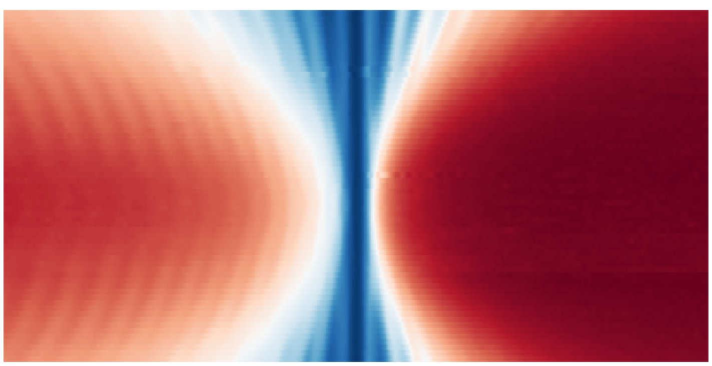
A Counterintuitive Set of Tunneling Effects Observed at Last

Graphene is the setting for the first demonstration of relativistic electrons' paradoxical ability to whiz through a barrier, provided the barrier is high enough.

By **Charles Day**

If an electron in a material has a speed that is independent of its energy and if it encounters a barrier head on, it can tunnel straight through. Derived by theorist Oskar Klein in 1929, this counterintuitive finding remained little tested in the lab because it is hard to make electrons approach a barrier head on and to stop them scattering off the edges of the sample. Now Mirza Elahi of the University of Virginia and his collaborators have observed evidence of Klein tunneling in monolayer graphene. What's more, they also observed the opposite effect, anti-Klein tunneling, in bilayer graphene. In anti-Klein tunneling, head-on electrons do not tunnel at all, while others approaching the barrier at an intermediate angle do [**1**].

Graphene's hexagonal lattice can be thought of as two identical interpenetrating triangular sublattices. One consequence of that view is that graphene's charge carriers—electrons that hop between the two sublattices—behave as if massless and relativistic at low energies. Another consequence is that the two sublattices bestow on the electrons a chiral property, pseudospin, that resembles spin, which controls the nature of the transmission across the barrier.



Credit: M. M. Elahi *et al.* [**1**]

To be sure that they were observing Klein or anti-Klein tunneling, Elahi and his collaborators needed to eliminate undesirable edge scattering. They did so by fashioning their graphene layers into so-called Corbino disks, the circular analogs of Hall bars. Such disks are effectively edgeless because the Hall effect turns radial currents flowing out of the disk center into circular currents at the disk perimeter. Through an applied field, the team diverted the circular trajectories so that the electrons encountered the edge barrier head on. The magnetic field also revealed the Klein and anti-Klein tunneling's pseudospin fingerprints, which appeared as a nontrivial dependence on the azimuthal angle of the tunneling electrons' outward trajectories. Specifically, the researchers observed, as predicted, a peak in the zero-angle Klein transmission and a dip in the anti-Klein transmission, with an intermediate peak reminiscent of the Brewster angle used in optics to design polarizers.

Charles Day is a Senior Editor for ***Physics Magazine***.

REFERENCES

1. M. M. Elahi *et al.*, "Direct evidence of Klein and anti-Klein tunneling of graphitic electrons in a Corbino geometry," **Phys. Rev. Lett. 132, 146302 (2024).**