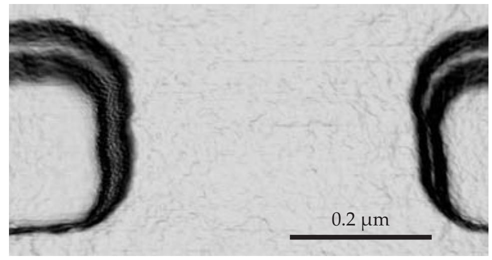
PHYSICS UPDATE

These items, with supplementary material, first appeared at www.physicstoday.org.

CONDUCTION ELECTRONS FLOW LIKE HONEY

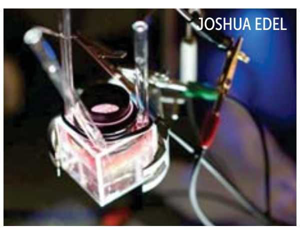


In most conductors, crystal defects and phonons scatter conduction electrons and impede the flow of current. But graphene exhibits anomalously weak electron–phonon scattering and can also be prepared in such a pure state that, at temperatures of a few degrees kelvin, an electron driven by a voltage difference moves ballistically. That is, the electron travels unimpeded through the bulk of the material until it hits a boundary, deposits some momentum there, and bounces back into the bulk to move freely until it again ricochets off a boundary. At higher temperatures, conduction electrons scatter off each other rather than off phonons. Due to those interactions, the electrons collectively flow as a viscous liquid, a phenomenon called electron hydrodynamics.

That collective flow has been observed in graphene samples with constant width, but Lancaster University PhD candidate Roshan Krishna Kumar, the University of Manchester's Andre Geim, and their international team have now added a new wrinkle by measuring the resistance of samples fabricated to have micrometer-scale constrictions such as those shown in the figure. At low temperature, the resistance was consistent with ballistic electron motion. But as the temperature was increased and collective effects became important, the investigators observed that the resistance fell. Though that so-called superballistic flow may be counterintuitive, the measured resistance drops were in accord with theoretical expectation, as was the observation that the drops were most pronounced for the thinner constrictions.

How does a fluid of electrons manage to flow through an aperture with less resistance than noninteracting, ballistically moving electrons? The key is that the flow is not uniform. Current density in the electron fluid is greatest near the centerline of the constriction and tapers off toward the sides. Because of that structure, the electron fluid is guided through the narrow channels in the graphene and avoids the boundary collisions that rob ballistic electrons of their momentum. (R. Krishna Kumar et al., *Nat. Phys.*, in press, doi:10.1038/nphys4240.) —SKB

NOW YOU SEE THIS NANOPLASMONIC MIRROR. NOW YOU DON'T.



JOSHUA EDEL

Surface plasmons—collective, light-driven oscillations of electrons in metal—have given us stained glass, flat lenses, and home pregnancy tests. Now they bring us the mirror–window, a liquid mirror whose reflectivity can be tuned, or eliminated altogether, with an applied voltage.

Developed by researchers led by Alexei Kornyshev, Anthony Kucernak, and Joshua Edel at Imperial College London, the device makes use of gold nanoparticles inside a cell filled with two immiscible electrolyte solutions—one aqueous, the other oily. Dispersed throughout one phase or the other, the nanoparticles interact negligibly with light, and the cell is transparent. But when the particles form a dense monolayer at the liquid–liquid interface, their plasmon resonances couple to each other and they become optically reflective.

To enable switching between those two states, Kornyshev and his coworkers charged their nanoparticles by tethering organic molecules to them. At equilibrium, the charged particles prefer the aqueous phase. But a few-hundred-millivolt potential applied across the two phases coaxes the particles to assemble at the interface. For the tactic to work, the particles must be just the right size: too small and the coupled plasmons won't resonate at visible wavelengths; too large and the particles will clump irreversibly. Particles around 16 nm in diameter gave the sought-after strong optical response—about 25% maximum reflectivity at visible wavelengths—and the organic tethers helped prevent agglomeration.

The video in the online version of this piece shows the mirror–window in action: As the initially transparent cell becomes reflective, the £10 symbol on a banknote positioned beneath the cell is displaced by the face of Queen Elizabeth II, which adorns a coin above. Currently, the transition from window to mirror takes a few hours, but the group's theoretical analysis suggests it should be possible to reduce the switching time to milliseconds. Once optimized, the technology could be used in a broad range of applications, including energy-efficient windows, switchable displays, and sensors. (Y. Montelongo et al., *Nat. Mater.*, in press, doi:10.1038/nmat4969.) —AGS

EVALUATING THE HABITABILITY OF EXOMOONS

Jupiter's moon Europa and Saturn's moon Enceladus are among the most promising places to look for extraterrestrial life in the solar system. Despite their distance from the Sun, the moons qualify as habitable because their proximity to their massive planetary hosts engenders tidal heating that is strong enough to melt water ice below their frozen surfaces. No one has yet detected a moon around an exoplanet. The objects are hard to find, even with the most powerful telescopes. Nevertheless, astronomers are theorizing about the habitability of exomoons.

For their study, Rhett Zollinger of Southern Utah University, John Armstrong of Weber State University, and René Heller of the Max Planck Institute for Solar System Research chose to focus on Mars-sized moons that orbit gas giants around M dwarf stars. Their choice was not arbitrary. Big moons are more likely to harbor life than small moons. Theory predicts that big moons are more likely found around gas giants than around terrestrial planets. And M dwarfs are the most abundant type of star in the Milky Way.

Because M dwarfs are dimmer than the Sun, their habitable zones—that is, the orbital locations where an Earth-like planet or moon with an Earth-like atmosphere can sustain surface water—lie closer to the star. From their modeling, Zollinger, Armstrong, and Heller discovered that for a wide range of M dwarf masses and other parameters, extreme tidal heating rendered the exomoons uninhabitable. So if there are moons around giant planets that orbit the most abundant type of star, in many cases, those moons could be uninhabitable, even when they occupy the star's habitable zone. (R. R. Zollinger, J. C. Armstrong, R. Heller, *Mon. Not. R. Astron. Soc.* **472**, 8, 2017.) —CD