LHC for quasiparticles reveals material secrets

Electron and holes smashed together inside a crystal.

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Quasiparticles underlie behaviour such as light-emission in semiconductors; a better understanding of their behaviour could lead to a new generation of light sources.

Smashing things together at high energies is a productive way for physicists to learn about the Universe — as the Large Hadron Collider (LHC) has shown.

Now, physicists in Germany and the United States have described a way to smash things together inside a semiconductor crystal. But rather than protons or electrons, the researchers instead collide short-lived entities known as quasiparticles. The experiments should reveal more about the properties and interactions of quasiparticles, some of which are fundamental to basic processes in physics — such as light-emission and superconductivity — but remain poorly-understood.

Nature Podcast

Lizzie Gibney talks to the researcher colliding quasiparticles together

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Quasiparticles are a way of modelling the cluster of interactions between many particles inside a solid material. An electron quasiparticle, for example, represents the combination of an electron moving in a material and the movements that it triggers in nearby atomic nuclei and electrons as it travels. Mathematically, this behaviour can be modelled as if all these motions represented a single, isolated particle travelling through empty space, with a defined mass, charge and energy.

It is intuitive for physicists to think in terms of quasiparticles, in the same way that it makes sense to follow a moving bubble in water, rather than trying to chart every molecule that surrounds it, says Mackillo Kira, a physicist at the University of Marburg in Germany and co-author of a report on the quasiparticle collider, published in *Nature*[1].

Quasiparticle collider

The principle behind the collider is the same as at the LHC — smash things together at a predetermined moment, then learn about their structure and interactions by studying the collision debris. But the set-up is very different. At the LHC, protons are isolated inside a 27-kilometre vacuum tube, and collided at nearly the speed of light. Kira's collisions take place within a tiny chunk of semiconductor and happen with one-quadrillionth (one-millionth of one-billionth) of the energy of those at the LHC.

Kira and his team use precisely timed terahertz pulses to collide electron quasiparticles with positively charged quasiparticles known as holes — the vacancies left when electrons are freed from atoms.

The team first shines an ultrashort laser pulse, lasting just 100 femtoseconds (10^{-15} seconds), onto a 60-nanometre-thick slab of the semiconductor tungsten diselenide. In the same way that light creates a current in a solar cell, the laser sets electrons free from atoms to move around the semiconductor, leaving positively charged holes behind. In this material, the electrons and holes don’t drift apart freely: they are bound by their electric attraction in a pair known as an exciton, another kind of quasiparticle.

The researchers then apply a strong, oscillating electromagnetic field that pulls the excitons apart, accelerating the electron and hole quasiparticles in opposite directions. Finally, it sends the quasiparticles smashing back into each other in a controlled collision. When pairs of oppositely charged quasiparticles meet, they annihilate and produce photons — particles of light — that the team maps.

Wang Yao, a physicist at the University of Hong Kong, says that the collisions reveal important information, such as the internal structure of the parent exciton, and how strongly electrons and holes bind together. That might help physicists to design new types of efficient light-emitting devices and solar cells.

Applied to other kinds of quasiparticles, the technique might help to elucidate mysterious phenomena within materials, such as high-temperature superconductivity, says Kira. It should be possible, for instance, to collide exotic quasiparticles such as Bogoliubov quasiparticles, which are broken halves of Cooper pairs, the weakly bound electrons responsible for superconductivity , or dropletons, a liquid-like cluster of three or more electron–hole pairs. “We are convinced that our new collider is quite broadly applicable to many quasiparticles in many different solids,” he says.

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References

1. Langer, F. *et al*. *Nature* **533**, 225–229 (2016).