On the discovery of flatland

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DOI: 10.1051/epn/2024404

Soon after Columbus put foot on the American continent on October 12th, 1492, there were attempts to minimize his achievement by arguing that it was not really difficult to embark on a ship and by that, discover a by then unknown continent. His reply was the now famous "Columbus's egg" where he challenged his critics to make a boiled egg stand on its tip. After their failing to do so, Columbus took the egg and boldly hit it on the table such that it could stand by itself.

Until the beginning of the 21st century, it was still widely believed that two-dimensional structures could not exist based on the well-known no-go theorem by Mermin and Wagner. It was thus in some way bold to nevertheless search for this "new world". And precisely 20 years ago, in 2004, the simplest route towards the 2D world was proposed by Andre Geim and Kostya Novoselov via their now famous "scotch-tape"-technique, a standard method for microscopy sample-preparation – similarly to what was sailing 500 years ago.

Geim and Novoselov did not only demonstrate and share their route to the new world, but also thoroughly explored "flatland". And already in 2010, they were awarded the Nobel prize for physics "for groundbreaking experiments regarding the two-dimensional material graphene". Since then, many other 2D materials and general so-called van der Waals heterostructures were explored and new physical concepts related to the emergence of Dirac cones that exist in two opposite valleys were developed. Also, material properties such as the low intrinsic spin-orbit coupling of graphene or the 2D-specific large excitonic binding energy in 2D semiconductors such as MoS_2 helped to open up several new research fields such as 2D spintronics or 2D optoelectronics and plasmonics. Finally, the discovery of a new class of 3D-materials that host Weyl points was arguably also triggered by first exploring the topological nature of the Dirac cones in graphene.

As in every mature field, there must be disruptive developments in order to continuously bind the interest of the scientific community. In the case of 2D materials, this was first the observation that encapsulating graphene by boron nitride may strongly enhance the crystal quality. The second breakthrough was the possibility of controlled misalignment of van der Waals crystals, giving rise to "Graphene 2.0" and the age of twistronics. And in 2018, Pablo Jarillo-Herrero and Yuan Cao demonstrated that twisting two graphene sheets by a "magic" angle of around 1° may give rise to a superconducting instability at a relatively large critical temperature of around 1 Kelvin compared to its superfluid density. This discovery attracted enormous interest and shortly after, superconductivity was even observed in ordinary Bernal-stacked bilayer graphene - somehow unexpected as simple graphene-structures are usually well described by single-particle physics.

Even though the investigation of 2D materials has brought immense progress to fundamental science with novel moiré-structures hosting exotic correlated and topological phases of matter that are yet to be fully understood, it is perhaps fair to say that flatland has still not entered the "real world". The main obstacle for large-scale industrial applications that make explicit use of the unique electronic or structural properties of van der Waals materials is still given by the somehow poor quality of epitaxially grown large-area samples. However, there are several teams world-wide working on their quality improvement and recently, well-defined twisted devices were successfully fabricated. Thus, the big breakthrough might be just around the corner and then, as it is the case for almost all ground-breaking discoveries, we might all again say: "Gosh, was that simple…" ■