of statistical mechanics could be clarified with the help of entanglement[7] — a remarkable proposition.

The kinematic approach is particularly successful because it does not concern itself with dynamical behaviour. However, this also means that only equilibrium states of statistical mechanics are analysed — how quantum systems actually equilibrate into these states is beyond the scope of the current theory. Recent insight into relaxation dynamics has been achieved by formulating the eigenstate thermalization hypothesis[8]. This hypothesis roughly states that in the long-time limit of many-particle systems undergoing unitary dynamics, the expectation values of thermodynamic observables behave like averages over thermodynamic equilibrium states. It has been suggested that entanglement may also be crucial to understanding this relaxation dynamics. Numerical evidence indicates that the growth of entanglement is the driving force behind this apparent thermalization of isolated quantum systems[9]. So the eigenstate thermalization hypothesis might also turn out to be a consequence of the dynamical behaviour of entanglement.

Quantum entanglement has come a long way. From its ghostly and conceptually obscure origins, it has become one of the most important and successful concepts in physics. The research of the past decade has shown that, in particular, the foundations of statistical physics are rooted in Einstein's spooky action at a distance. ❐

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EPR PARADOX

Nonlocal legacy

Eighty years ago, an article of four pages and eighteen equations appeared in *Physical Review* (**47,** 777–780; 1935), delivering a mighty blow to quantum mechanics — a theory that was still in its infancy. The authors were A. Einstein, B. Podolsky and N. Rosen, and they conjectured a paradox whose only solution entailed that quantum theory failed to provide a complete description of the physical reality. The troublesome meaning of the EPR paper, as it is nowadays known, was immediately recognized, even making the headlines of the *New York Times*.

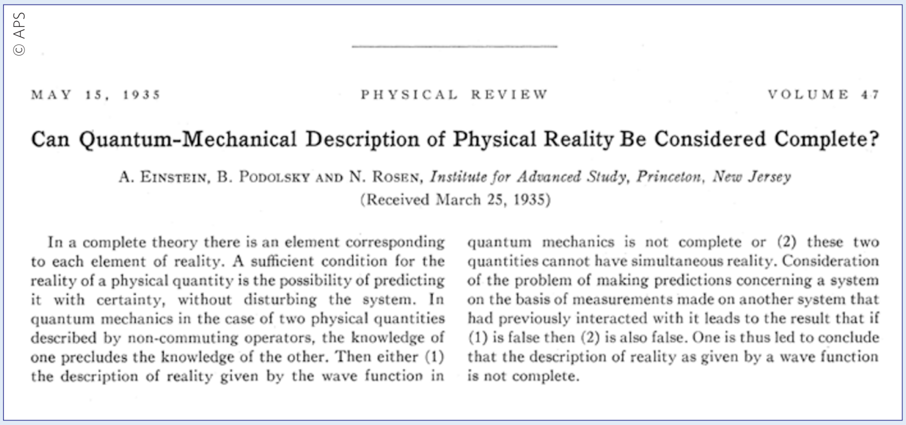
Although no physical theory should be considered complete in the sense of being definitive, the trio questioned the ability of quantum mechanics to comprehensively link the evident objective reality to suitable theoretical concepts. The whole argument, in modern terms, hinged on the fact that for an entangled pair of particles, selecting an observable to measure at one end alters which property should be considered real at the other end — without any interaction necessary. And as the authors noted, "No reasonable definition of reality could be expected to permit this."

Yet, eight decades and countless violations of Bell's inequalities later, we have become accustomed to living with such an unreasonable definition of reality. There is essentially no solution to the EPR paradox because physicists have surrendered to the idea that 'spooky action at distance' doesn't necessarily constitute paradoxical behaviour — and that our current description of nature therefore has to be fundamentally nonlocal.

But does this mean that Einstein, Podolsky and Rosen were wrong, and that quantum mechanics is in fact a complete theory? Not really. One could argue that their claims backfired somewhat, as they became an integral part of modern quantum mechanics, with EPR pairs turned into the currency for evaluating the performance of quantum devices and protocols. However, the true legacy of the EPR paradox lies in the investigation of the relationship between locality and reality, which remains far from exhausted.

Nonlocality has in fact been increasingly regarded no longer as a by-product of quantum theory, but one of its essential features. And this has paved the way to the development of research focused on the maximum degree of nonlocal correlations a given theory allows (*Nature Phys.* **10,** 264–270; 2014). Surprisingly, theories that allow stronger nonlocality than quantum mechanics have been found not to generate obvious contradictions with experiments or relativity. And studying their implications has revealed unexpected connections to the theory of information and communication, historically closer to the remit of computer science.

The result of Einstein, Podolsky and Rosen's paper did not deliver the fatal blow to quantum mechanics they perhaps wished for, but there is no doubt that it constitutes a milestone in physics, whose influence has yet to wane.



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Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?

A. Einstein, B. Podolsky and N. Rosen, *Institute for Advanced Study, Princeton, New Jersey*
(Received March 25, 1935)

In a complete theory there is an element corresponding to each element of reality. A sufficient condition for the reality of a physical quantity is the possibility of predicting it with certainty, without disturbing the system. In quantum mechanics in the case of two physical quantities described by non-commuting operators, the knowledge of one precludes the knowledge of the other. Then either (1) the description of reality given by the wave function in quantum mechanics is not complete or (2) these two quantities cannot have simultaneous reality. Consideration of the problem of making predictions concerning a system on the basis of measurements made on another system that had previously interacted with it leads to the result that if (1) is false then (2) is also false. One is thus led to conclude that the description of reality as given by a wave function is not complete.

FEDERICO LEVI