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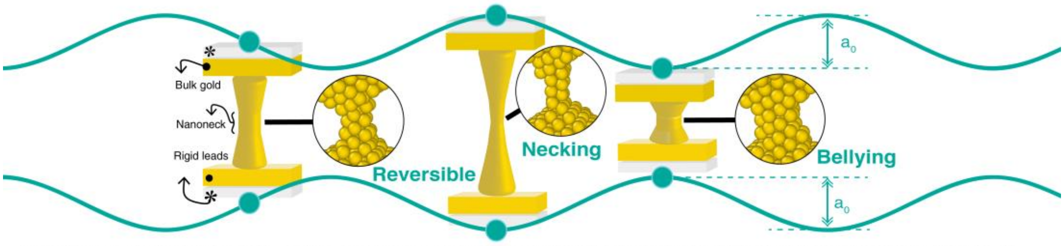
PRESS RELEASE

Solid or liquid: Strongly shaken nanostructures

If subjected to vibrations, nanocontacts mimic the behaviour of a liquid, but remain solid from a structural perspective. This is what a new piece of research done thanks to computer simulations shows. The study has been published in Nature Communications



Ali Khosravi, Antoine Lainé, Andrea Vanossi, Jin Wang, Alessandro Siria & Erio Tosatti. Understanding the rheology of nanocontacts. Nature Communications 13, 2428 (2022).

Trieste, 14 June 2022

A metallic junction between two solids, when forced to vibrate at ambient temperature, inexplicably becomes liquid. This is what occurs in the nano-world according to some experimental observations. However, sometimes appearances are deceptive, as explained in a recent research study published in Nature Communications, conducted by a team of scientists at SISSA, ICTP, CNR-IOM in Trieste, and the École Normale Supérieure (ENS) in Paris. Thanks to computer simulations, the researchers found a surprising solution to this strange phenomenon, which up to now has remained without an explanation.

This new research shows that melting does not actually occur. If subjected to vibrations, the nanocontacts mimic the behaviour of a liquid, but remain solid from a structural perspective. Why is that? This happens because, in contrast to what occurs in macroscopic systems, nanoscale plastic deformations are reversible during oscillations, meaning they occur and then reverse in each cycle. More in detail, what happens during stretching is that two of the very small crystalline surfaces inside the nanocontact slide one over the other, as in standard macroscopic plastic deformation. In the second half of the cycle, however, they go back to their original state, and so on, until the next cycle, mimicking what a liquid would do but still maintaining the crystalline structure.

This reversible rheological steady state, impossible in a system that was not of nanometric size, is at the origin of the apparent liquefaction of the junctions.
The results of this computational research, according to the authors, could have significant impact in applications in the nanotechnological sector.

Computer simulations for the nano-world

“Stiffness, as opposed to softness”, explain authors Erio Tosatti and Andrea Vanossi, “is a fundamental property of solids. This is obvious in our daily experiences, but is very subtle from a physics point of view. A second Pandora’s box in physics is the behaviour of matter subjected to external forces that are not fixed, for example, oscillatory in time. Knowing how a contact between two solid pieces will react mechanically when subjected to strong oscillations is fundamental not only for basic research, in physics and in materials science, but also in applied research, and from an engineering standpoint. In physics, these studies fall under the so-called field of “rheology”, the science that studies the evolution of matter subjected to stress depending on time”.
Physicists claim that in materials mechanics, when it is important to truly understand what is going on, “it is eventually only analysing what happens at a nanometric level, at the interatomic distance, that we can understand what actually happens and forecast phenomena in an intimate manner. Obviously, actually seeing all of this is impossible, since we are talking about extremely small sizes: a few tens of atoms in frenetic agitation caused by stress, as well as by temperature. In addition, theory, the other tool offered by physics, also fails to provide help in these dynamic and nanoscopic conditions. Fortunately a third route is available, namely fine-tuned computer simulations. These are numerical experiments, which are ideal precisely for systems that depend on time and have very small dimensions, which on the one hand can imitate actual experiments, and on the other connect well with theory. And that is what we did in our new research.”

The puzzle of shaken nanojunctions

“The moment two bodies touch, they do that through nanoasperities present on their surfaces, with the formation of solid nanojunctions. This happens especially in metals. For example, when an electrical switch is flipped, the current would not pass through if these minuscule nanocontacts did not form.” The study of these nanocontacts, generally invisible and thus not well-known “even though important for many aspects, has not been paid sufficient attention so far, explain Erio Tosatti and Andrea Vanossi. And yet, the questions that arise are quite intriguing, such as the one that had emerged in previous experiments where the researchers observed that if subjected to violent vibrations, the nanojunction

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between two gold electrodes underwent apparent liquefaction. All of this without any heating. Why does this happen? “To find out”, say the authors of the research published in Nature Communications “we relied on simulations. And what we found explains the observations while contradicting the suggestion of liquidity”.

It seems like a liquid, but it is not one

“Thanks to simulations, and even more importantly, their theoretical interpretation, we realised that while in the macroworld plastic deformation caused by mechanical stress of various types is not reversible, at a nanometric level it may be.” At the origin of the apparent liquefaction is this “forward and backward” movement among the internal micro-surfaces of the solid nanocontact, between a plastically deformed conformation and the original one. This is why what showed the rheology of a liquid, may be actually remain solid.” The research scientists explain: the two solid halves of the nanocontact slide over one another in the stop-and-go fashion which is typical of “stick-slip” friction of solids”.
The explanation is extremely interesting, say the authors, the first among them being Ali Khosravi, a PhD student at SISSA and ICTP, especially because it reveals a physical behaviour that is not only new, but also unexpected. As such, it expands basic knowledge in the novel field of nanorheology with possible applicability to other systems and metals. Finally, it might even be interesting for its possible practical implications: “We are not engineers, but we cannot help imagining the fate of electrical switches inside an airplane or a missile, with contacts that are designed in gold, during the vibrations in the launching stage. The mechanical stiffness between the switch blades, and the friction between them, must in some way be connected to those of each nanocontact, a myriads of them, between the two blades. These properties, when under super-intense vibrations, could actually generate this type of phenomena with possible repercussions at various levels. Knowing what happens and why it happens, especially in extreme and rare conditions that could occur when you least expect it, might not be irrelevant in terms of safety and efficiency.”

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IMAGE
Crediti: Ali Khosravi

SISSA
Scuola Internazionale
Superiore di Studi Avanzati
Via Bonomea 265, Trieste
W www.sissa.it

Facebook, Twitter
@SISSAschool

CONTACTS
Nico Pitrelli
→ pitrelli@sissa.it
T +39 040 3787462
M +39 339 1337950

Donato Ramani
→ ramani@sissa.it
T +39 040 3787230
M +39 333 7675962

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