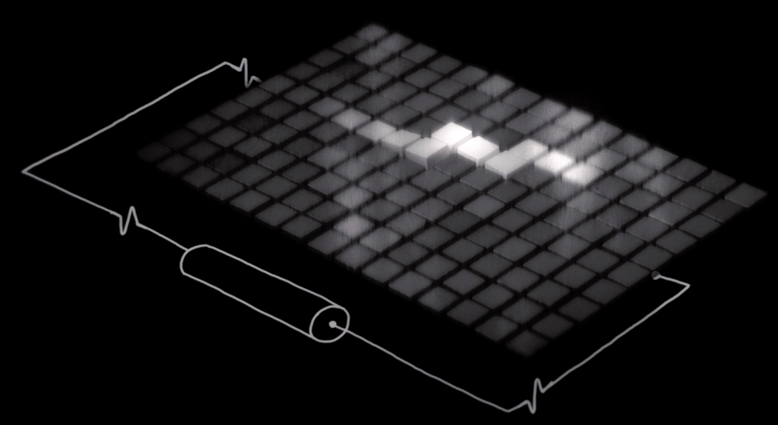
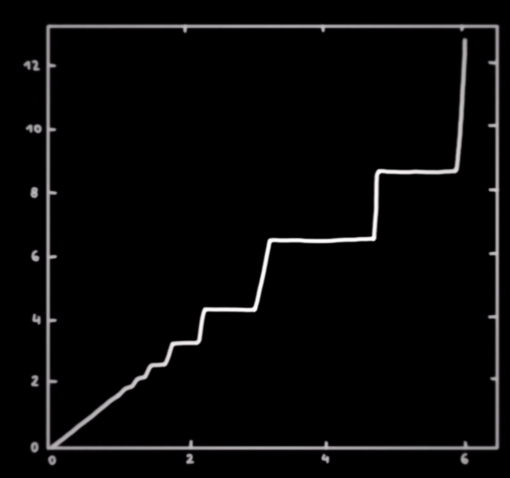
TOPOLOGICAL PHYSICS

Quantum Hall effect



1980: Klaus Von Klitzing studies the movement of electrons in a two-dimensional metal placed in a very strong magnetic field.

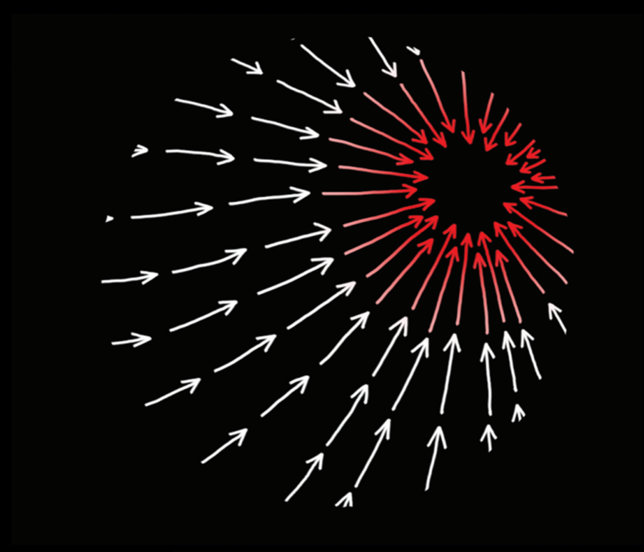


His graph shows unexpected plateaux.

$$\frac{h}{8e^2} \quad \frac{h}{6e^2} \quad \frac{h}{4e^2} \quad \frac{h}{3e^2}$$

The values of these plateaux turn out to be universal !

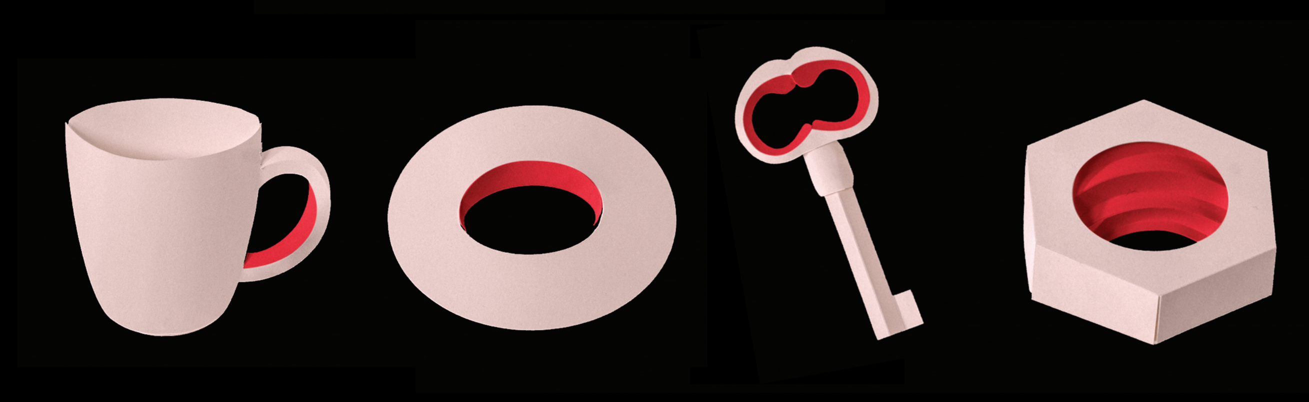
1982: The physicist David Thouless has the idea to analyse Von Klitzing's findings within the reciprocal space, a mathematical construct where electrons translate as arrow-like vectors picturing their velocities.



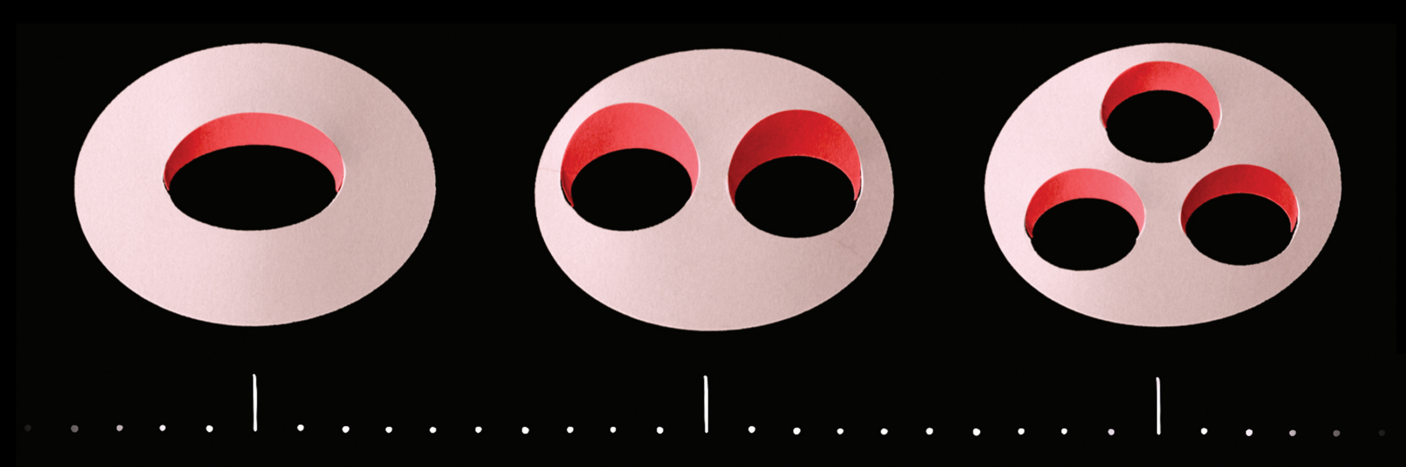
Here, the reciprocal space is a ball that electrons must cover. Thouless identifies a topology problem.

Topology in Solids

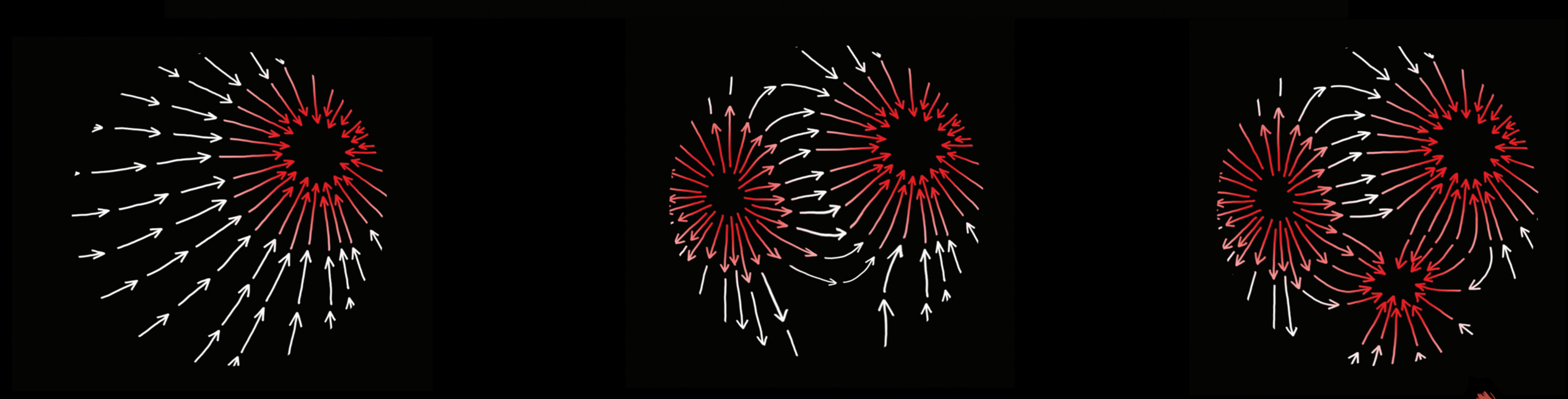
In mathematics, topology is the study of invariant properties in objects, properties that are not affected by deformations : holes, for example.



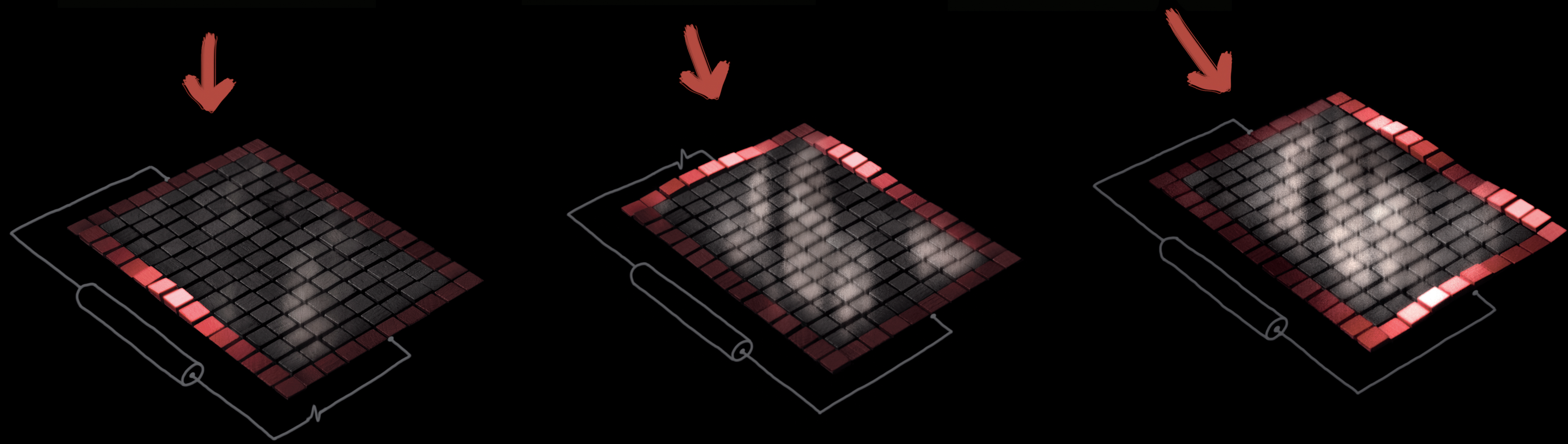
Objects can therefore be classified according to their number of topological invariant, such as holes…



… or the number of hair swirls on a hairy ball, just like the electrons in this case.



Thouless calculates that each "swirl" equates to an electron wave traveling on the edges of the sample. These waves are at the source of Von Klitzing's plateaux.

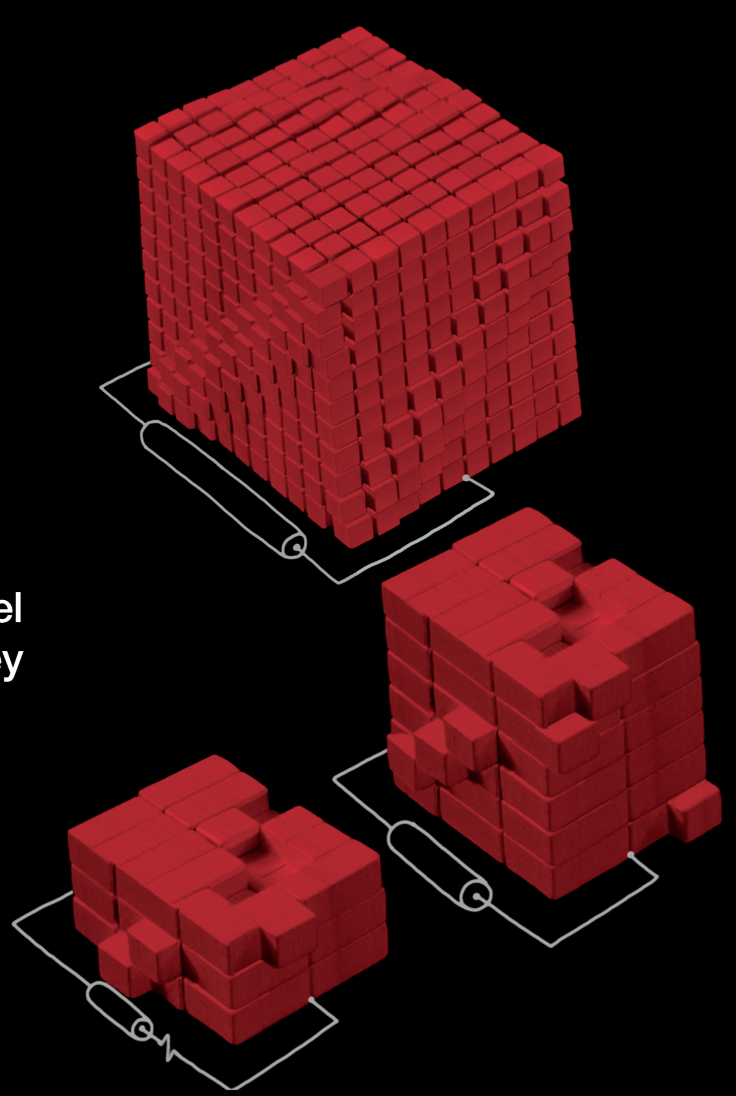


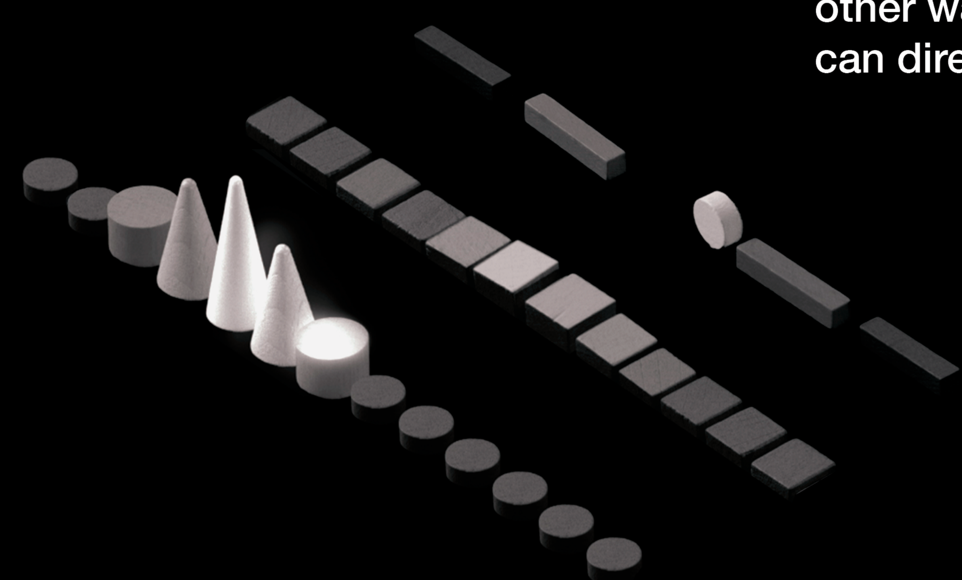
Beyond solids

Since then, physicists have applied topology to other waves and created artificial materials that can direct those waves at will.

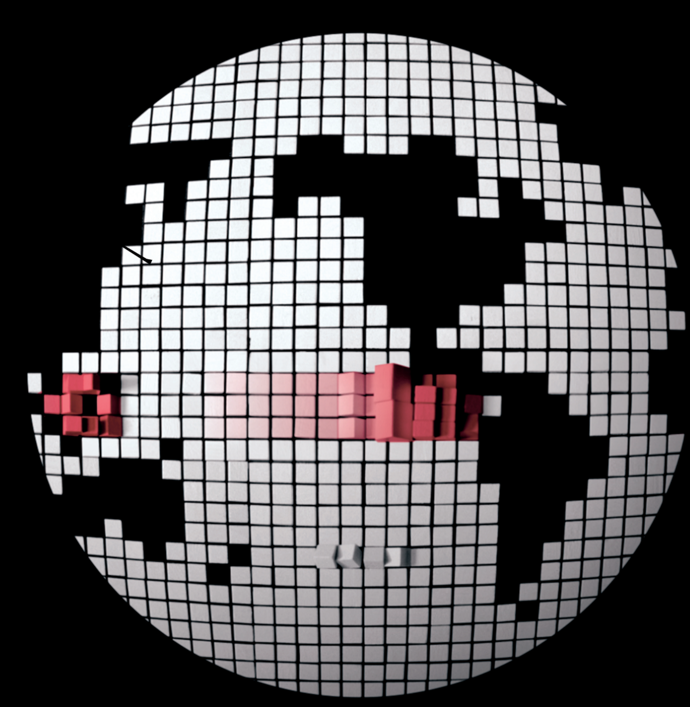
Topological insulators

2000 and further: physicists discovered that these topological properties can be observed in other materials, not just two-dimensional ones, and even without a magnetic field. Electrical current can only travel on the surface of such materials, they are "topological insulators".



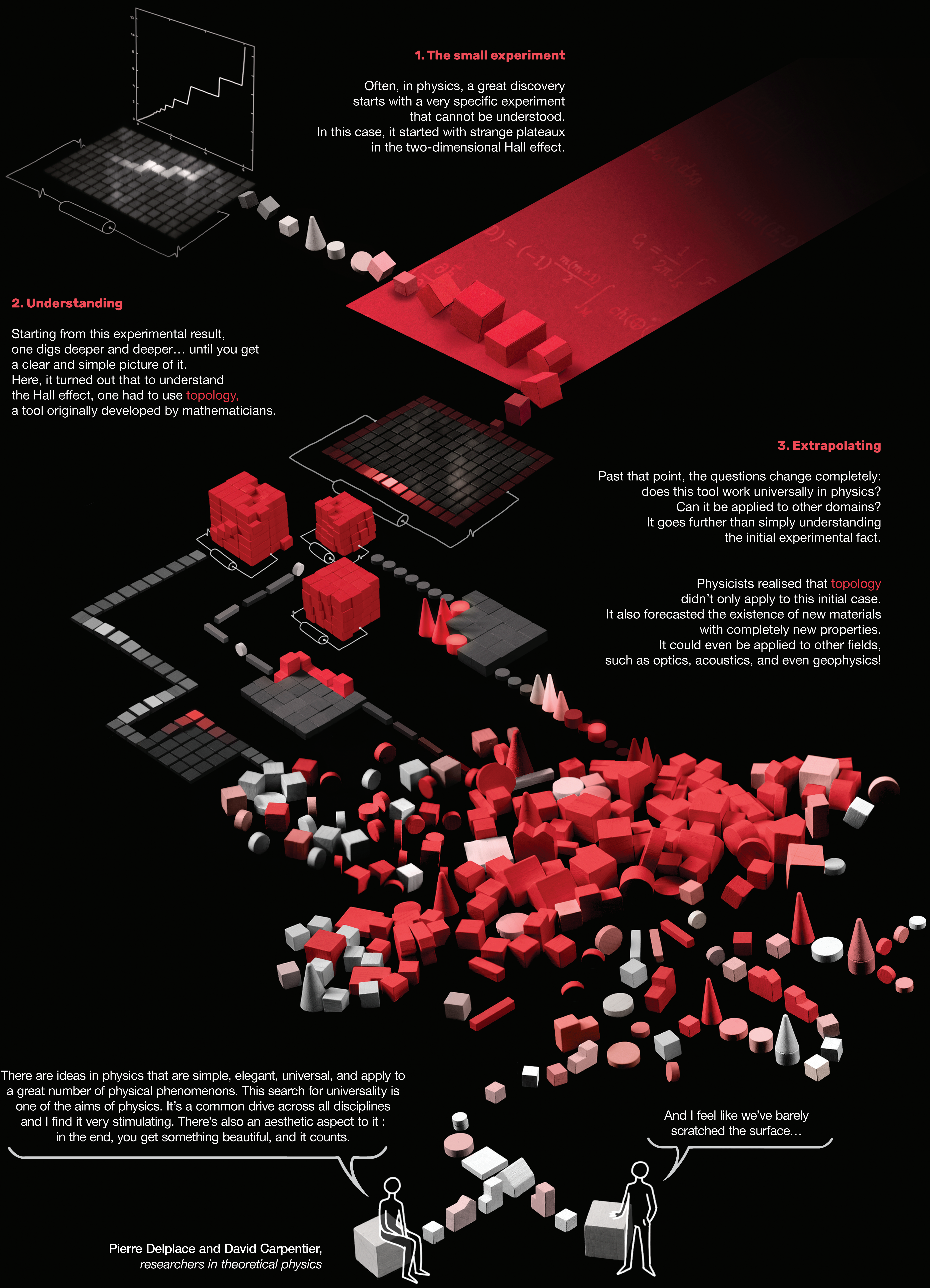


Topology can even be applied to waves in the ocean. This led to an understanding of the origin of some equatorial waves, that can only propagate eastward.



THE MAKING OF A GREAT DISCOVERY

The example of topology in quantum physics



1. The small experiment

Often, in physics, a great discovery starts with a very specific experiment that cannot be understood. In this case, it started with strange plateaux in the two-dimensional Hall effect.

2. Understanding

Starting from this experimental result, one digs deeper and deeper… until you get a clear and simple picture of it. Here, it turned out that to understand the Hall effect, one had to use topology, a tool originally developed by mathematicians.

3. Extrapolating

Past that point, the questions change completely: does this tool work universally in physics? Can it be applied to other domains? It goes further than simply understanding the initial experimental fact.

Physicists realised that topology didn't only apply to this initial case. It also forecasted the existence of new materials with completely new properties. It could even be applied to other fields, such as optics, acoustics, and even geophysics!

There are ideas in physics that are simple, elegant, universal, and apply to a great number of physical phenomenons. This search for universality is one of the aims of physics. It's a common drive across all disciplines and I find it very stimulating. There's also an aesthetic aspect to it : in the end, you get something beautiful, and it counts.

And I feel like we've barely scratched the surface…

Pierre Delplace and David Carpentier,
researchers in theoretical physics