PHYS-756 Lectures on twisted bilayer graphene

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Cursus	Sem.	Type
Physics		Opt.

Language of teaching	English
Credits	2
Session	
Exam	Oral presentation
Workload	60h
Hours	**28**
Lecture	21
Exercises	7
Number of positions	**50**

Frequency

Every 2 years

Remark

Next time: Spring 2025

Summary

Twisted Bilayer Graphene (TBG) is a change of paradigm in condensed matter: with flat topologic bands, it provides a platform for unconventional superconductivity, correlated insulation, Plankian metal phase, etc. This course will provide rigorous yet pedagocical introduction to the topic.

Content

The lecture course will will provide rigorous yet pedagogical introduction to the physics of twisted bilayer graphene (TBG) and similar moiré heterostructures. The course is equally aimed towards theorists and experimentalists, with the goal to boost the existing theoretical and experimental efforts on the topic at EPFL. The historical perspective on how this topic has appeared and had been developed will be given, together with the overview of the milestone theoretical models. The objective of these in-depth lectures is to train theory and experimental students interested in working on the related moiré systems.

The lecture course will be organized in 14 lectures, two lectures per week, with 7 exercise sets. The topics will cover the following aspects of the TBG physics:

(i) Discovery of TBG. Moiré periodicity, commensurability. Effective continuum model. Flat bands and magic angles. Symmetry and topology.

(ii) Atomistic modelling of TBG and TTG: DFT and its challenges, constructing effective tight binding model. Lattice relaxation effects at small twist angles and their importance for the magic-angle physics. Moiré domains, inhomogeneities, symmetry breaking: review from the experimental side.

(iii) Origin of magic angles in twisted bilayer graphene. Generalization to twisted graphene multilayers. Flat band of TBG as the Lowest Landau Level. Effective magnetic field, integer fluxes and quantum Hall wave functions on torus. Quantum geometry of the flat bands, and their holomorphicity.

(iv) Quantum geometry (Fubini-Study metrics) of the electronic states, ideal flat band criterion. Origin of band flatness and quantum geometrical obstructions. Wannier functions, their localization spread, and connection to Fubini-Study metrics. Twisted bilayer graphene from quantum geometric point of view.

(v) TBG in quantized magnetic fields: Hofstadter Butterfly, Wannier diagrams and Quantum Hall conductance sequence. Fractional Chern Insulator states: an analytical approach. TBG in integer flux quantum, reentrant magic angle physics in integer flux quanta. Review of experiments.

(vi) Quantum-geometrical conductivity in TBG: origin, essence, experimental significants. Bound on superfluid weight in topological flat bands (Peotta-Torma effect). Application to twisted bilayer graphene. Estimates of Tc for different pairing mechanisms. Review on correlated models.

(vii) Twisted Trilayer Graphene (TTG): a novel platform for unconventional superconductivity. Prediction and experiment. Pauli limit breaking (superconductivity in magnetic fields of 10 T). Re-entrant superconductivity in magnetic fields. TTG in strong magnetic flux Hofstadter Butterfly, Wannier diagrams and Quantum Hall conductance sequence. Revisiting Pauli limit for flat bands, review on experiments.

(viii) Other twisted moiré materials, including twisted transtion metal dicalchogenides: theoretical promises, effective models, review of experiments and perspectives. Outline: "twistronics" as a new interdisciplinary direction: Perspectives, ideas and challenges.

Hosted by Prof. Oleg Yazyev

Note

The current epidemiological situation will allow in-person classes, in this case the course will not be recordered.

Keywords

twisted bilayer graphene, moiré heterostructure, flat topological bands, topology and quantum geometry

Learning Prerequisites

Required courses

Solid State Physics I, II; Quantum Mechanics I, II; Complex Analysis I, II

Recommended courses

Quantum Mechanics IV (Diagrammatics); Advanced Solid State (Band Structure Calculations); Topology

Learning Outcomes

By the end of the course, the student must be able to:

- Navigate across the diverse literature on the moiré materials
- Perform simple band structure calculations
- Understand concepts of Landau level, holomorphicity, and flat band interactions

Resources

Bibliography

1. Each lecture will be supplement will be supplemented with key references in the form of most relevant research papers.
2. By the end of the course, the LaTeX lecture notes will be availbale (to be posted on arXiv).