MAX PLANCK INSTITUTE
FOR THE SCIENCE OF LIGHT

Of the Geometry of Light

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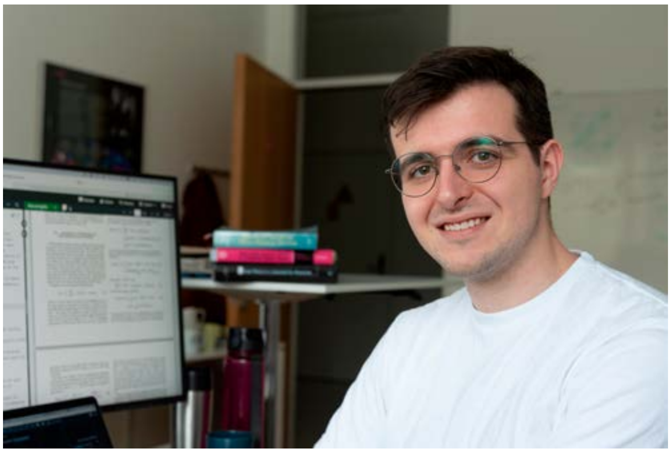
Quantum geometry is a mathematical tool that describes how quantum states change with the parameters of a system. This abstract geometric description helps researchers, for example, to better understand the properties of quantum materials or to improve the fundamental limits on measurement precision in quantum metrology. A German-Japanese research team involving the Max Planck Institute for the Science of Light in Erlangen and the Advanced Institute for Materials Research at Tohoku University in Sendai has applied quantum geometry to photonic systems and, with their new method, expanded the toolkit for topological photonics. Their results were published in Physical Review Research.

Quantum geometry describes quantum states in systems with changing system parameters, such as an electron spinning in a magnetic field whose direction is slowly changing. The state of the electron evolves, and this change is quantified by what is known as the quantum geometric distance. With the help of this abstract geometric description, it is possible, for example, to explain superconductivity – defined as the resistance-free conduction of current – in exotic quantum materials. Another example can be found in quantum metrology: by applying quantum geometry, fundamental limits on measurement accuracy can be determined.

In an international research project, Anton Montag, a doctoral student at the Max Planck Institute for the Science of Light in Erlangen, and Dr. Tomoki Ozawa, a world-leading expert in topological photonics at the Advanced Institute for Materials Research at Tohoku University in Sendai, have applied quantum geometry to non-Hermitian systems, which are commonly encountered in topological photonics.

In comparison to conventional descriptions of closed physical systems, non-Hermitian descriptions are significantly more complex: they include the exchange between the system and its environment. Thus, important additional properties, such as the gain and loss of intensity or energy, are incorporated into this mathematical approach. In recent years, the field of research on non-Hermitian topological systems has developed rapidly and provided far-reaching insights for experimental physics. Numerous theoretical predictions, such as the non-Hermitian



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Anton Montag, doctoral student in the research group of Dr. Flore Kunst "non-Hermitian topological phenomena" at the Max Planck Institute for the Science of Light in Erlangen

© Tomoki Ozawa

Dr. Tomoki Ozawa, group leader at the Advanced Institute for Materials Research at Tohoku University in Sendai, Japan skin effect, the funneling of light, and unidirectional invisibility, have been verified in photonic experiments.

Montag and Ozawa have investigated whether “quantum-geometric” effects influence the behavior of non-Hermitian photonic systems, thereby introducing a new degree of complexity into the mathematical description. The scientists recently published their key findings.

Artificial Potentials for Light – When polarized light passes through an anisotropic medium (a medium that exhibits different properties in different directions), in which the change in intensity depends on the polarization of the light, it does not travel in a straight line but is deflected. The path is determined by “quantum geometry.” Through the non-Hermitian extension, it is now also possible to control how much the light gains or loses intensity along its path – a programmable artificial potential for light, so to speak.

Direct Measurement of the Quantum Metric – The German-Japanese team has developed a method to measure the quantum metric directly in an experiment. The underlying principle is as follows: a photonic system is excited with a weak periodic signal, and the system’s response is measured. The excitation produces a small amount of light that escapes from the system. The intensity of this escaping light is directly proportional to the quantum metric – it can essentially be read off directly.

“For this particular research question, the collaboration with the Japanese group was an ideal setup. Dr. Tomoki Ozawa contributed his exceptional expertise in topological photonics, while the expertise from the Erlangen group led by Dr. Flore Kunst added a focus on the field of “non-Hermitian topological phenomena”,” says Anton Montag. “I am quite excited by the result, as it is fundamentally different from the situations of (ordinary) Hermitian quantum mechanics, highlighting a unique feature of non-Hermitian systems,” adds Tomoki Ozawa.

In recent years, experimental topological photonics has made enormous strides. Many of the predictions can therefore be directly verified experimentally. Conversely, artificial potentials for light offer new design possibilities for photonic systems. The same principle also applies to extremely cold atomic gases. There, such artificial potentials are used, for example, to generate artificial magnetic fields. Atom losses from the gas – previously considered a problem – could, according to this theory, be specifically utilized to generate non-Hermitian effects in ultracold atomic gases.

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