The demonstration of hydrodynamic cloaking and shielding at the microscale

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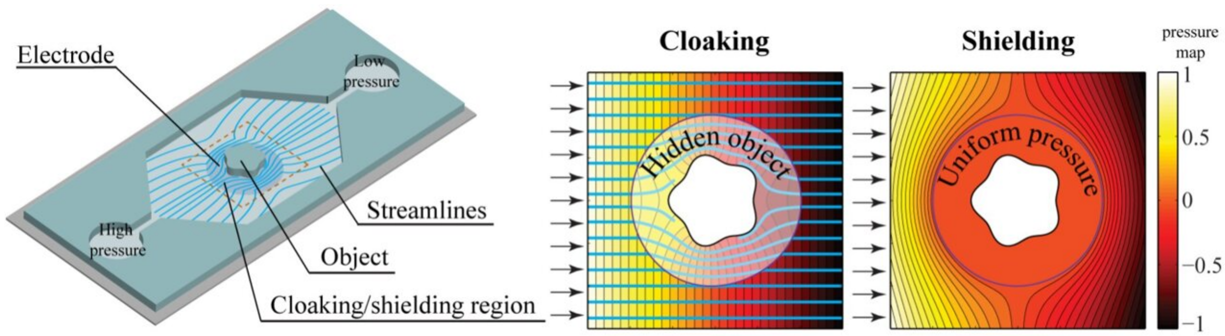

Left. Schematic of the setup designed to cloak/shield an object – in this case a star-shaped object. Right. Flow streamlines and pressure distribution around the object for the cases of hydrodynamic cloaking and shielding. Credit: Boyko et al.

Researchers at Technion—Israel Institute of Technology, Technische Universität Darmstadt, and IBM Research Europe have recently proposed a new strategy to simultaneously achieve microscale hydrodynamic cloaking and shielding. While the idea of cloaking or shielding objects has been around for some time now, in contrast with other previously developed methods the technique they proposed allows physicists to dynamically switch between these two states.

"When we started with our research, we were aware of work in this direction that is based on porous metamaterials," Steffen Hardt, who led the research team at TU Darmstadt, told Phys.org. "Our idea was that you do not need such metamaterials if you can inject momentum in a region around the object to be cloaked/shielded. Effectively, this means that you superpose the external flow field by some tailor-made local flow field. As a result, the total flow field (external and local one) comes out such that cloaking or shielding is achieved."

As part of their previous studies, the researchers developed methods to locally inject momentum using what is known as electroosmotic flow (i.e., motion of liquids typically induced by an applied voltage across a porous material or other fluid conduits). The key objective of their new study was to demonstrate a new method to cloak/shield objects in a fluid flow and make this functionality real-time adaptive, as previously proposed approaches based on metamaterials are not.

The new cloaking/shielding principle came to action thanks to a close co-operation between Ph.D. students Evgeniy Boyko and Michael Eigenbrod, who worked out the theory, and Vesna Bacheva who carried out the experiments. In their experiments, the researchers placed an object at the center of a microfluidic chamber, made up of two parallel plates separated by a small gap (a few tens of micrometers in size). They then filled the chamber with water and applied a pressure difference between its inlet and outlet. This allowed them to generate a hydrodynamic flow around the object.

"Cloaking (causing the flow field outside a certain region around the object to look as if there is no object) or shielding (eliminating the forces that the flow exerts on the object) requires an accurate control of the fluid velocity in the region surrounding the object," said Moran Bercovici, who led the part of the team at Technion. "We achieved this by locally injecting momentum using an electrokinetic phenomenon called field effect electro-osmosis."

To achieve capacitive control over the local surface charge, the team embedded an electrode at the bottom of the microfluidic device and adjusted its electric potential. Ions with an opposite charge contained in the water shielded the surface, forming what is known as an electric double layer.

"Applying an external electric field along the channel exerts a force on the mobile charges, which carry the rest of the liquid with it through viscous interaction," Hardt explained. "This effect can be thought of as 'conveyer belt' placed at the surface, whose velocity can be controlled by the electrode's potential. The induced velocity can be dynamically modified to switch between conditions that yield cloaking and shielding."

Remarkably, the cloaking/shielding mechanism resulting from the strategy used by the team can be adapted in real-time. In other words, it allows researchers to turn cloaki/shield effects on and off; or switch back and forth between cloaking and shielding conditions.

The new technique and paradigm introduced by this team of researchers could also have implications for other areas of physics. For instance, it could allow physicists to cloak objects in electromagnetic or acoustic fields.

Overall, the principle outlined in the recent paper published in *Physical Review Letters*, can be used to determine how an object interacts with a fluid flow (e.g., what force the flow exerts on the object). This could prove particularly useful for studying the effects of fluid flow on biological systems, such as cells.

"The principle we used for momentum injection in a flow can be very much refined if we do not only use a single electrode (as in our recent paper), but an array of individually addressable electrodes," added

Federico Paratore, from IBM Research Europe. "This would allow unprecedented opportunities for shaping a flow field, going much further than only cloaking or shielding modes."

More information: Microscale hydrodynamic cloaking and shielding via electro-osmosis. *Physical Review Letters*(2021). DOI: 10.1103/PhysRevLett.126.184502.

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