New mechanism moving droplets at record-high speed and long distance without extra power

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Transporting droplets on solid surfaces at high speed and long distances without additional force, even against gravity, is a formidable task. But a research team comprising scientists from City University of Hong Kong (CityU) and three other universities and research institutes has recently devised a novel mechanism to transport droplets at record-high velocity and distance without extra energy input, and droplets can be moved upward along a vertical surface, which has never been achieved before. The new strategy to control droplet motion can open up new potential in applications in microfluidic devices, bio-analytical devices and beyond.

The conventional methods for transporting droplets include leveraging the wetting gradient on the surface to induce a driving force and move the droplet from hydrophobic to hydrophilic surface. However, the fundamental trade-off underpinning droplet hydrodynamics imposes limitations: transporting droplets at high speed necessitates a large wetting gradient and in turn is limited to a short distance, while long transport distance demands a small wetting gradient to reduce the adhesive force between the liquid and solid surface, and the transport velocity is then constrained.

To overcome these challenges, the researchers have devised a new strategy that achieves the unidirectional and self-propelled liquid droplet transportation on diverse substrates. Their work demonstrates unprecedented performance: The highest transport velocity (1.1m/s) is 10 times higher than ever before reported, and represents the longest unlimited transport distance.

Manipulation of surface charge density

The key to this breakthrough lies in the manipulation of surface charge via liquid contact, which was realized for the first time. The research team first dropped a chain of water droplets on the specially designed superamphiphobic (super water- and oil-repellent) surface that they had previously developed. Upon impact on the surface, the droplets immediately spread, retracted and rebounded from the surface. This resulted in the separation of electrons from the droplets, and the impacted surface became negatively charged.

By adjusting the height from which the droplets fell on the surface, the surface charge density on the surface changed gradually, forming a gradient. When a droplet was subsequently placed on that surface, the surface charge density gradient acted as a driving force. The droplet would then self-propel and move in the direction of higher charge density.

Unlike the chemical or morphological gradients, which are difficult to change once they are created, the charge density gradient can be easily changed, enabling the reprogramming of droplet motion paths. The research demonstrates that high velocity and ultra-long transport of droplets can be stimulated at room temperature and does not require extra energy.

Such droplet transport not only manifests on flat surfaces, but also flexible and vertically placed ones. In addition, various liquids can be transported, including those with low surface tension, low dielectric constant, blood and salt solutions.

Application potential in microfluidic devices

"We envision that our innovation in using surface charge density gradient to program droplet transport, which was not explored before, will open up a new research direction and potential in applications. For example, in bio-medicine, the design of surfaces with preferential charge density gradient may influence cell migration and other behaviours," said Professor Wang. Professor Deng also said that this strategy could be applied in microfluidic lab-on-a-chip devices and bio-analytical devices, as well as in the fields of materials science, fluid dynamics and beyond.

More information: Qiangqiang Sun et al. Surface charge printing for programmed droplet transport, *Nature Materials* (2019). DOI: 10.1038/s41563-019-0440-2

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