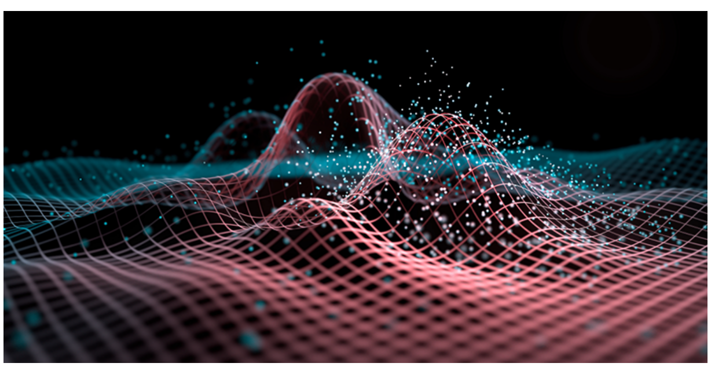
Breakthrough Prize for Quantum Field Theorists

The 2024 Breakthrough Prize in Fundamental Physics goes to John Cardy and Alexander Zamolodchikov for their work in applying field theory to diverse problems.

By **Michael Schirber**

Many physicists hear the words "quantum field theory," and their thoughts turn to electrons, quarks, and Higgs bosons. In fact, the mathematics of quantum fields has been used extensively in other domains outside of particle physics for the past 40 years. The 2024 Breakthrough Prize in Fundamental Physics has been awarded to two theorists who were instrumental in repurposing quantum field theory for condensed-matter, statistical physics, and gravitational studies.

"I really want to stress that quantum field theory is not the preserve of particle physics," says John Cardy, a professor emeritus from the University of Oxford. He shares the Breakthrough Prize with Alexander Zamolodchikov from Stony Brook University, New York.



The study of quantum fields is central to particle physics, but it has also led to breakthroughs in condensed-matter, statistical physics, and gravitational studies.
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The Breakthrough Prize is perhaps the "blingiest" of science awards, with $3 million being given for each of the five main awards (three for life sciences, one for physics, and one for mathematics). Additional awards are given to early-career scientists. The founding sponsors of the Breakthrough Prize are entrepreneurs Sergey Brin, Priscilla Chan and Mark Zuckerberg, Julia and Yuri Milner, and Anne Wojcicki.

The fundamental physics prize going to Cardy and Zamolodchikov is "for profound contributions to statistical physics and quantum field theory, with diverse and far-reaching applications in different branches of physics and mathematics." When notified about the award, Zamolodchikov expressed astonishment. "I never thought to find myself in this distinguished company," he says. He was educated as a nuclear engineer in the former Soviet Union but became interested in particle physics. "I had to clarify for myself the basics." The basics was quantum field theory, which describes the behaviors of elementary particles with equations that are often very difficult to solve. In the early 1980s, Zamolodchikov realized that he could make more progress in a specialized corner of mathematics called two-dimensional conformal field theory (2D CFT). "I was lucky to stumble on this interesting situation where I could find exact solutions," Zamolodchikov says.

CFT describes "scale-invariant" mappings from one space to another. "If you take a part of the system and blow it up by the right factor, then that part looks like the whole in a statistical sense," explains Cardy. More precisely, conformal mappings preserve the angles between lines as the lines stretch or contract in length. In certain situations, quantum fields obey this conformal symmetry. Zamolodchikov's realization was that solving problems in CFT—especially in 2D where the mathematics is easiest—gives a starting point for studying generic quantum fields, Cardy says.

Cardy started out as a particle physicist, but he became interested in applying quantum fields to the world beyond elementary particles. When he heard about the work of Zamolodchikov and other scientists in the Soviet Union, he immediately saw the potential and versatility of 2D CFT. One of the first places he applied this mathematics was in phase transitions, which arise when, for example, the atomic spins of a material suddenly align to form a ferromagnet. Within the 2D CFT framework, Cardy showed that you could perform computations on small systems—with just ten spins, for example—and extract information that pertains to an infinitely large system. In particular, he was able to calculate the critical exponents that describe the behavior of various phase transitions.

Cardy found other uses of 2D CFT in, for example, percolation theory and quantum spin chains. "I would hope people consider my contributions as being quite broad, because that's what I tried to be over the years," he says. Zamolodchikov also explored the application of quantum field theory in diverse topics, such as critical phenomena and fluid turbulence. "I tried to develop it in many respects," he says. The two theorists never collaborated, but they both confess to admiring the other's work. "We've written papers on very similar things," Cardy says. "I would say that we have a friendly rivalry." He remembers first encountering Zamolodchikov in 1986 at a conference organized in Sweden as a "neutral" meeting point for Western and Soviet physicists. "It was wonderful to meet him and his colleagues for the first time," Cardy says.

"Zamolodchikov and Cardy are the oracles of two dimensions," says Pedro Vieira, a quantum field theorist from the Perimeter Institute in Canada. He says that one of the things that Zamolodchikov showed was the infinite number of symmetries that can exist in 2D CFT. Cardy was especially insightful in how to apply the mathematical insights of 2D to other dimensions. Vieira says of the pair, "They understood the power of 2D physics, in that it is very simple and elegant, and at the same time mathematically rich and complex."
Vieira says that the work of Zamolodchikov and Cardy continues to be important for a wide range of researchers, including condensed-matter physicists who study 2D surfaces and string theorists who model the motion of 1D strings moving in time. One topic attracting a lot of attention these days is the so-called AdS/CFT correspondence, which connects CFT mathematics with gravitational theory (see **Viewpoint: Are Black Holes Really Two Dimensional?**). Cardy says that there's also been a great deal of recent work on CFT in dimensions more than two. "I'm sure that [higher-dimensional CFT] will win lots of awards in the future," he says. Zamolodchikov continues to work on extensions of quantum field theory, such as the "$T\overline{T}$ deformation," that may provide insights into fundamental physics, just as CFT has done.

Zamolodchikov and Cardy and the 18 other Breakthrough winners will receive their awards on April 13, 2024, at a red-carpet ceremony that routinely attracts celebrities from film, music, and sports. Cardy says that he is looking forward to it. "I like a good party."

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