Active Brownian motion of a self-propelled particle with rotational inertia

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Self-propelled colloids, active polymers and membranes, driven (vibrated) granular layers and hybrid synthetic-biological systems are striking examples of systems containing synthetic active Brownian particles. Such particles autonomously convert the available energy of the environment into their own directed mechanical motion. In most studies the self-propelled Brownian particles move in overdamped regime. However, there is a variety of situations in which the overdamped approximation is not justified, for instance, when self-propelled particles move in a low-viscosity medium or when their rotational diffusivity is enhanced by internal active processes or external control. Recently, experiments with the self-propelled particles in a low-pressure gas and weakly ionized gas-discharge plasma have appeared. A distinctive feature of such media is an extremely low viscosity at which the inertial effects play a significant role, resulting in underdamped Brownian motion. At present, there is a gap in the theory in the field where rotational inertia significantly affects the random walk of active particles at all time scales.

In this study, we describe the two-dimensional motion of a self-propelled particle in a harmonic trap. We take into account both translational and rotational inertia and velocity fluctuations. General analytical equations for the mean kinetic energy and mass transfer function of a self-propelled Brownian particle are presented. The proposed theory is confirmed by numerical simulations in a wide range of medium viscosity.

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