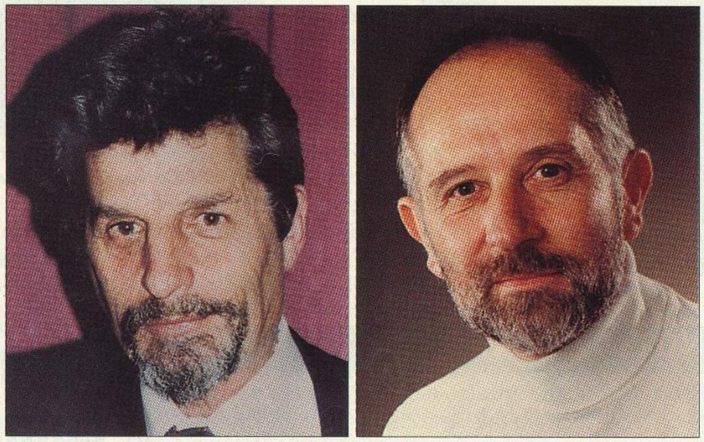
Quantum effects clinch Wolf prize

Yakir Aharonov and Sir Michael Berry have won the Wolf prize for the discovery of subtle and unexpected consequences of quantum theory, write **Murray Peshkin** and **Lev Vaidman**

Last month the 1998 Wolf prize for physics was awarded to Yakir Aharonov of Tel-Aviv University in Israel and the University of South Carolina in the US, and Sir Michael Berry of the University of Bristol in the UK. The official citation states that the award was made for "their discovery of quantum topological and geometrical phases and their incorporation into many fields of physics". The prize, which is awarded by the Israel-based Wolf foundation, is worth $100 000. It will be presented by the President of Israel, Ezer Weimann, in Jerusalem later this year.



Honoured for the discoveries that bear their names – Yakir Aharonov and Sir Michael Berry

Surprising result

In 1959 Aharonov and the late David Bohm showed that, according to standard quantum mechanics, the motion of a charged particle can be influenced by electromagnetic fields with which the particle makes no contact. The simplest case involves a beam of electrons, which is split and then recombined. The beam is split coherently into two beams, which pass on two sides of a magnetized solenoid. When the beams are recombined they have a phase difference, observable in an interference experiment, that depends on the magnetic flux in the solenoid. This came as a great surprise to most of the physics community because it challenged our fundamental understanding of the electromagnetic field as a physical entity carrying localized momentum and energy and interacting locally with charged particles. In fact the Aharonov–Bohm (AB) effect was doubted by many until it was confirmed by experiment.

The AB work has had a widespread impact both on fundamental theory and on diverse practical applications. First, it introduced a topological phase – a phase that depends on the topological characters of the interfering beam paths. Second, experiments to demonstrate the AB effect have also been interpreted as giving the first direct experimental proof of the gauge principle, which underlies all of modern quantum field theory. (This principle instructs us to represent the interaction of fields with particles through certain line integrals of the potentials, rather than through the electromagnetic fields.)

Aharonov and others have extended the AB effect to related phenomena involving particles with other interactions. Conceptual systems consisting of electrons bound to magnetic flux lines have led to models with fractional angular momentum that may have unusual statistics. On the practical side, the AB effect has enabled experiments to chart the magnetic fields in superconductors on a microscopic scale. In normal mesoscopic circuits, the effect has opened up a new field of investigation of normal conduction phenomena.

Geometric delight

Berry's discovery of the geometrical quantum phase also came as a surprise to the physics community. In his words, the phase is "an unexpected memory effect in the quantum systems whose environment is cycled". He considered the quantum phase acquired by a system undergoing slow cyclic evolution due to a changing environment, such as a slowly rotating external field. For many years the phase in such a situation was calculated as the time integral of the energy at every point in the cyclic evolution of the system. Berry discovered that this natural approach yields incorrect results – quantum systems undergoing cyclic evolution acquire, in addition to the "dynamical" phase given by the energy integral, a geometric phase. A familiar classical analogue of this is the the reduced rate of rotation of a Foucault pendulum at latitudes away from the Earth's poles.

This geometrical phase, now called the Berry phase, has provided a powerful unifying – and essentially geometric – conceptual framework applicable to diverse physical systems. It has been applied to photons, spin-½ nuclei and molecules. The 1991 Wolf prize in chemistry was awarded to Alexander Pines of the University of California, Berkeley, for the observation of geometrical phases in nuclear magnetic resonance experiments. The Berry phase has also been applied to anomalies in quantum field theory. Recently, Berry and Jonathan Robbins of Bristol University used it to connect spin and statistics in non-relativistic quantum mechanics, without all of the assumptions of relativistic field theory.

Contrasting approaches

The physics styles of the two awardees are strikingly different. Aharonov relies principally on his physics intuition. Frequently he discovers a novel effect intuitively, and it is only later that its rigorous proof is developed, often in collaboration with others. In contrast, Berry usually approaches the physics through sophisticated mathematical analysis. The geometric phase is one of many examples where he did this with great success. Other examples include the application of catastrophe theory to optics for the study of twinkling starlight, studies of the quantum signatures of classically chaotic systems, and the application of different asymptotic formulae for divergent series encountered in various branches of physics.

An example of these different approaches is their recent investigation of a peculiar interference phenomenon, wherein a small shift of superposed quantum waves can result in a very large net shift, sometimes in the opposite direction. Aharonov found this effect by discovering surprising outcomes of weak measurements on pre- and post-selected quantum systems. Berry employed the mathematical analysis of unusual functions that oscillate faster than any of their Fourier components to explain and extend this curious result.

Bristol University has double cause to celebrate the 1998 Wolf prize. Berry discovered the geometric phase at Bristol, where he has been based since 1965, and the Aharonov–Bohm effect was discovered at Bristol in 1959 while Yakir Aharonov was a PhD student there.

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