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The annihilation of exceptional points from various degeneration points was observed for the first time in the world.

A team of researchers from the University of Warsaw in Poland, the Institute Pascal CNRS in France, the Military University of Technology in Poland and the British University of Southampton has shown that it is possible to control the so-called exceptional points. For the first time, physicists also observed the annihilation of exceptional points from different degeneracy points. You can read about the discovery that may contribute to the creation of modern optical devices in the latest "Nature Communications".

The universe around us is made of elementary particles, most of which have their antiparticles. When a particle and an antiparticle, that is, matter and antimatter, meet each other, annihilation occurs. Physicists have long been able to produce quasiparticles and quasiantiparticles – elementary excitations: charge, vibration, energy - trapped in matter: most often in crystals or liquids. – The world of quasiparticles can be very complicated, although paradoxically, the quasiparticles themselves help simplify the description of quantum phenomena – explains Jacek Szczytko from the Faculty of Physics of the University of Warsaw. – Without quasiparticles it would be difficult to understand the operation of transistors, light-emitting diodes, superconductors and some quantum computers. Even abstract mathematical concepts can become quasiparticles, as long as they can be implemented in physical systems. One of such abstract concepts are exceptional points.

Theorists from Institute Pascal CNRS in France, Guillaume Malpuech and Dmitry Solnyshkov expound. – The so-called "exceptional points" are specific system parameters leading to the commonality of two different solutions that can only exist in systems with losses, i.e. those in which the oscillations slowly fade over time – explains Guillaume Malpuech. – They allow the creation of efficient sensors, single-mode lasers, or unidirectional transport. What is important, each exceptional point has a non-zero topological charge - a certain mathematical feature that describes the fundamental geometric properties and allows you to determine which exceptional point will be the "antiparticle" for another exceptional point – adds Dmitry Solnyshkov.

Scientists from the University of Warsaw and the Military University of Technology in cooperation with researchers from the CNRS and the University of Southampton analysed the optical resonator filled with liquid crystal. Liquid crystals are a special phase of matter in which certain directions are distinguished despite its liquid form. It can be probed, for example, by a light beam, which behaves differently depending on the direction of incidence in relation to the optical axes of the liquid crystal. This feature, combined with the easy tunability by an external electric field, is the basis for the operation of common liquid crystal

displays (LCD). Polarized light - that is, a specific direction of vibrations of the electric field of an electromagnetic wave - perfectly "senses" the direction of optical axes, and these are related to the direction of the elongated molecules of the liquid crystal.

– In the conducted research, the liquid crystal layer was placed between two flat mirrors – describes Wiktor Piecek from the Military University of Technology in Warsaw. – The whole structure creates an optical cavity, through which only light with a specific wavelength can pass.

This condition is met for the so-called cavity resonance modes - that is, light with a certain colour (energy), polarization and direction of propagation. This corresponds to a situation where a photon that falls into the cavity can bounce multiple times between the two mirrors. The presence of a liquid crystal, the orientation of which can be changed by applying a voltage, allows the energy of the cavity modes to be tuned. In addition, the resonance condition changes when the light is incident at an angle, which in particular can lead different cavity modes to intersect with each other, i.e. have the same energy despite different polarization of the light.

For the specific orientation of the liquid crystal considered in the article, the two different cavity modes should intersect only for the four specific incidence angles of light when considering an ideal structure without any losses. In fact, the light trapped in the cavity can escape through imperfect mirrors or be scattered. The average time the photon remains inside the microcavity can be determined on the basis of spectroscopic measurements. Moreover, due to the orientation of the liquid crystal layer, a difference was observed in the scattering of light polarized along and perpendicular to the axis of the liquid crystal. As a result, at the place of each degeneracy point for an idealized lossless cavity, a pair of so-called exceptional points were observed for which both the energy and lifetime of the photon in the cavity are the same.

Mateusz Król, who is the first author of the publication, describes the experiment. – In the tested system it was observed that the position of exceptional points can be controlled by changing the voltage applied to the cavity. First of all, as the electric bias is reduced, the exceptional points created from different degeneracy points get closer to each other, and for a suitably low voltage, they overlap. As the approaching points have an opposite topological charge, they annihilate at the time of the encounter, so they disappear, leaving no exceptional points. – This type of topological singularity behaviour, i.e. the annihilation of exceptional points from different degeneracy points, has been observed for the first time. Earlier work showed the annihilation of exceptional points, but they appeared and disappeared at exactly the same degeneracy points – adds Ismaël Septembre, a PhD student at the CNRS.

Exceptional points have been intensively studied in many different areas of physics in recent years. – Our discovery will allow the creation of optical devices whose topological properties can be controlled by voltage – concludes Barbara Piętka from the Faculty of Physics of the University of Warsaw.

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Physics and astronomy at the University of Warsaw appeared in 1816 as part of the then Faculty of Philosophy. In 1825, the Astronomical Observatory was established. Currently, the Faculty of Physics at the University of Warsaw consists of the following institutes: Experimental Physics, Theoretical Physics, Geophysics, the Department of Mathematical Methods and the Astronomical Observatory. The research covers almost all areas of modern physics, on scales from quantum to cosmological. The Faculty's research and teaching staff consist of over 200 academic teachers, 81 of whom are professors. About 1,000 students and over 170 doctoral students study at the Faculty of Physics at the University of Warsaw.

SCIENTIFIC PUBLICATION:

M. Król, I. Septembre, P. Oliwa, M. Kędziora, K. Łempicka-Mirek, M. Muszyński, R. Mazur, P. Morawiak, W. Piecek, P. Kula, W. Bardyszewski, P. G. Lagoudakis, D. D. Solnyshkov, G. Malpuech, B. Piętka & J. Szczytko *Annihilation of exceptional points from different Dirac valleys in a 2D photonic system*

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CONTACT:

Jacek Szczytko
Faculty of Physics University of Warsaw
email: jacek.szczytko@fuw.edu.pl
Phone number +48 55 32 764

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"Trajectory of exceptional points on the real part of the light spectrum" (*visualisation: Mateusz Król, source: Faculty of Physics, University of Warsaw*).