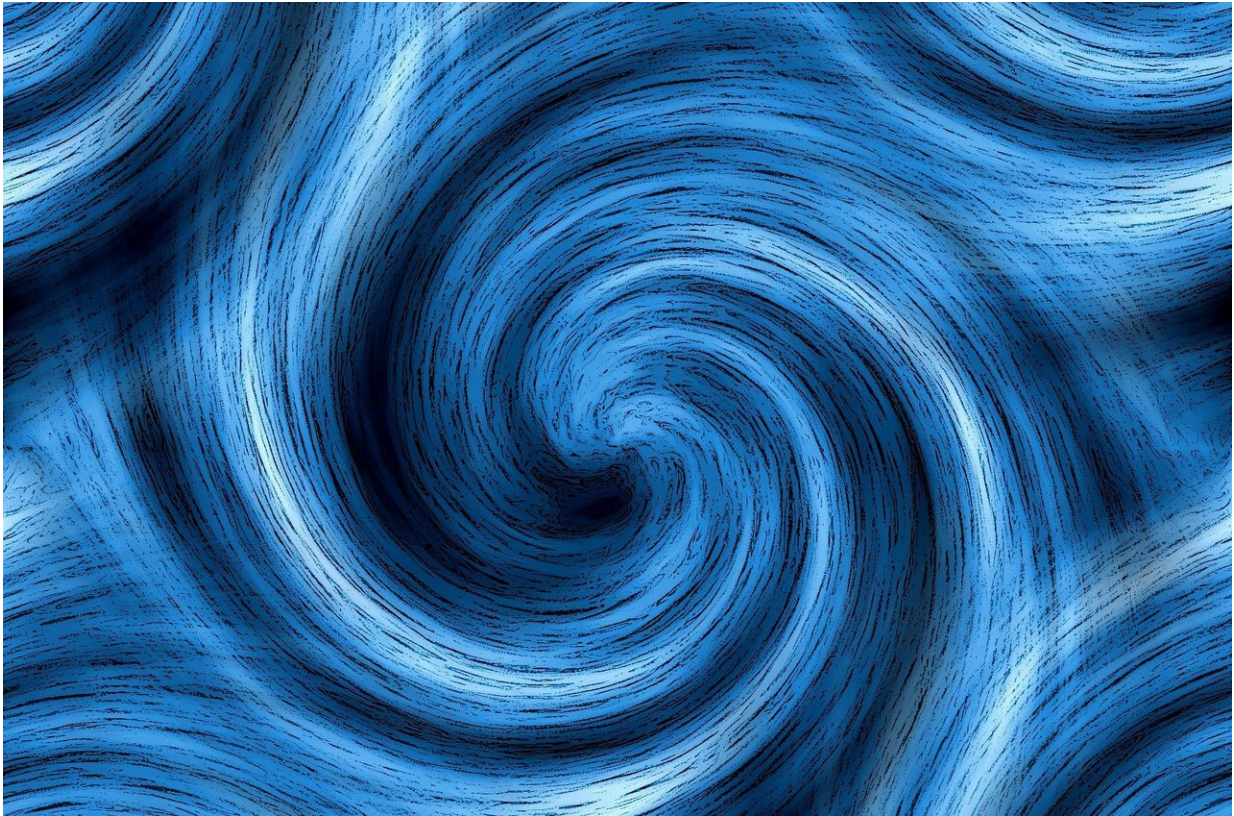


# Twisting whirlpools of electrons

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In Jules Verne's famous classic *20,000 Leagues Under the Sea*, the iconic submarine Nautilus disappears into the Moskenstraumen, a massive whirlpool off the coast of Norway. In space, stars spiral around black holes; on Earth, swirling cyclones, tornadoes and dust devils rip across the land.

All these phenomena have a vortex shape, which is commonly found in nature, from galaxies to milk stirred into coffee. In the subatomic world, a stream of elementary particles or energy will spiral around a fixed axis like the tip of a corkscrew. When particles move like this, they form what we call "[vortex beams](#)." These beams imply that the particle has a well-defined orbital angular momentum, which describes the rotation of a particle around a fixed point.

Thus, vortex beams can give us new ways of interacting with matter, e.g. enhanced sensitivity to magnetic fields in sensors, or generating new absorption channels for the interaction between radiation and tissue in medical treatments (e.g. radiotherapy). But vortex beams also enable new channels in basic interactions among elementary particles, promising new insights into the inner structure of particles such as neutrons, protons or ions.

Matter exhibits wave-particle duality. This means that scientists can make massive particles form vortex beams simply by modulating their wave function. This can be done with a device called a "passive phase mask," which can be thought of as a standing obstacle in the sea. When waves at sea crash into it, their "wave-ness" shifts and they form whirlpools. Physicists have been using the passive phase mask method to make vortex beams of electrons and neutrons.

But now, scientists from the lab of Fabrizio Carbone at EPFL have demonstrated that it is possible to use light to dynamically twist an individual electron's wave function. They were able to generate an ultrashort vortex electron beam and actively switch its vorticity on the attosecond ( $10^{-18}$  seconds) timescale.

To do this, the team exploited one of the fundamental rules governing the interaction of particles on the nanoscale level: energy and momentum conservation. What this means is that the sum of the energies, masses

and velocities of two particles before and after their collision must be the same. This constraint causes an electron to gain orbital angular momentum during its interaction with an ad hoc prepared light field, i.e. a chiral plasmon.

In experimental terms, the scientists fired circularly polarized, ultrashort laser pulses through a nano-hole in a metallic film. This induced a strong, localized electromagnetic field (the chiral plasmon), and individual electrons were made to interact with it. The scientists used an ultrafast transmission electron microscope to monitor the resulting phase profiles of the electrons. What they discovered was that during the interaction of the electrons with the field, the [wave function](#) of the electrons took on a chiral modulation, a right- or left-handed movement whose "handedness" can be actively controlled by adjusting the polarization of the laser pulses.

"There are many practical applications from these experiments," says Fabrizio Carbone. "Ultrafast [vortex](#) electron beams can be used to encode and manipulate quantum information; the electrons' orbital [angular momentum](#) can be transferred to the spins of magnetic materials to control the topological charge in new devices for data storage. But even more intriguingly, using light to dynamically twist matter waves offers a new perspective in shaping protons or ion beams such as those used in medical therapy, possibly enabling new radiation-matter interaction mechanisms that can be very useful for selective tissue ablation techniques."

**More information:** G. M. Vanacore, et al. Ultrafast generation and control of an electron vortex beam via chiral plasmonic near fields. *Nature Materials* 06 May 2019. [DOI: 10.1038/s41563-019-0336-1](https://doi.org/10.1038/s41563-019-0336-1)

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