Swimming modes & interactions of anisotropic active colloids

Riedel, S.M.I.

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Summary

This summary is intended for a general audience, and no scientific background is assumed. Readers interested in a more detailed scientific context and description are referred to the introduction of this thesis in **Chapter 1***.*

This thesis (titled: *Swimming Modes & Interactions of Anisotropic Active Colloids*) presents our new insights into how curved microscopic particles move and interact with each other. These particles belong to a class of colloidal systems known as microswimmers: microscopic objects that can propel themselves through a liquid medium by converting energy from their surroundings into motion.

Our work is motivated by the observation that many self-propelled microscopic organisms in nature - such as bacteria, sperm cells, or certain algae - are not spherical (anisotropic). Instead, they often have elongated or curved shapes, which play an important role in determining how they swim and how they interact with each other and with their environment. One example is the malaria parasite, whose motile stage has a distinctive crescent shape that plays an important role in how it moves through host tissues during infection. Inspired by this morphology, this thesis focuses on the fabrication and study of artificial microswimmers with a similar curved, crescent-like geometry.

Experimentally, these particles were produced using high-resolution 3D microprinting. Self-propulsion was then achieved through local energy conversion: a catalytic reaction on the particle surface creates chemical gradients in the surrounding liquid, which drive the particle forward and enable it to swim autonomously.

In **Chapter 2**, we show that microswimmers shaped like curved rods begin to form clusters at much lower particle densities than spherical particles. We explore a full range of shapes, from straight rods to curved rods and round particles. Our analysis indicates that clustering is determined by a balance between the likelihood of particles "interlocking" and the stability of the clusters that form. Among the shapes studied, half-donut (180°

crescent-shaped) particles are the most efficient at clustering.
We also report for the first time that crescent-shaped particles can reverse their swimming direction at higher fuel concentrations. This surprising behavior significantly reduces their ability to form stable clusters.

In **Chapter 3**, we investigate why the particles reverse their swimming direction when the fuel concentration increases. We observe that this behavior occurs across a range of related particle shapes — including disks, donuts and crescents — as well as for different material compositions and sizes of anisotropic swimmers. These differences mainly shift the hydrogen peroxide concentration at which the reversal takes place. Our results show that the swimming direction is determined by the interplay between the particle's shape and changes in its surface properties that occur when the pH of the solution varies. With our experimental findings we directly confirm predictions that had previously been based only on computer simulations.

In **Chapter 4** we again study interactions between non-spherical microswimmers, this time focusing on a "lock-and-key" type interactions between two self-propelled particles: a crescent-shaped particle (the "lock") and different types of partner particles (the "keys"). In this clustering process, when two particles come together, they can form a pair, but that pair can also break apart again. Because of this constant forming and breaking, we describe the process using an idea from chemistry called "chemical equilibrium". To quantify this behavior, we now compare how often pairs form with how often they separate and summarize this balance with a single constant. Our results show that the shape of the key particle strongly affects the overall lock-and-key clustering and thereby can provide insight into the stability of individual pairs. Understanding how to control the pair breakup time is important for systems made of several different types of particles. In such systems, particles can bind to the wrong partner, so mechanisms that allow incorrect pairs to break apart — similar to error-correction — are crucial.

In summary, by examining how curved microswimmers move and form clusters with each other and with differently shaped particles, this work sheds new light on how the shape of a self-propelled unit affects its motion as well as the interactions between particles at the microscopic scale.