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Editorial: Classical Statistical Mechanics Using Confined Brownian Particles

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Editorial on the Research Topic

Classical Statistical Mechanics Using Confined Brownian Particles

The understanding of statistical physics at the mesoscopic scale inside fluidic environments is crucial—most importantly since the processes which determine the functioning of life itself work at this scale in similar environments. Studying such processes under controlled conditions in the laboratory are thus the starting point in tackling more complex problems involving actual mechanisms which generate life.

The advent of micro-particle confinement techniques using optical, electric or magnetic fields has enabled diverse research in this area employing single or multiple particles confined in well-calibrated force fields. In addition, the ability to introduce external forces facilitate scenarios where particles may be in equilibrium or even out of equilibrium with the fluidic environment, so that tenets of both equilibrium or non-equilibrium statistical mechanics may be tested, and existing theories may even need to be extended to understand experimental results. The problems become even more fascinating when particles that are "active", or tailored to move spontaneously due to the influence of their environment, are brought into the picture. With regard to this, a very exciting area of contemporary research is in the study of the so-called "hot" Brownian motion—the extraordinary Brownian motion displayed by active particles under non-equilibrium conditions produced by a temperature gradient in the environment, or due to energy supplied to the system externally. The presence of interactions between particles, as well as that between the particle(s) and the fluid also lead to really complex physics and may thus simulate a variety of life processes. In addition, recent efforts have also been successful in extracting work out of such trapped mesoscopic particles—facilitating the construction of Brownian engines that already have had enormous impact in terms of driving new research as well as identifying feasible and wide-ranging applications. Indeed, advanced microfabrication techniques and clever experimental designs to create nanorobots and optimize their capability of performing work have increased the scope of applications even further.

All these studies can only be facilitated by advanced experimental techniques, in which there has been tremendous progress with the advent of advanced techniques including high speed electronics, and innovative detection and data analysis methods which enable the application of large trapping forces as well as very precise detection of particle dynamics to even picometer scales. Such techniques have understandably ushered a new domain in addressing fundamental science questions, while also stretching the limits and capabilities of particle confinement, and careful calibration of both the particle and its environment.

Our research topic "Classical Statistical Mechanics Using Confined Brownian Particles" presents a set of eight papers that provide an excellent overview of present state-of-the-art research—including theoretical, numerical, and experimental studies—on several of the areas mentioned above. In

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accordance with current trends in overall research in this area—the maximum number of research papers in our research topic are also written around active particles and the statistics connected to their dynamics. Thus, Dabelow and Eichhorn provide explicit theoretical expressions for connecting the irreversibility of the trajectories of active particles—which are driven by the fluctuating non-equilibrium Ornstein-Uhlenbeck force—with the particle positions in terms of the difference in forward and backward path probability ratios. Auschra et al. investigate coarse-grained simulation models of self-thermophoretic microswimmers suspended in a fluid, and verify the coarse-grained description of the fluid in terms of a local molecular temperature field, and its role for the particle's thermophoretic self-propulsion and hot Brownian motion. Moving on to experiments with active particles, Kumar et al. describe their work on optically trapping upconverting nanoparticles (NaYF4:Yb,Er), and report signatures of hot Brownian motion in the axial fluctuations of the particles when they are trapped using light at a wavelength corresponding to their absorption maxima . Patil and Ghosh—in their brief research report—share their experimental results on helical shaped, magnetically actuated, reciprocal swimmers, where they show for the first time results at high activity levels where the degree of randomness in the reciprocal sequence—which plays an important role in determining the effective motility of the swimmers—is further affected by the presence of a surface, which in turn results in a non-monotonic increase of motility as a function of magnetic drive . Finally, Su et al. describe their quest to measure the effective temperature of Hot Brownian Motion in the ballistic regime by constructing an optical setup that can measure such motion of a single optically trapped and heated colloidal mcroparticle in water with very high temporal and spatial resolution.

The rest of the collection provides a glimpse of the diversity of the research in this area—with each paper addressing entirely different questions. In this, Armstrong et al. measure the swimming force of individual *E. coli* bacteria in solutions of varying viscosity, and by using probe-free force measurements, are able to quantitatively validate and compare the classic Resistive Force theory—which gives a robust description of the swimming speed of a cell—and certain proposed modifications to the theory that explain experimental observations more accurately. Chetrite et al. demonstrate that the metastable Mpemba effect (the Mpemba effect referring to systems whose thermal relaxation time is a non-monotonic function of the initial temperature) for a colloidal particle immersed in water arises from a non-monotonic temperature dependence of the maximum amount of work that can be extracted from the local-equilibrium state at the end of a fast relaxation to local equilibrium. Lastly, Mortensen et al.tackle an important issue in video microscopy-based calibration of diffusing particles in a fluid, namely that of motion blur—and provide explicit and exact expressions for the variance of measured positions and the mean-squared displacement of a Brownian particle confined in various geometries—the expressions being valid for all exposure times of the camera.

It is our hope that the scientific community—consisting both of specialists in the field and general practitioners—will find these articles timely and engrossing, and perhaps eke out new ideas and directions for exciting new research from them. Our effort in compiling this issue will then stand vindicated.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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