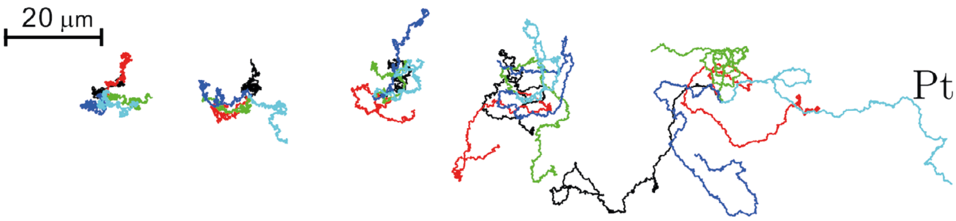
# Colloidal active matter – DOI: 10.1051/epn/2024303

**In the last two decades, significant research progress has been made in artificially equipping colloidal particles with their own drive ("motor"). They are then called active particles. In this case, a single active colloid typically moves much faster and more dynamically than a passive one, which follows purely diffusive Brownian motion. Typical particle trajectories are shown in Figure 1.**

On average, a self-propelled particle moves ballistically at a constant speed. An active particle thus constantly converts energy into mechanical motion and is damped by the solvent. These irreversible processes permanently generate entropy, the hallmark of non-equilibrium. Only on large time scales does the movement become diffusive again, but with a much larger diffusion coefficient. The motion of an active colloid is also called a persistent random walk, analogous to a walker who remembers his previous direction of movement and mainly continues in the same direction, and its dynamic behaviour is also referred to as active Brownian motion.

Whenever such self-propelled particles with an internal degree of freedom are involved, the resulting system is generally referred to as active matter. This term is also used for macroscopic objects such as robots, while the term colloidal active matter is used for mesoscopic particles including living systems such as microbes, bacteria, sperm, *etc.*

At this point we can give a few examples of artificially imprinted self-propulsion. Firstly, a particle can move by periodically moving limbs. A human swimmer does this by swinging his arms and legs. He also utilises inertia, but on the micrometre scale this becomes increasingly difficult. There is a scallop theorem, which states that in viscous fluids one can only move forwards if one uses a movement pattern that cannot be mirrored in time. This is why many bacteria rotate a flagellar helix, because the sense of rotation makes the movement irreversible in time. Recently, however, there have also been many other mechanisms that manage without mechanical movement. One important mechanism is that the particle itself generates a gradient of some physical variable (temperature, concentration of an additive, *etc.*) and then moves by itself within this gradient. This phenomenon is also known as self-phoresis.




▲ Typical trajectories of self-propelled colloids in two spatial dimensions for increasing activities (from left to right). © https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.99.048102

An important example of self-phoresis is a solvent enriched with hydrogen peroxide. Hydrogen peroxide decomposes into water and oxygen. If you use a colloidal "Janus particle" with two different substances (such as a plastic particle with a metal cap), the decomposition reaction is catalysed by the metal. This creates a gradient of hydrogen peroxide concentration in which the particle itself moves. Besides this diffusiophoresis also thermo- or electrophoresis are utilised. The activity can also be generated by external fields: a key example of this are so-called Quincke rollers: non-conducting particles that start to rotate under the influence of an oscillating electric field, in random directions perpendicular to the field. In large ensembles, such rotating microspheres can form an ordered stream of particles due to collisions and hydrodynamic interactions. Also magnetic fields can also be used to set (anisotropic) particles in motion in random directions.

In all the systems mentioned, the activity already drives the individual constituents out of equilibrium, as can be seen from the non-time-reversible movements - and thus detailed balance ubiquitous in passive systems is violated. Further fascinating properties emerge when large ensembles of interacting active particles are considered. Characteristics of the collective behaviour of such active many-particle systems are manifold and range from motility-induced phase separation, to polar flocking and active turbulence.

The EPL Focus Issue on Statistical Physics of Self-Propelled Colloids published in October 2023 summarizes current research on various aspects of single and collective dynamics of self-propelled colloidal particles. ■

## References


[1] Hartmut Löwen, Sabine Klapp and Holger Stark, *EPL 144* 17001 (2023), https://iopscience.iop.org/article/10.1209/0295-5075/acfbae

[2] EPL Focus Issue on Statistical Physics of Self-Propelled Colloids, https://iopscience.iop.org/collections/epl-230203-116