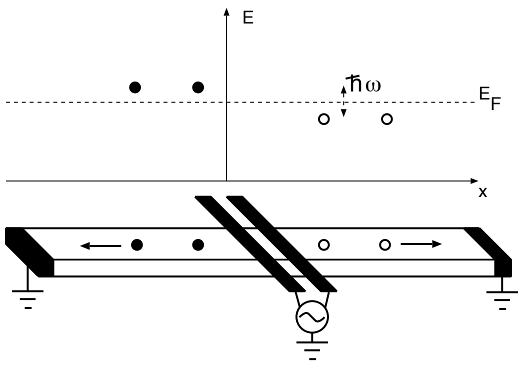
Single electrons ride the Fermi sea

Minimal-excitation states for electron quantum optics using levitons,
J. Dubois, T. Jullien, F. Portier, P. Roche, A. Cavanna, Y. Jin, W. Wegscheider, P. Roulleau and D. C. Glattli, *Nature* **502**, 659 (2013).

Recommended with a commentary by Carlo Beenakker, Leiden University

Here's a thought experiment (see figure): Imagine a conducting wire interrupted by a tunnel barrier, high enough that no current flows. The barrier is quickly lowered and raised again, so that a single electron tunnels through it, leaving behind a hole in the Fermi sea. The electron-hole pair is pulled apart by an electric field, but retains a long-distance correlation of the spin degree of freedom. Classically, one might think of the pair as a spatial separation of the crest and the trough of a wave. Quantum mechanically, the electron and hole form an entangled Bell pair.

One can imagine applications in the context of quantum electronics for a device that produces Bell pairs on demand `[arXiv:1201.1509]`, and indeed in quantum optics the on-demand generation of polarization-entangled photon pairs is an essential component of quantum information protocols `[arXiv:1308.4257]`. A recent experiment from the Saclay group led by Christian Glattli has made the first key step towards the control of single electrons and holes in the Fermi sea, required for such applications.



Production of entangled electron-hole pairs in the Fermi sea. The left and right ends of the conductor are grounded, while the potential on the gate electrodes at the center is periodically modulated with a Lorentzian profile. Such a quantum pump produces spatially separated electron-hole pairs (black and white circles), differing in energy by a multiple of the pump frequency ω. The electron (e) and hole (h) produced during a given cycle are in the same spin band $\uparrow$ or $\downarrow$, so that their wave function $|\uparrow_e\uparrow_h\rangle + |\downarrow_e\downarrow_h\rangle$ is that of an entangled Bell pair. Figure from `arXiv:cond-mat/0502055`.

The experiment builds on a theoretical breakthrough of Leonid Levitov and coworkers [arXiv:cond-mat/9501040], who in 1995 discovered how to modulate the barrier height such that only a single electron or hole wave packet is produced. If one would just arbitrarily lower and raise the barrier, one would shake up the Fermi sea and create a multitude of quasiparticle excitations. The required time-dependent voltage profile $V(t)$ is a sum of Lorentzian pulses of quantized area h/e. Each pulse introduces a 2π phase difference in the wave functions at the two sides of the barrier, which amounts to the transfer of a single electron wave packet, spatially separated from the hole at the other side of the barrier.

The Saclay experiment continues a very succesful line of work that uses quantum Hall edge channels to create electronic analogues of quantum optical interferometric experiments (see the review in arXiv:1102.0466). Here the Hong-Ou-Mandel experiment from quantum optics is used to demonstrate the single-electron nature of the wave packets. In this experiment two wave packets are made to collide at a beam splitter and the outgoing currents are correlated. In the original optical experiment one thus detects the bunching of bosons, while here the antibunching of fermions suppresses the current fluctuations. This is indeed what is observed: Time-shifted Lorentzian voltage pulses $V(t)$ and $V(t+\tau)$ generate trains of indistinguishable electrons, moving along quantum Hall edge channels towards a quantum point contact that plays the role of a beam splitter. The outgoing currents show partition noise (negative correlation) for nonzero τ, but for $\tau \to 0$ the noise vanishes.

Glattli et al. have proposed the name *leviton* for a single-electron wave packet riding the Fermi sea, perhaps anticipating the name *levitonics* for the quantum-electronics applications. Whether or not this name will catch on, it is clear that the capability to perform scattering experiments with minimal perturbation of the Fermi sea holds great promise.