

Diffusing wave paradox may be used to design micro-robotics

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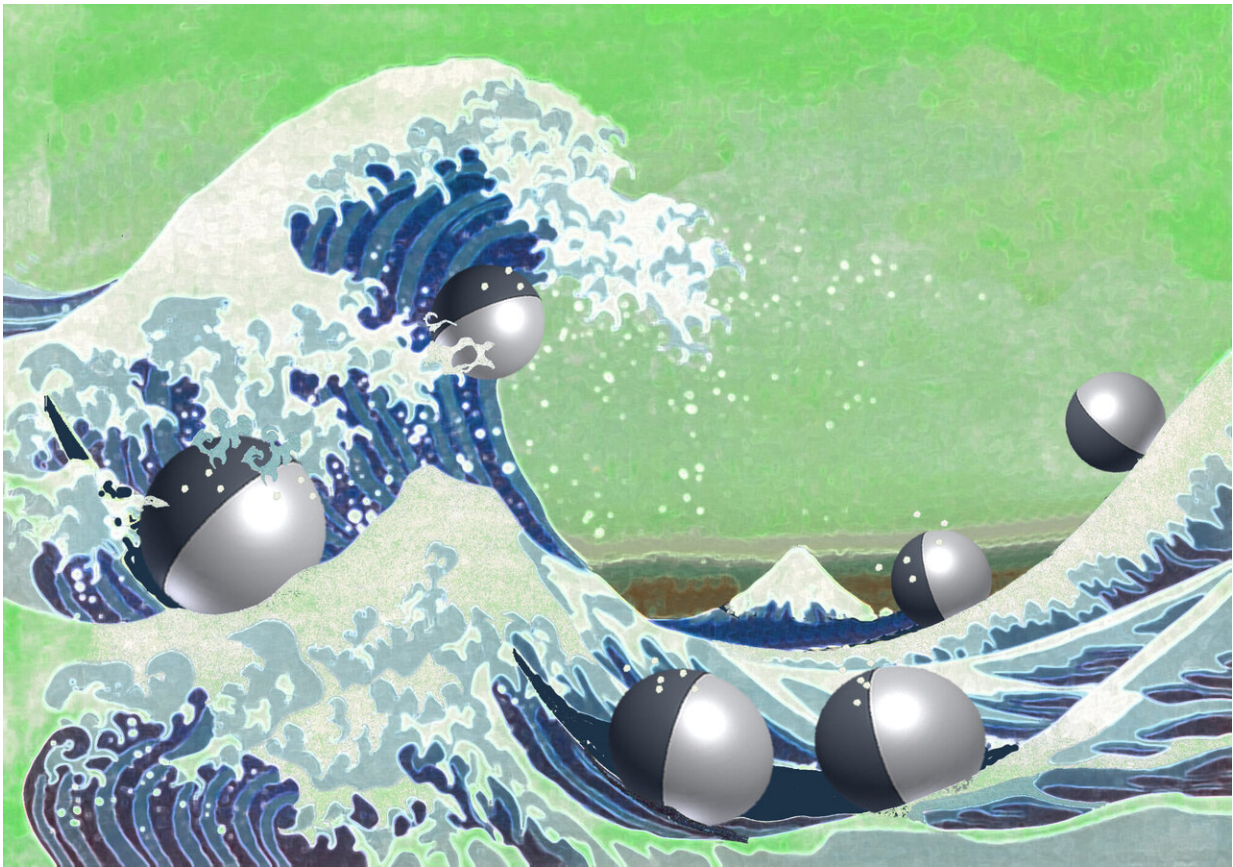


Illustration of the diffusing wave paradox, as exhibited by active particles that are half-coated by a carbon cap. Credit: Celia Lozano, University of Konstanz

Amoeba are unusual creatures that form when a dispersed population of cells spontaneously comes together and reorganizes itself into a

multicellular macroscopic organism. To do this, a few leader cells emit chemical pulses that cause the other individual cells to move in the direction opposite to that of the traveling pulses, leading to the formation of dense clusters.

The observation that the amoeba cells move counter to the traveling wave, which is called the "diffusing wave paradox," has puzzled researchers for a long time. This is because this movement differs from the amoeba's usual behavior when searching for food in a maze-like environment. In these scenarios, the chemical signals are static instead of pulsed, and the amoeba cells move toward the higher chemical concentrations.

The ability of the amoeba cells to sometimes move counter to a traveling chemical wave suggests that the cells possess some kind of memory. However, in a new study, Celia Lozano and Clemens Bechinger at the University of Konstanz, Germany, have demonstrated the same behavior in microparticles when illuminated by light pulses of varying speeds. As microparticles are memory-less, the behavior in this case must be explained by a mechanism that doesn't depend on memory.

"Despite having no brain, synthetic microswimmers are able to mimic some sophisticated behaviors of living organisms—in particular, their response to running pulses is similar (even though of very different origin)," Bechinger told *Phys.org*. "In view of future applications of microswimmers as autonomous microrobots, it will be important to coordinate and synchronize their behavior. The diffusing wave paradox can play an important role in this context."

Although numerical simulations have predicted that self-propelled microparticles called active particles are capable of moving both along and against a traveling pulse, the new study marks the first time that this behavior has been experimentally demonstrated.

In experiments, the researchers used [spherical particles](#) that are half-coated by a carbon cap and placed in a viscous liquid. When illuminated by light, the particles propel themselves forward with the cap in front. The researchers demonstrated that the active particles' movement in relation to a pulse depends on the speed of the pulse. At low pulse speeds, the particles have enough time to reorient themselves, if needed, so that their caps are facing in the same direction as that of the traveling pulses. This orientation ensures that the particles travel in the same direction as the pulses.

At high pulse speeds, on the other hand, the pulses come too quickly for the particles to reorient themselves before the next one comes. This is because the speed of the particles' rotation is limited by the friction of the viscous liquid. So if the particles' caps are initially facing the oncoming pulses, the particles will move counter to the direction of the traveling pulses, resembling the behavior of amoeba in the diffusing wave paradox.

This method opens the doors to a new kind of steering strategy to guide active particles in two possible directions. Currently, most steering strategies depend on topographical or static optical structures, which allow only for controlling particle movement in a single direction.

In addition to steering, the researchers also demonstrated that the new approach could be used for sorting active particles. As an example, they demonstrated that, since large particles can orient themselves faster than smaller ones, using intermediate [pulse](#) velocities makes it possible to steer large particles in the direction of the wave and [smaller particles](#) in the opposite direction, on average.

Although the mechanisms are different for [active particles](#) and amoeba, both systems exhibit the diffusing wave paradox behavior. In the case of the synthetic [particles](#), the behavior may one day lead to the design of

micro-robotic systems that can achieve complex controlled movements, despite having limited signal-processing abilities.

"Possible applications of microswimmers is to load them with drugs, which are then delivered to specific places," Bechinger said. "Because of their directed active motion, such targeted drug delivery can be accomplished much more efficiently compared to purely diffusive motion. In a similar way, synthetic swimmers may also be equipped with sensing mechanisms, to explore liquid environments. Finally, there is ongoing work to assemble microswimmers, such as gears or small motors, which may perform mechanical work at small length scales."

More information: Celia Lozano and Clemens Bechinger. "Diffusing wave paradox of phototactic particles in traveling light pulses." *Nature Communications*. DOI: [10.1038/s41467-019-10535-z](https://doi.org/10.1038/s41467-019-10535-z)

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