EDITORIAL

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Moiré magic three years on

Three years after the observation of superconductivity in twisted bilayer graphene, the study of the rich variety of phenomena that arise in moiré materials is keeping researchers fruitfully busy.

It is not often that a new class of materials emerges to take a field by storm. When the organizers of a major conference have to stream a talk in the hallways because so many researchers itch to hear about a new result, it is a sign such a stir is happening. Almost exactly three years ago, at the American Physical Society meeting, Pablo Jarillo-Herrero announced to hundreds of captivated physicists that he had observed superconductivity in twisted bilayer graphene[1]. Those results marked the emergence of the field of moiré materials, van der Waals 2D materials in which a slight difference in periodicity or a small twist angle generates a wealth of intriguing phenomena.

The realization that moiré patterns can modify the electronic properties of a material dates back to experiments on bilayer graphene reported in 2009 by Eva Andrei's group[2], and the idea that certain twist angles would be particularly interesting was put forward shortly thereafter by Allan McDonald and other theorists[3,4]. Their calculations showed that certain 'magic' twist angles would result in flat electronic bands near the Fermi level. Flat bands imply a dramatic slowdown of the electrons, so that Coulomb interactions dominate over the kinetic energy and the electrons become strongly correlated, giving rise to exotic phenomena. However, it was only in 2016, after Emanuel Tutuc and collaborators reported a tear-and-stack method for the fabrication of samples with accurate layer alignment[5], that it became possible to control the twist angle.

When Jarillo-Herrero and co-workers managed to fabricate bilayer graphene samples twisted at the magic angle, 1.1°, the observation of superconductivity came as a surprise. Intriguingly, the phase diagram showed insulating phases next to the superconducting states, a feature tantalizingly similar to those seen in high-temperature superconductors. This similarity stimulated great interest, because, despite 30 years of research, the mechanism underlying high-temperature superconductivity remains unknown. The discovery that a potentially similar mechanism is at work in easily tunable 2D materials raised hopes to solve this long-standing puzzle.

Many groups swiftly got to work to explain and extend the initial results, mixing and matching different 2D layers and obtaining almost all known condensed matter behaviours. Beyond superconductivity, moiré materials offer a rich playground to explore collective phenomena, and a wealth of properties are being investigated. You can get a taste for the variety of current research directions by looking at our In Briefs on the study of excitons, solitons, higher-order topological insulator states and structural reconstructions in moiré systems. To understand how the field is evolving, we have asked nine scientists working on different aspects of moiré materials about the most exciting directions of research: you can read their thoughts in a Viewpoint in this issue.

Understanding the microscopic mechanisms underlying the superconducting phase in magic-angle twisted bilayer graphene remains an active line of research; a hot topic of debate is whether superconductivity is driven by electronic correlations, as in high-temperature superconductors, or by a more conventional coupling. Because magic-angle twisted bilayer graphene hosts topological bands, it's even possible that the superconducting state is topological. Beyond bilayer graphene, the search is on for more robust superconductivity in moiré systems made of three or more graphene layers.

Magnetic properties are coming into the spotlight, as some moiré materials display a type of magnetism that arises not from the spins of the electrons, as usual, but from their orbital angular momentum. Reports about the use of electrical currents to switch the polarization and magnetic order in moiré materials and induce transitions between their magnetic and superconducting phases made physicists excited about potential applications in quantum electronic devices. Moreover, moiré materials based on transition metal dichalcogenides exhibit intriguing optical properties and host long-lived excitons that can be electrically manipulated, features that could be harnessed in quantum optical devices.

Finally, the tunability of moiré materials makes them a practical platform to simulate fundamental models in condensed matter physics and realize exotic states of matter, such as supersolids and quantum spin liquids.

On March 14, the 2021 American Physical Society March meeting will open its virtual doors. The field of moiré materials has branched out in many directions since Jarillo-Herrero's landmark talk, and over 200 moiré-related presentations are in the programme. We are looking forward to hearing what's new.

1. Cao, Y. et al. Unconventional superconductivity in magic-angle graphene superlattices. *Nature* **556**, 43–50 (2018).
2. Li, G. et al. Observation of Van Hove singularities in twisted graphene layers. *Nature Phys.* **6**, 109–113 (2010).
3. Suárez Morell, E. et al. Flat bands in slightly twisted bilayer graphene: tight-binding calculations. *Phys. Rev. B* **82**, 121407 (2010).
4. Bistritzer, R. & MacDonald, A. H. Moiré bands in twisted double-layer graphene. *Proc. Natl Acad. Sci. USA* **108**, 12233–12237 (2011).
5. Kim, K. et al. van der Waals heterostructures with high accuracy rotational alignment. *Nano Lett.* **16**, 1989–1995 (2016).