Materials in the Flatland

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When one writes by a pencil, thin flakes of graphite are left on a surface. Some of them are only one ångström thick and can be viewed as individual atomic planes cleaved away from the bulk. This strictly two-dimensional material called graphene was presumed not to exist in the free state and remained undiscovered until a few years ago. In fact, there exists a whole class of such two-dimensional crystals. The most amazing thing about graphene probably is that its electrons move with little scattering over huge (submicron) distances as if they were completely insensitive to the environment only a couple of ångströms away. Moreover, whereas electronic properties of other materials are commonly described by quasiparticles that obey the Schrödinger equation, electron transport in graphene is different: It is governed by the Dirac equation so that charge carriers in graphene mimic relativistic particles with zero rest mass. The very unusual electronic properties of this material as well as the possibility for its chemical modification make graphene a promising candidate for future electronic applications.

Probably the most important "property" of graphene is that it has opened a floodgate of experiments on many other 2D atomic crystals: BN, $NbSe_2$, TaS_2, MoS_2, *etc*. One can use similar strategies to those applied to graphene and obtain new materials by mechanical or liquid phase exfoliation of layered materials or CVD growth. An alternative strategy to create new 2D crystals is to start with an existing one (like graphene) and use it as an atomic scaffolding to modify it by chemical means (graphane and fluorographene are good examples). The resulting pool of 2D crystals is huge, and they cover a massive range of properties: from the most insulating to the most conductive, from the strongest to the softest.

If 2D materials provide a large range of different properties, sandwich structures made up of 2, 3, 4, … different layers of such materials can offer even greater scope. Since these 2D-based heterostructures can be tailored with atomic precision and individual layers of very different character can be combined together, – the properties of these structures can be tuned to study novel physical phenomena (Coulomb drag, Hofstadter butterfly, metal-insulator transition, etc.) or to fit an enormous range of possible applications, with the functionality of heterostructure stacks "embedded" in their design (tunnelling or hot-electron transistors, photovoltaic devices).