Scientists build an exceptional surface out of exceptional points

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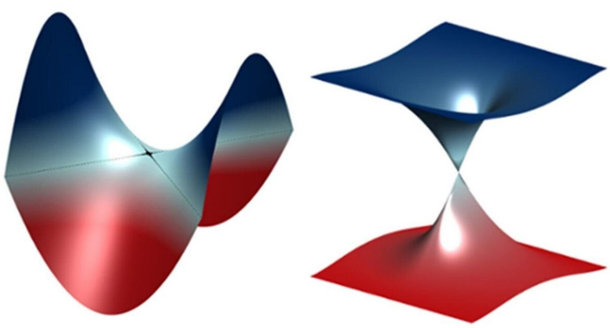

Left graph plots exceptional point conditions in three-dimensional space, calculated from experimental measurements in CNM, forming an exceptional surface with an exceptional saddle point, indicated by the point at the intersection of the dark lines on the surface. Right graph plots energy dissipations of the two modes (photon and magnon), where different dependences on the tuning parameters occur near the intersection of blue and red surfaces. Credit: Argonne National Laboratory

Scientists at the U.S. Department of Energy's (DOE) Argonne National Laboratory are exceptional in many respects. Working in collaboration with the Imperial College London, for example, they have conducted research on a phenomenon in information processing systems called "exceptional points." This phenomenon has found applications in microwave, optical and mechanical technologies.

"Our team experimentally detected an exceptional surface, a continuous three-dimensional curving surface of exceptional points," said Xufeng Zhang, who led this international research project and works as an assistant scientist at the Center for Nanoscale Materials (CNM) at Argonne, a DOE Office of Science User Facility. Past research by others had detected exception points, and subsequent researchers had plotted lines of measured exceptional points, but this is the first time researchers have plotted surfaces.

"Our original contribution is to have mapped three-dimensional surfaces of exceptional points based on experimental measurements, and the result is strikingly beautiful graphs."—Xufeng Zhang, assistant scientist at the Center for Nanoscale Materials

"Think of two systems, each of which has its own loss of energy to the environment," explained Zhang. "Also imagine that these systems are coupled so that they can exchange energy between them."

When these systems are far apart, little interaction occurs between them, and energy-related calculations yield two independent solutions tied to their interactions with the environment alone. As they approach each other and interact together, the systems enter a transition phase where there is only one solution. That is considered an exceptional point. As the systems move even closer, the exceptional point vanishes, and the calculations yield pairs of "hybrid solutions," a mixture of the solutions for each system.

A possible application of exceptional points is sensors with greatly enhanced sensitivity to disruptions such as slight fluctuations in a magnetic field. Another application is mode conversion, which allows, for example, the signals from the two parties in a telephone call to be kept in separate modes, thereby essentially eliminating any undesired interference.

"Our original contribution is to have mapped three-dimensional surfaces of exceptional points based on experimental measurements, and the result is strikingly beautiful graphs," Zhang said. These exceptional surfaces themselves have what Zhang calls "exceptional saddle points," the most exceptional point among all the other exceptional points on the surfaces. These saddle points have heightened desired behavior over the other exceptional points.

The team's experimental apparatus combines two systems: a specialized printed circuit board that confines microwaves and a microscale magnetic sphere of yttrium iron garnet, which produces resonances called "magnons."

"Magnons are quantized quasiparticles associated with spin waves, a collective excitation of the magnetic ordering in a crystal lattice," Zhang explained. "What is important here is that changing the magnetization at one point in the lattice affects the neighboring sites like a wave rippling through the surface of a placid pond."

The team used a magneto-electro-optical spectrometer at the CNM to measure the response to different tunings of the photon-magnon coupling strength and position in their apparatus, then plotted the results in three-dimensional graphs of an exceptional surface.

While highly abstract and mathematical, this pivotal discovery could have real world impact in information processing. As one of several possible examples, information transfer demands that noise not corrupt the zeros and ones being transmitted, and exceptional surface mapping could help provide much greater protection for this process.

"Our work also opens up exciting new possibilities for quantum information processing with highly desired functionalities," Zhang noted.

More information: Xufeng Zhang et al, Experimental Observation of an Exceptional Surface in Synthetic Dimensions with Magnon Polaritons, *Physical Review Letters* (2019). DOI: 10.1103/PhysRevLett.123.237202