Working towards programmable matter: Unexpected behavior discovered in active particles

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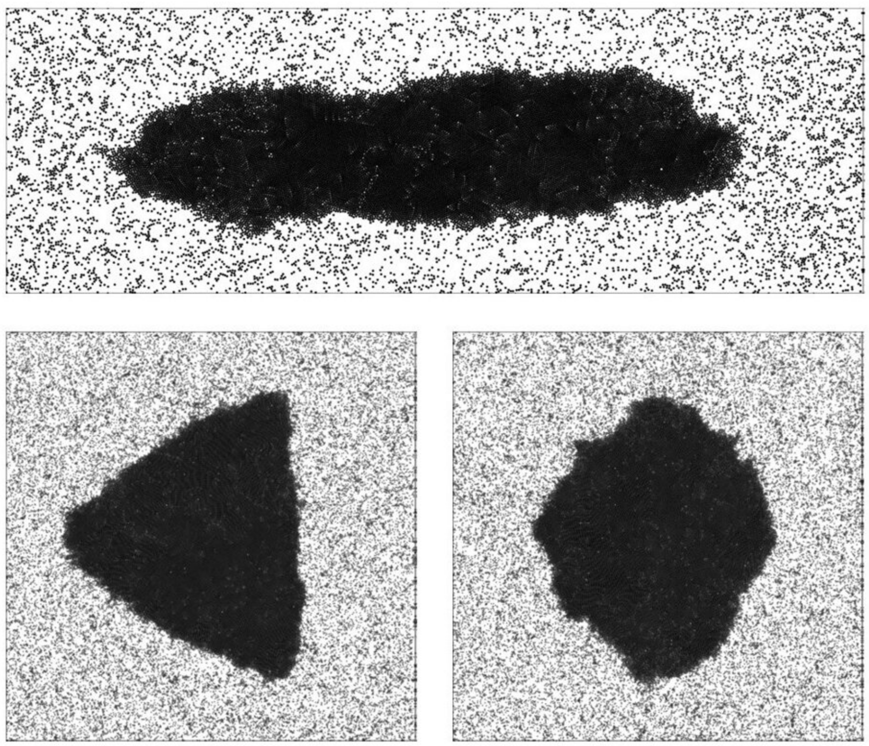

In the particles examined, the shape of the cluster depends on how strongly the orientation of the particles influences their propulsion speed. Credit: *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.131.168203

Investigating systems consisting of self-propelled particles—so-called active particles—is a rapidly growing area of research. In theoretical models for active particles, it is often assumed that the particles' swimming speed is always the same. This is not so, however, for particles produced in many experiments, for example for those propelled by ultrasound for medical applications. In these cases, the propulsion speed depends on the orientation.

How this dependency affects the behavior of systems consisting of many particles—in particular, how it affects the formation of clusters—is something which a team of physicists led by Prof. Raphael Wittkowski from the University of Münster (Germany) have now been the first to demonstrate in a collaborative project with Prof. Michael Cates from the University of Cambridge (United Kingdom/England).

Using a combination of computer simulations and theoretical derivations, they studied the behavior of systems consisting of many active particles whose speed depends on orientation, and in the process they discovered a series of new effects. The results of the study have been published in the journal *Physical Review Letters.*

What is interesting from a physics point of view is that systems consisting of many active particles can spontaneously form clusters—even when the individual particles do not attract one another at all. When measuring the movement of the particles in the simulations, the researchers came up with a particularly surprising result.

"Normally, on a statistical average, the particles in such clusters simply stay where they are," explains lead author Dr. Stephan Bröker from the Institute of Theoretical Physics at the University of Münster. "For that reason, we had expected that that would be the case here, too." In fact, however, the physicists discovered something else: The particles constantly move out of the cluster on the one side and move back in on the other, thus producing a permanent flow of particles.

There is also another difference from the "normal" case: the clusters which form in systems of active particles are normally circular. However, in the particles examined, the shape of the cluster depends on how strongly the orientation of the particles influences their propulsion speed—which can be stipulated by the experimentalist.

"Theoretically, at least, we can make the particles arrange themselves into any shape we want," explains co-lead author Dr. Jens Bickmann. "We can paint with them, so to speak." In the simulations the researchers observed ellipses, triangles and squares. "This gives the results a practical importance," says Dr. Michael te Vrugt from the Wittkowski team and a co-author of the study.

"For technical applications—for example, for the realization of programmable matter, it has to be possible to control the way the particles self-assemble—and with our approach that is indeed possible."

More information: Stephan Bröker et al, Orientation-Dependent Propulsion of Active Brownian Spheres: From Self-Advection to Programmable Cluster Shapes, *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.131.168203

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