Magnetic fields and lasers elicit graphene secret

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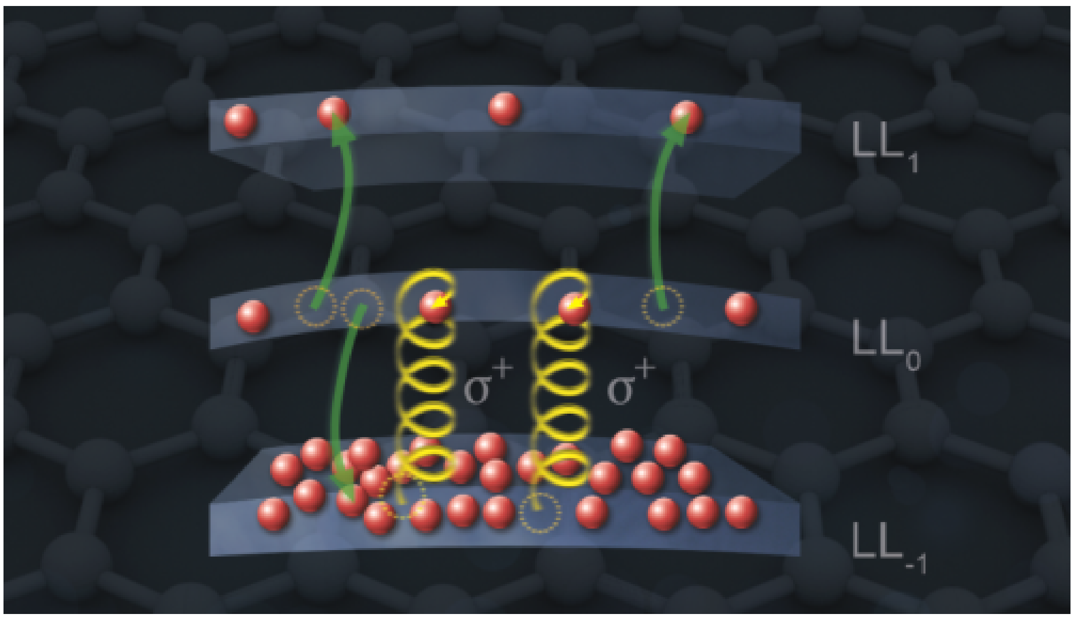

This is a model of the electron redistribution through Auger scattering that HZDR researchers discovered in graphene. Credit: HZDR/Voigt

Scientists at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) have studied the dynamics of electrons from the "wonder material" graphene in a magnetic field for the first time. This led to the discovery of a seemingly paradoxical phenomenon in the material. Its understanding could make a new type of laser possible in the future. Together with researchers from Berlin, France, the Czech Republic and the United States, the scientists precisely described their observations in a model and have now published their findings in the scientific journal *Nature Physics*.

Graphene is considered a "wonder material": its breaking strength is higher than steel and it conducts electricity and heat more effectively than copper. As a two-dimensional structure consisting of only a single layer of carbon atoms, it is also flexible, nearly transparent and approximately one million times thinner than a sheet of paper. Furthermore, shortly after its discovery ten years ago, scientists recognized that the energy states of graphene in a magnetic field - known as Landau levels - behave differently than those of semiconductors. "Many fascinating effects have been discovered with graphene in magnetic fields, but the dynamics of electrons have never been studied in such a system until now," explains physicist Dr. Stephan Winnerl from HZDR.

The HZDR researchers exposed the graphene to a four-Tesla magnetic field - forty times stronger than a horseshoe magnet. As a result, the electrons in graphene occupy only certain energy states. The negatively charged particles were virtually forced on tracks. These energy levels were then examined with free-electron laser light pulses at the HZDR. "The laser pulse excites the electrons into a certain Landau level. A temporally delayed pulse then probes how the system evolves," explains Martin Mittendorff, doctoral candidate at the HZDR and first author of the paper.

Electron redistribution surprises scientists

The result of the experiments has astonished the researchers. This particular energy level, into which new electrons were pumped using the laser, gradually emptied. Winnerl illustrates this paradoxical effect using an everyday example: "Imagine a librarian sorting books on a bookshelf with three shelves. She places one book at a time from the lower shelf onto the middle shelf. Her son is simultaneously 'helping' by taking two books from the middle shelf, placing one of them on the top shelf, the other on the bottom. The son is very eager and now the number of books on the middle shelf decreases even though this is precisely the shelf his mother wishes to fill."

With intense light from the HZDR's free-electron lasers materials can be examined on the atomic level. Credit: HZDR/Frank Bierstedt

Because there were neither experiments nor theories regarding such dynamics before, the Dresden physicists initially had difficulty interpreting the signals correctly. After a number of attempts, however, they found an explanation: collisions between electrons cause this unusual rearrangement. "This effect has long been known as Auger scattering, but no one expected it would be so strong and would cause an energy level to become depleted," explains Winnerl.

This new discovery could be used in the future for developing a laser that can produce light with arbitrarily adjustable wavelengths in the infrared and terahertz ranges. "Such a Landau-level laser was long considered impossible, but now with graphene this semiconductor physicists' dream could become a reality," says Winnerl enthusiastically.

Berlin researchers calculate complex model for Dresden experiments

After the fundamental model used in the experiments had worked satisfactorily, the precise theoretical work followed, which was carried out at the Technical University Berlin. Berlin scientists Ermin Malic and Andreas Knorr confirmed, using complex calculations, the Dresden group's assumptions and provided detailed insights into the underlying mechanisms. The HZDR researchers additionally cooperated with the French High Magnetic Field Laboratory in Grenoble (Laboratoire National des Champs Magnétiques Intenses - LNCMI), the Charles University Prague and the Georgia Institute of Technology in Atlanta (USA).

More information: Martin Mittendorff, Stephan Winnerl et al.: "Carrier dynamics in Landau quantized graphene featuring strong Auger scattering", *Nature Physics*, in press, DOI: 10.1038/NPHYS3164

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