Graphene, Dirac fermions and topological matter

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ECTS	3
Language	Anglais
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Volume : 30 hours of main lecture and around four exercices sheets
Exam : At least one oral presentation of a research article

Description

In the past years, condensed matter physics has witnessed tremendous progress with the synthesis of new carbon based materials such as nanotubes and graphene and more recently with the emergence of new exotic materials named topological insulators. The electronic properties of all these materials share the property that they are largely described by solutions of Dirac equations in low dimensions. Simulating Dirac matter *in situ* with cold atoms in specific optical lattices is also an important direction followed in quantum optics. This course aims at introducing these new emerging concepts to Master 2 students.

Outlook of the course :

0) A short general introduction to topological effects in matter.

I) Graphene and graphene-like materials : the massless Dirac equation in two dimensions

- Tight-binding model on the honeycomb lattice and the 2D massless Dirac equation
- Relativistic Landau levels and quantum Hall effect in graphene
- How to generate a gap in graphene
- A graphene-like material in 3D : the Weyl semi-metal and its experimental realization

II) Berry phases and topological invariants

- Berry phases and Berry curvatures : generalities
- Study of various examples such as the Aharonov-Bohm effect, the semi-classical equation of motion of a Bloch electron, the Berry phase in quantum spin systems.
- Berry phases in Bloch space: Application to Graphene-like systems
- Chern invariants and Chern insulators (and its experimental realizations)

III) Introduction to topological insulators and superconductors

- The integer quantum Hall effect and chiral edge states
- 2D topological insulators and helical edge states
- 3D topological insulators and topological magnetoelectric effects
- Majorana fermions as edge states of topological superconductors