Electronic corkscrews

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The regular arrangement of atoms within a solid, crystalline material forms a constant background to which its electrons must conform. We recently discovered that it is possible for electrons in certain materials to break free from the rules imposed by such atomic arrangements, and assemble into collective structures shaped like corkscrews. The possible applications of these electronic corkscrews in technology as well as fields of science ranging from chemistry to robotics are currently being investigated at the University of Amsterdam.

→ It has been known for several decades that given the right circumstances, electrons in semiconducting materials refuse to march in time with the atomic lattice in which they live, and instead gather into collective structures that do not fit snugly into their atomic backgrounds. Typical arrangements formed by the electrons as they rebel against the order of the atomic lattice include stripes, checkers, honeycombs, and their three-dimensional equivalents (see Figure 1). We recently discovered that it is also possible for electrons in some crystals to congregate into spiral structures. These electronic corkscrews are special because, in addition to not fitting into the atomic harness, they also spontaneously develop a handedness. That is, corkscrews look different from any of their mirror images, just like your right hand always looks the same as your left hand when viewed in a mirror.

How to become a spiral

Spiral structures are well known to develop in magnets, where they also emerge being neither left nor right-handed despite the underlying atomic lattice. In these cases, however, the corkscrew is formed by the microscopic bar magnets that make up a magnetic material, while the electrons themselves do not form a spiral. The bar magnets are good escape artists, easily escaping the restrictions of the atomic background because they can rotate the orientations of their north and south poles around three independent directions. Electrons, which do not have a north or south pole, are unable to copy this rotation trick and need to be much more organized in order to generate a corkscrew structure.

The first step for the electrons is to assemble into lines, standing a little more closely together than normally between every third pair of atoms (see top of Figure 2). Next, three sets of such lines, each oriented along a different direction, combine in such a way that the densely packed regions of electrons are linked in a spiral shape (bottom of Figure 2). We have recently been able to experimentally confirm our theoretical description of this highly orchestrated assembly of electrons into corkscrews patterns.

“We recently discovered that it is also possible for electrons in some crystals to congregate into spiral structures”

Corkscrew technology

The presence of a collective organisation of electrons defying the rules of the underlying atomic structure brings with it significant consequences for the material properties of their host. The characteristic features of traditional patterns such as stripes of electrons, for example, are used in switches and memory devices and even feature in sustainable energy applications. The corkscrew's special contribution of developing a handedness could find use in areas such as molecular motors for nanobots, specialized light detectors and in steering stereospecific chemical reactions. Next to these more applied aspects, electronic corkscrews have been argued to be important in the fundamental physics of superconductors: a mysterious and currently poorly understood class of materials that lose all electrical resistance when cooled with liquid nitrogen. Our ongoing work at the University of Amsterdam, supported by an NWO Vidi grant, will thus help define the role played by electronic corkscrews both in future technologies and fundamental aspects of science. Ω

→ References

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2] Castellan, J.-P., Rosenkranz, S., Osborn, R., Li, Q., Gray, K.E., Luo, X., Welp, U., Karapetrov, G., Ruff, J.P.C. and Van Wezel, J. (2013). ‘Chiral Phase Transition in Charge Ordered 1T-TiSe2’ Physical Review Letters 110, 196404.

Figure 1:
Typical arrangements of electrons breaking the rules of the underlying atomic lattice include stripes (top), checkerboards (bottom left) and honeycomb structures.

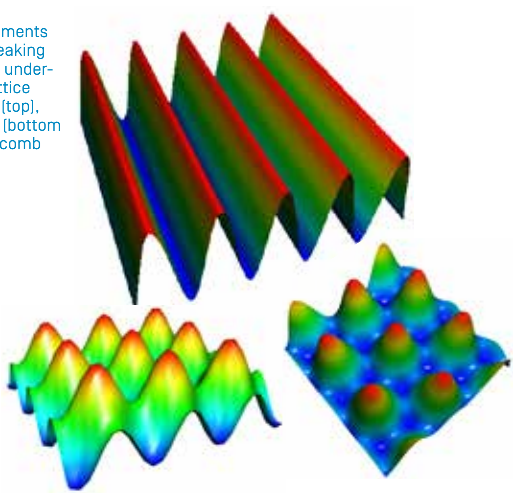

Figure 2:
Step-by-step instructions for the formation of an electronic corkscrew.
(a) Electrons line up, bunching together between every third pair of atoms.
(b) Many such lines together fill up the cubic arrangement of atoms in the material.
(c) Finally, putting together three sets of lines, running in three orthogonal directions, yields a spiral pattern, shown here as coloured lines.

Figure reproduced from:
Van Wezel J. and Littlewood, P. (2010). ‘Chiral symmetry breaking and charge order’, Physics 3, 87