — •Joscha Mecke[1,2], Yongxiang Gao[1], Gerhard Gompper[2], and Marisol Ripoll[2] — [1]Institute for Advanced Study, Shenzhen University, Shenzhen, PR China — [2]Institute of Advanced Simulation, Forschungszentrum Jülich, Germany

Materials consisting of active particles with an intrinsic rotation can be considered as chiral active matter. We study a colloidal chiral active system, consisting of magnetic microrotors of diameter 0.8 μm in an externally applied rotating magnetic field. The stabilised colloids synchronously rotate with the rotating field and solely interact via steric and hydrodynamic interactions, granting odd and active stresses already at low densities and large colloidal separations. We address the system by means of experiments as well as particle based hydrodynamics simulations (MPC) of the active colloidal suspension. The rotors' transverse, anti-symmetric, and non-reciprocal interactions lead to a pair-rotation about the centre of mass and subsequently to the formation of multiscale vortices. Energy is injected on the particle level and is transported to the largest scales in the system, unless it is dissipated at a hydrodynamic damping length, a process reminiscent of turbulence, even in the absence of dominant inertial contributions. The rich phenomenology of our system additionally includes odd diffusion and enhancement of effective diffusive transport by the introduction of obstruction, directed transport by virtue of symmetry breaking at confining walls, and correlations between vorticity and density which allow for a measurement of the system's odd viscosity.

DY 24.9 Wed 17:30 H43

Chirotactic response of microswimmers in 3D chiral active fluids with odd viscosity — •Yuto Hosaka[1], Michalis Chatzittofi[1], Ramin Golestanian[1,2], and Andrej Vilfan[1,3] — [1]Max Planck Institute for Dynamics and Self-Organization (MPIDS), 37077 Göttingen, Germany — [2]Rudolf Peierls Centre for Theoretical Physics, University of Oxford, Oxford OX1 3PU, United Kingdom — [3]Jožef Stefan Institute, 1000 Ljubljana, Slovenia

Odd viscosity is a property of chiral active fluids with broken time-reversal and parity symmetries. We show that the flow of such a fluid around a rotating axisymmetric body is exactly solvable [1]. Using this solution and the generalized Lorentz reciprocal theorem [2], we determine the orientational dynamics of microswimmers with an arbitrary surface slip velocity. Swimmers with a force-dipole moment exhibit precession around the axis of the odd viscosity. In addition, pushers show *bimodal chirotaxis*, i.e., alignment parallel or antiparallel to the axis, while pullers orbit in a plane perpendicular to it. A chiral swimmer that itself has a broken parity symmetry can exhibit *unimodal chirotaxis* and always align in the same direction. Since the chirotactic response of microswimmers is prohibited in 2D fluids, our theoretical results highlight the critical role of three-dimensionality in transport phenomena in chiral active fluids.

[1] Y. Hosaka, M. Chatzittofi, R. Golestanian, and A. Vilfan, Phys. Rev. Research **6**, L032044 (2024).

[2] Y. Hosaka, R. Golestanian, and A. Vilfan, Phys. Rev. Lett. **131**, 178303 (2023).

DY 24.10 Wed 17:45 H43

Chirality and symmetry breaking in Dictyostelium Discoideum: Probing odd dynamics in cellular behavior — •Fereydoon Taheri — IMSEAM, Heidelberg University, Heidelberg, Germany

The interplay between chirality and symmetry breaking is a fundamental aspect of many biological systems, and Dictyostelium discoideum offers a unique model to explore these phenomena. This bacteria-guzzling amoeba that lives in soil, serves as a powerful model organism for studying fundamental cellular processes such as cell-cell signalling, collective movement, and self-organization in multicellular complexes. In this study, we present an in-depth investigation into the motility patterns of D. discoideum, with a focus on the inherent chirality observed during intercellular interactions. By analyzing the off-diagonal components of the diffusion tensor, we connect this chirality to asymmetries in the velocity correlation function. These off-diagonal terms capture the coupling between orthogonal velocity components, providing a quantitative measure of non-reciprocal motion and breaking of time-reversal symmetry. Our analysis reveals that these contributions are directly linked to chiral trajectories and it is not merely a byproduct of individual behavior but plays a functional role in mediating the efficiency and directionality of cell-cell communication influencing both individual and collective behaviors during aggregation and morphogenesis.

Invited Talk DY 24.11 Wed 18:00 H43

How to model frictional contacts in sheared and active colloids — •Friederike Schmid[1], Kay Hofmann[1], Kay-Robert Dormann[2], and Benno Liebchen[2] — [1]Johannes Gutenberg Universität Mainz — [2]Technische Universität Darmstadt

In simulations of colloidal matter, frictional contacts between particles are often neglected. For spherical colloids, such an approximation may have a significant impact on the results in certain situations (e.g., colloids under shear, chiral active matter), since frictional contacts induce a coupling between translational and orientational degrees of freedoms of particles which is otherwise absent. Models for implementing frictional contacts have been proposed in the granular matter community. Owing to the large size of granular particles, these models do not include thermal noise. On the colloidal scale, thermal fluctuations are important and should be incorporated in a thermodynamically consistent manner.

In the present talk, we show how to derive the correct fluctuation-dissipation relation for frictional contacts with arbitrary - linear or nonlinear - relation between the friction force and the relative velocity at the contact point, and how to implement the corresponding stochastic force terms. Among other this results in a new generalized class of dissipative particle dynamics (DPD) thermostats with rotation-translation coupling. Possible effects of frictional contact interactions are demonstrated using the example of Poiseuille flow and motility induced phase separation in active Langevin particles.