Presentation

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Do you want to know what Condensed Matter Physics is? Check out our documentary!

Brief Vita:

The So Close Project

The Wonders of
Condensed Matter Physics

So Close and Such a Stranger: a documentary about Condensed Matter Physics

16,972 views

So Close Project
Published on Jan 1, 2016

www.elsapradat.com
Research interests

- Graphene and other 2D crystals
- Topological insulators: graphene, quantum wells
- Topological superconductors: Majorana nanowires
Outline

- Opening
  * Motivation and introduction to topology
  * Topology in electronic systems
  * Example: Polyacetylene
- 2D topological phases
  * QHE and the Chern number
  * QSHE and the $\mathbb{Z}_2$ topological invariant
  * 2D topological insulators
- Topological superconductors
  * 1D-TS
  * Majorana bound states
- Periodic table of topological materials
- Applications of topological materials
The Nobel Prize in Physics 2016
David J. Thouless, F. Duncan M. Haldane, J. Michael Kosterlitz

The Nobel Prize in Physics 2016

Photo: A. Mahmoud
David J. Thouless
Prize share: 1/2

Photo: A. Mahmoud
F. Duncan M. Haldane
Prize share: 1/4

Photo: A. Mahmoud
J. Michael Kosterlitz
Prize share: 1/4
The Nobel Prize in Physics 2016
David J. Thouless, F. Duncan M. Haldane, J. Michael Kosterlitz

The Nobel Prize in Physics 2016 was divided, one half awarded to David J. Thouless, the other half jointly to F. Duncan M. Haldane and J. Michael Kosterlitz "for theoretical discoveries of topological phase transitions and topological phases of matter".
In Mathematics, topology is concerned with the properties of certain objects, called “topological spaces”, that are invariant under certain transformations, called a “continuous map”.


Continuous deformations such as stretching, crumpling and bending... ...but not tearing or gluing.
The number of holes or “genus” serves as a classification index and is a “topological invariant.”

2D manifold with one hole: torus

Reversible continuous transformation: homeomorphism
New paradigm to understand phases of matter

Landau’s paradigm

Order parameter: continuous field
Phase transitions: discontinuities in the order parameter

Topology paradigm

Topological invariant: discrete set of values
Topological phase transitions: changes in the topological number
Topology

- New paradigm to understand order in physical systems

Knots are thought in Mathematics as mappings between two spaces

Local order (symmetry)  Global order (topology)
Topology in electronic systems

Topological band theory for non-interacting electrons

“Continuous maps between two spaces can be classified into discrete homotopy classes”

Electronic band

\[ \text{band} : \mathbf{k} \rightarrow |\Psi(\mathbf{k})\rangle \]

Topological invariant \( C \)

(discrete set of values for \( C \))

\[ C = 0 \]

Trivial

\[ C = 1 \]

Non-trivial

\[ C = 2 \]

Example:

Su–Schrieffer–Heeger model
Polyacetylene

1D carbon chain with alternating bonds

Unit cell
**SSH model**

- **1D carbon chain with alternating bonds**

\[
H_{SSH} =
\begin{pmatrix}
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\
\ldots & 0 & t_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\ldots & t_1 & 0 & t_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\ldots & 0 & t_2 & 0 & t_1 & 0 & 0 & 0 & 0 & 0 & 0 \\
\ldots & 0 & 0 & t_1 & 0 & t_2 & 0 & 0 & 0 & 0 & 0 \\
\ldots & 0 & 0 & 0 & t_2 & 0 & t_1 & 0 & 0 & 0 & 0 \\
\ldots & 0 & 0 & 0 & 0 & t_1 & 0 & t_2 & 0 & 0 & 0 \\
\ldots & 0 & 0 & 0 & 0 & 0 & t_2 & 0 & t_1 & 0 & 0 \\
\ldots & 0 & 0 & 0 & 0 & 0 & 0 & t_1 & 0 & t_2 & 0 \\
\ldots & 0 & 0 & 0 & 0 & 0 & 0 & 0 & t_2 & 0 & t_1 \\
\ldots & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & t_1 & 0 \\
\ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots & \ldots 
\end{pmatrix}
\]
SSH bandstructure

The two sublattices define a pseudospin

\[ \langle x_n | \Psi_k \rangle = \begin{pmatrix} \psi_k^A \\ \psi_k^B \end{pmatrix} e^{ikx_n} \]

\[ |t_1| < |t_2| \]

\[ \Delta = 2|t_1 - t_2| \]

No winding
SSH bandstructure

The two sublattices define a pseudospin

\[ \langle x_n | \Psi_k \rangle = \begin{pmatrix} \psi^A_k \\ \psi^B_k \end{pmatrix} e^{ikx_n} \]

Winding number \( w = 1 \)
SSH bandstructure

The two sublattices define a pseudospin

\[ |t_1| < |t_2| \]

No winding

\[ |t_1| > |t_2| \]

Winding number \( w = 1 \)

Topologically trivial

Topologically non-trivial
SSH bandstructure

- Topological transition at $|t_1| = |t_2|$ (band inversion)
SSH bandstructure

Topological transition at $|t_1| = |t_2|$ (band inversion)

**Topological gap**

Bulk-boundary correspondence

Edge states
Topological insulator

- Topological transition at $|t_1| = |t_2|$ (band inversion)

**Bulk-boundary correspondence**

- Edge states are there because of the non-trivial topology of the bulk
- They are topologically protected
- You can perturb the boundary (doping, changes in the hoppings close to the boundary) and they are robust
- The boundary states are the most important manifestation of topology in a material
- This is a 1D instance of the bulk-boundary correspondence