



ECE Distinguished Lecture

Quantum Metamaterials

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Abstract

According to Wikipedia a metamaterial is any material engineered to have properties that are not readily realized in naturally occurring crystals. In practice the metamaterial notion has been employed mainly to design exotic properties for light wave in matter by patterning it on sub-optical wavelengths. The advent of two-dimensional materials in recent years has opened up an emerging opportunity to realize quantum metamaterials, in which many-particle matter waves waves that exhibit strongly-correlated and topologically non-trivial properties rare in naturally occurring crystals appear at will. For example, two-dimensional van der Waals crystals that are overlaid with a difference in lattice constant or a relative twist form a moiré pattern. In semiconductors and semimetals, the low-energy electronic properties of these systems are accurately described by Hamiltonians that have the periodicity of the moiré pattern – artificial crystals with lattice constants on the 10 nm scale. Over the past several years substantial progress has been made in the fabrication of these moire metamaterials, especially ones based on graphene, hexagonal boron nitride, and transitional metal dichalcogenides (TMDs). Since the miniband widths in both graphene and TMD moiré materials can be made small compared to interaction energy scales, for different reasons [1,2] in the two cases, the birth of moiré materials has opened up a new platform to study strongly correlated electrons and excitations, a platform that can be used both for simulation and for design and has been surprisingly rich. An important property of moiré materials is that their band filling factors can be tuned over large ranges without introducing chemical dopants, simply by using electrical gates.

In addition to realizing Mott insulators, density waves, a variety of different types of magnets, and superconductors – states of matter that are familiar from the study of strongly correlated atomic scale crystals – moire materials have emerged as perhaps the best platform uncovered to date for studies of topologically non-trivial matter, especially strongly interacting topologically non-trivial matter. The role of band topology is natural in graphene moires, where it derives from the interesting band topology of graphene monolayers, but has been an unexpected bonus [3] in the case of TMD moires where it derives from twists in the layer degree of freedom. I will discuss the latest developments in this evolving story.

[1] R. Bistritzer, and A.H.MacDonald, Proceedings of the National Academy of Sciences 26, 12233 (2011).

[2] F. Wu, T. Lovorn, E. Tutuc, and A.H.MacDonald, Phys. Rev. Lett. 121, 026402 (2018).

[3] F. Wu, T. Lovorn, E. Tutuc, I. Martin, and A.H.MacDonald, Phys. Rev. Lett. 122, 086402 (2019).

Bio

Allan MacDonald, a professor of physics at The University of Texas at Austin, shared the 2020 Wolf Prize in Physics with Pablo Jarillo-Herrero and Rafi Bistritzer for his groundbreaking work in a field known as twistrionics, which holds extraordinary promise to "lead to an energy revolution," according to the Wolf Foundation. Previously MacDonald received the Ernst Mach Honorary Medal for Merit in the Physical Sciences from the Czech Academy of Sciences in 2012 and the Herzberg Medal from the Canadian Association of Physicists in 1987. MacDonald also shared the 2007 Oliver E. Buckley Condensed Matter Physics Prize of the American Physical Society with Steve Girvin and Jim Eisenstein for theoretical work on exciton condensates in quantum Hall systems.

MacDonald has served on the executives of the Condensed Matter Divisions of the Canadian and American Physical Societies, and on numerous national and international advisory panels, including for the Kavli Institute for Theoretical Physics, and the Canadian Institute for Advanced Research. He has helped organize many scientific meetings including the 2018 International Conference on Magnetism for the International Union of Pure and Applied Physics.

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