Collective behaviour of energy depot repulsive particles

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In this work we consider an active particle model, that reproduces the motion of microscopic biological objects, such as cells or bacteria, that is described with Langevin dynamics. The particles are able to take energy from their environment, store it into an internal energy depot and convert it into kinetic energy [1]. This model uses a velocity dependant friction function [2]. We have studied a two dimensional suspension of repulsive particles, where the interaction between the particles is implemented with a WCA potential.

$$\dot{\mathbf{v}} = -\gamma(\mathbf{v})\mathbf{v} - \frac{1}{m}\boldsymbol{\nabla}U(\mathbf{r}) + \mathcal{F}(t) \ , \qquad (1)$$

$$\gamma(\mathbf{v}) = \gamma_0 - \frac{q_0 d_2}{c + d_2\mathbf{v}^2}. \qquad (2)$$

The parameters q_0, d_2 and c express the properties of the energy depot. The pump rate of energy from the environment into the internal depot is q_0. d_2 is The rate of conversion of the internal depot energy to the particles kinetic energy, this implies that the particle is self propelling. c represents the internal dissipation, which takes into account the energy loss due to intern dissipative processes. In our study we fix the parameters d_2, and c, and we study the effect of different q_0 values.

The friction function will cancel at some velocity v_0, $\mathbf{v}_0^2 = \frac{q_0}{\gamma_0} - \frac{c}{d_2}$, this imposes two regimes onto the system; when $\mathbf{v} > \mathbf{v}_0$ the friction will be positive and the motion is damped. When $\mathbf{v} < \mathbf{v}_0$ we have negative friction, meaning that the motion of the slow particles is pumped as if the particles had an additional source of energy.

We have studied both dynamical and structural features of the system. So far we have studied the diffusion through the mean squared displacement, finding different regimes as we increase q_0 (Fig. 1). The main studied structural feature is a phase transition between an ordered an a disordered state for different volume fractions φ and values of q_0 (Fig. 2).

The interest of this model comes from the fact that its able to mimic several properties of the biological microscopic matter, as self propulsion, colective motion or out of equilibrium phase transitions. The interest in the model comes from the difference from other models such as Vicsek's or Active Brownian Particles, that address self-propulsion as a random process, while here the friction is the cause of this phenomenon.

[1] Schweitzer, F., Ebeling, W., & Tilch, B. (1998). Complex motion of Brownian particles with energy depots. Physical Review Letters, 80(23), 5044.

[2] Erdmann, U., Ebeling, W., Schimansky-Geier, L., & Schweitzer, F. (2000). Brownian particles far from equilibrium. The European Physical Journal B-Condensed Matter and Complex Systems, 15(1), 105-113.

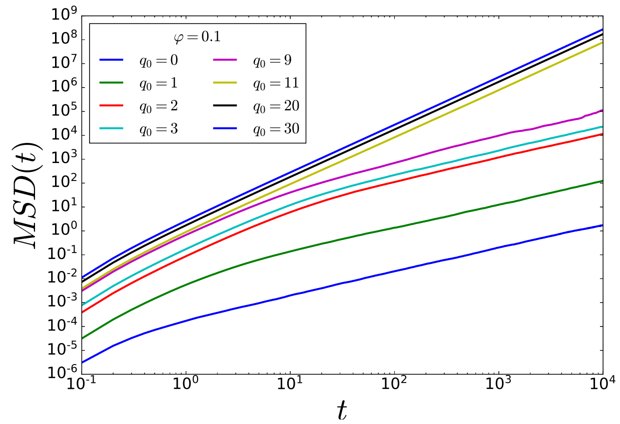

Fig. 1. Mean squared displacement over time for different systems of $\varphi = 0.1$ and different values of q_0.

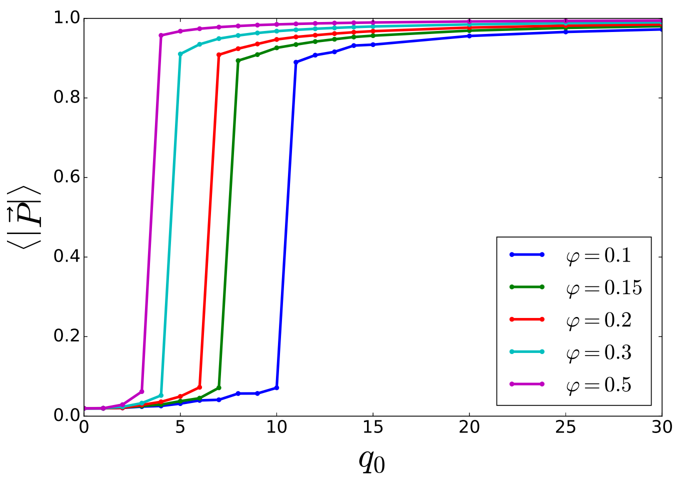

Fig. 2. a) Mean polar order parameter as a function of q_0 parameter for the studied volume fractions φ.