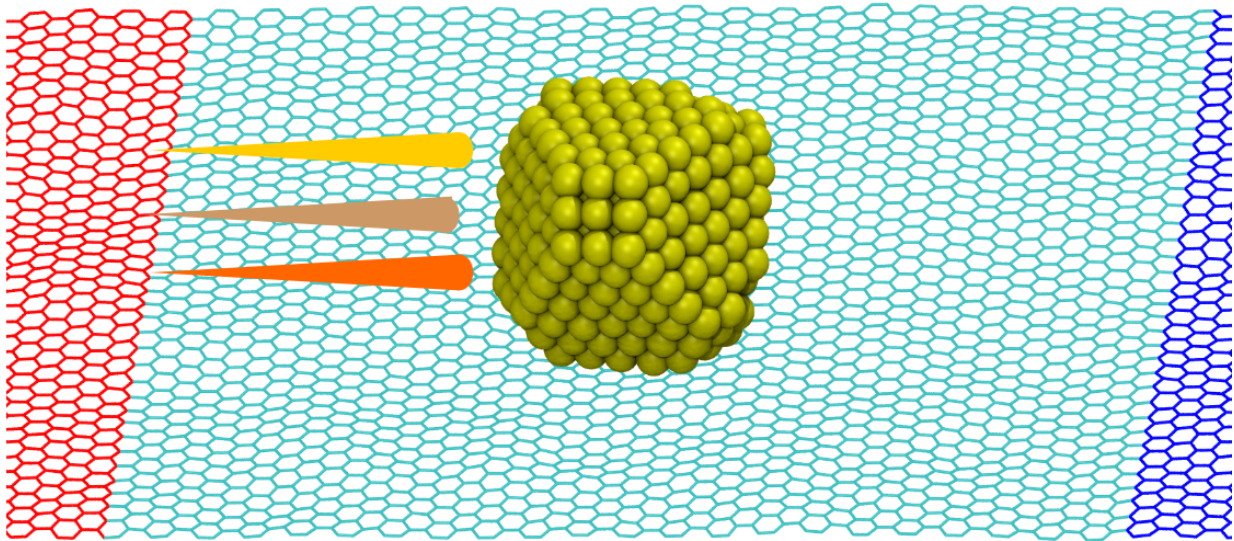


Moving objects at the nanoscale using thermal regions

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The theoretical predictions of these study could be of great interest in the frame of manipulating materials at the nanoscale for technological applications. Credit: Emanuele Panizon

Researchers report that it is possible to move a nanoparticle on the surface of a graphene sheet by applying a temperature difference at the ends of the membrane—a nanocluster on the surface will drift from the

hot region to the cold one. In addition, contrary to the macroscale physical laws, the force acting on the particle—the so-called thermophoretic force—should not decrease as the sheet length rises, instead sporting a so-called ballistic behavior, as a bullet in a gun barrel. In fact, simulations show that vertical thermal oscillations of the graphene membrane flow ballistically from hot to cold, providing a push to the object.

To use another analogy, these vertical waves, known as flexural phonons, push the nanocluster in the same way that ocean waves push a surfboard to shore, no matter how far away the wave came from. These theoretical predictions could be of great interest in manipulating materials at the nanoscale. The research has been published in the *Proceedings of the National Academy of Sciences*.

"Temperature gradients in a fluid impart on a body a force that can displace it. Such a phenomenon, technically referred to as thermophoresis, has been known for centuries. More recently, numerical simulations have indicated that such a gradient-induced spatial shift also works for molecules or small clusters placed on a solid two-dimensional membrane like [graphene](#). But no one ever tried to understand the physics behind the process. This was the aim of our study," the scientists explain.

Using specific software, the researchers have simulated the behaviour of a tiny gold nanocluster, made of a few hundred atoms, adsorbed on a [graphene sheet](#) suspended between two ends with different temperatures.

"In such a condition, the particle actually moves from the hot to the cold end. Surprisingly, though, the thrust impressed to it only depends on the thermal gradient and not on the sheet length," say the researchers. Thus, it is shown that the distance between the two ends of the membrane has no influence on the force acting on the gold cluster—this force remains constant up to and beyond a 100-nanometer sheet length.

"We have named this peculiar thermophoresis ballistic, to distinguish it from the diffusive one, which naturally holds in the [macroscopic world](#). Using a simple metaphor, imagine the two ends of the graphene sheet as the top and the bottom of a slide at the playground, and the [temperature difference](#) as the height gap. In the macroscopic world we experience in everyday life, the closer the ends of the slide are, the faster the drop of the object will be. In the nanoworld, according to our simulations, this is not what happens. At this scale, force and dropping speed only depend on the temperature gradient. But not on the distance... We have found that the force experienced by the particle is due to vertical thermal movements, known as flexural phonons, which are particularly wide and soft in a graphene membrane. The flexural phonons flux flows from hot to cold without losing strength and pushing the object over the surface," the scientists write.

How can such vertical thermal waves give a horizontal push to the gold cluster? "Our study shows that a precise anharmonic mechanism plays a crucial role in graphene and in other two-dimensional flexible membranes. This mechanism provides flexural phonons with mechanical momentum, which they usually don't have. Acting as if they carry a mass, phonons transfer part of their momentum to the gold particle, inducing it to move... It's exactly like a tablecloth on a table—a corrugation in the centre (the flexural phonons), meaning higher cloth density in the centre, forces the extremes to contract (the longitudinal phonons, in the case of graphene). The deposited particle is only sensitive to the corrugation, which pushes it forward."

The authors conclude, "When this project started, we were not expecting to be able to observe such a variety of phenomena, it was a purely theoretical study. Our results, though, open the way to future experiments, as a distance-independent mechanical [force](#) could well possess practical applications."

More information: Emanuele Panizon et al, Ballistic thermophoresis of adsorbates on free-standing graphene, *Proceedings of the National Academy of Sciences* (2017). [DOI: 10.1073/pnas.1708098114](https://doi.org/10.1073/pnas.1708098114)

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