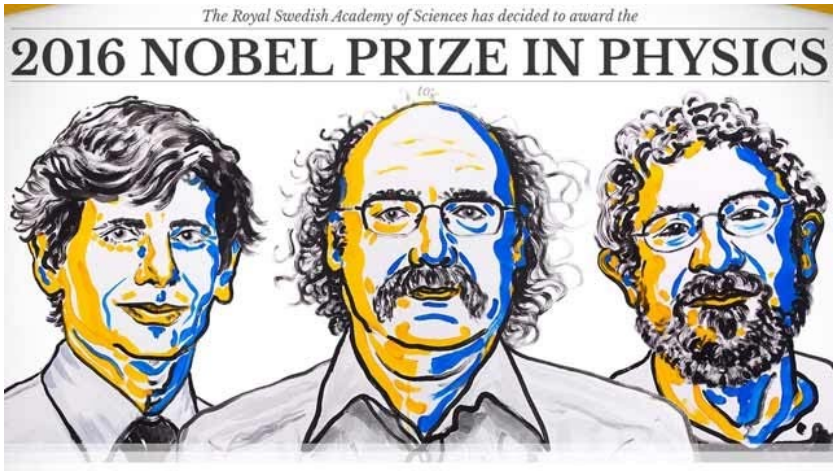
Nobel Prize in Physics (2016): Topological Phases of Matter

KEVIN LI

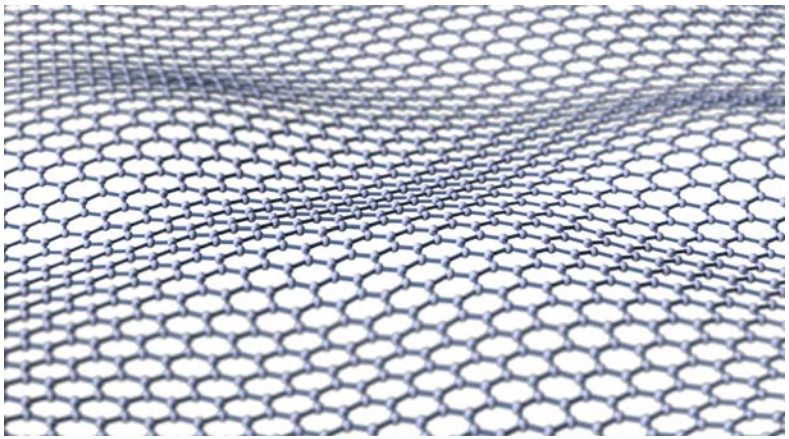
Joint Recipients

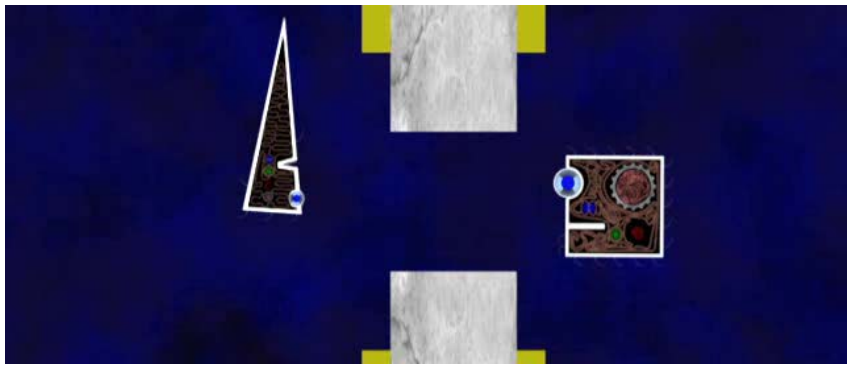
- David J. Thouless (UWash Seattle) [1/2]
- F. Duncan M. Haldane (Princeton University) [1/4]
- J. Michael Kosterlitz (Brown University) [1/4]



Overview

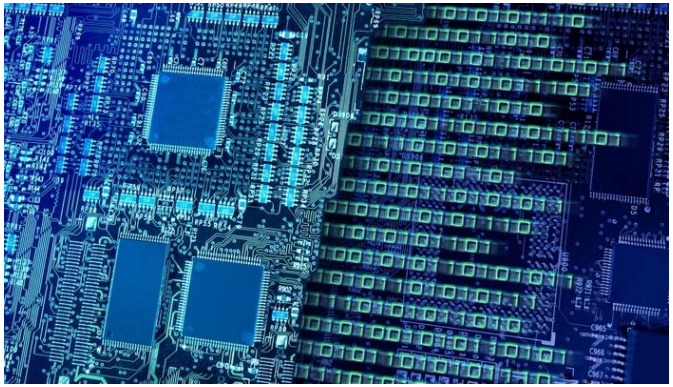
- Utilized topology and other mathematical methods to explain unusual phenomena in “flatlands” (i.e. atom-thick surfaces and layers that are essentially characterized as two-dimensional), superfluids/conductors, nanofibers





Condensed Matter Physics – A Hot Topic

- Physics that occurs on flatlands and micro-scale is vastly different than the world we see around us – especially when multiple atoms come very close together.
- Condensed matter physics linked with materials science and is applied to conductors and semiconductors → new materials and composites, superconductivity, quantum computing



Temperature: The Game Changer

- When we go to very low temperatures, close to absolute zero (-273.15 Celsius), matter begins to behave strangely – and quantum physics is much more easily visible.
- For example, when at a low enough temperature some conductors can become superconductors – ie no electrical resistance, and some fluids become superfluids that when swirled can spin forever without slowing down.

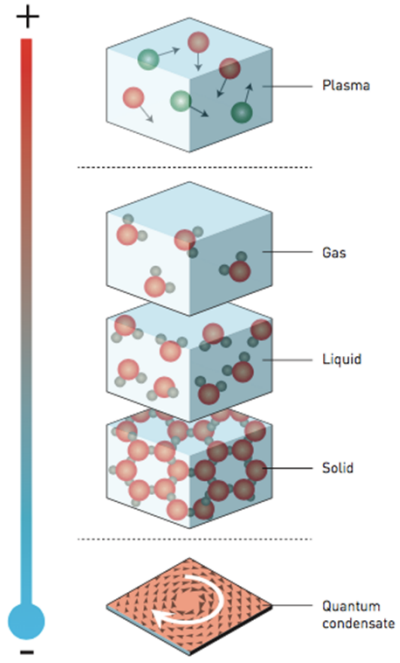
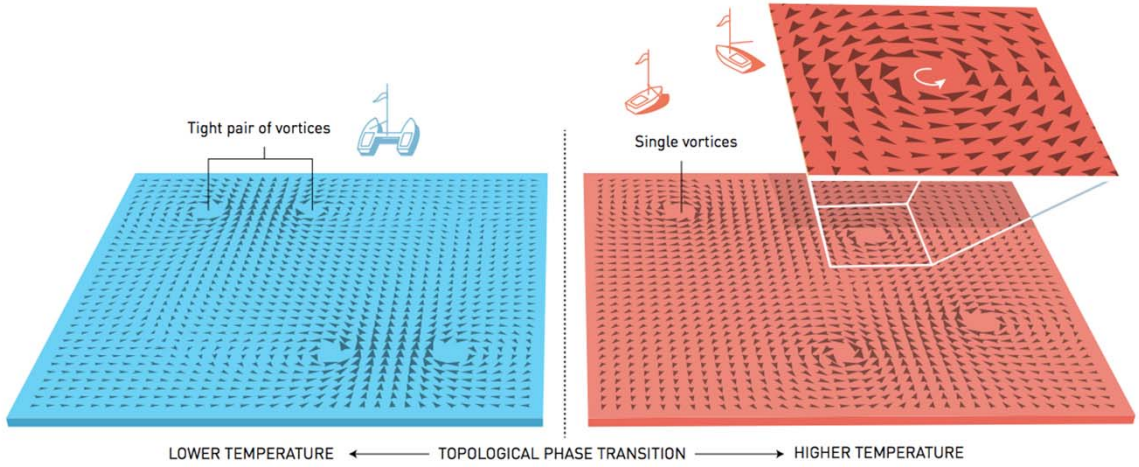


Fig. 1 Phases of matter. The most common phases are gas, liquid and solid matter. However, in extremely high or low temperatures matter assumes other, more exotic states.

Transitions and Phases in Flatlands

- Previously believed that thermal fluctuations destroy order in two-dimensional matter – so no ordered phases means no transitions as well.
- Thouless and Kosterlitz created new theory of topological phase transitions, with the explanation of vortices: at low temperatures, they form tight pairs, and at higher temperatures, they “sail” apart from one other(KT transition)

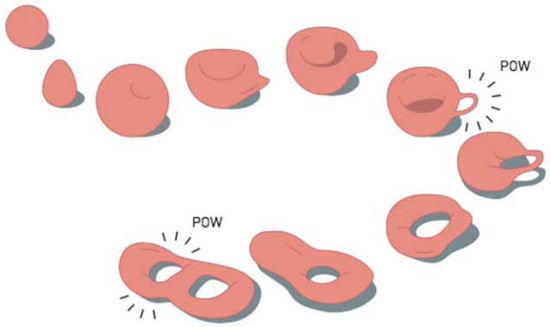


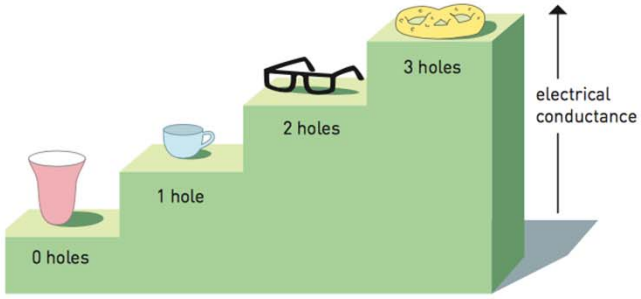
The Quantum Hall Effect

- Thouless and Haldane challenged the current quantum mechanical theory of how materials conduct electricity – using topology.
- Quantum Hall Effect: The quantum-mechanical version of the Hall Effect (voltage from perpendicular electrical current and magnetic field); discovered by Klitzing w/ two thin conducting layers subjected to magnetic field.

The Problem and the Solution

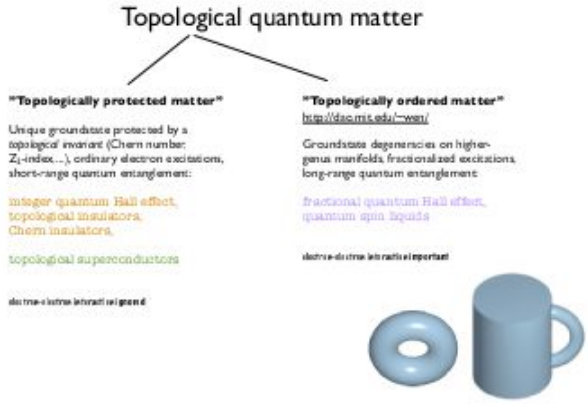
- For the quantum Hall effect, electrical conductance in layers only assumed certain values, but only in multiples of integers – even with varying levels of temperature, magnetic field, and impurities in the semiconductor.
- Thouless used topology to solved this problem: as we know, holes can be a way to distinguish objects (thus bowl and sphere are in same group, as well as donut and coffee mug with handle, etc.)





(continued)

- In quantum Hall effect, electrons move freely in layer b/t semiconductors; form topological quantum fluid, which exhibits certain qualities as described by condensed matter physics
- Similarly to how you can't see if a coffee cup has a hole by looking at part of it, you can't find if there is a TQF by looking at some of them. Because conductance is determined by collective motion of electrons and topology is stepwise, conductance is quantized.
- TQFs have unusual properties especially at their borders
- Haldane discovered that topological quantum fluids can form in semiconductor layers even without a magnetic field (validated in 2014)



Topological Magnetic Atomic Chains

- Haldane theorized in 1982 the presence of two types of chains of magnetic atoms: odd and even.
- A chain of even magnets is topological whereas an odd is not; moreover, the chain must be viewed as a whole to determine the presence of topological properties, which are found at the ends of the chains (known as spin halves)
- This has led to the discovery of new topological matter such as topological superconductors, insulators, and metals.
- https://johncarlosbaez.wordpress.com/2016/10/07/kosterlitz-thouless-transition/

Questions?