Quantum leap into the future

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Once regarded as the craziest idea of them all, quantum theory now underlies our understanding of the physical universe and is the basis of most modern technology. Cormac O'Raifeartaigh explains how the theory tookshape over a century ago.

By the end of the 19th century, most physical phenomena could be described by the known laws of physics. Yet as scientists began to probe the atomic world using new technologies, strange effects began to appear that could not be explained.

In 1900, Max Planck showed that the radiation of energy from a hot body could be successfully predicted only if it was assumed that heat energy was emitted in discrete chunks, or "quanta" (just as financial transactions occur in multiples of one cent).

In 1905, a young Albert Einstein noticed that the phenomenon of photoelectricity could be explained if it was assumed that energy was transferred as quanta. These ideas were at first ignored, because countless experiments had shown that light and heat energy behaved like waves, not streams of particles.

In 1913, the young Danish scientist Niels Bohr suggested that electrons in atoms are confined to certain stable, discrete energy states (described as separate orbits) and that radiation would be emitted only when electrons made quantum leaps from one orbit to another.

By 1925, with the insistence by Wolfgang Pauli that no two electrons could share one quantum state, the physical properties of the elements of the periodic table were understood in terms of the electronic structure of their atoms.

The spectacular success of ad hoc quantum ideas in atomic physics spurred efforts to discover an underlying theory. In 1924, French PhD student Louis-Victor de Broglie made the startling proposal that "perhaps all entities considered particles have associated wavelike properties, and this duality gives rise to quantum effects".

The wavelike properties of electrons were soon verified experimentally, and in 1926 the Austrian physicist Erwin Schrödinger published a wave equation for the electron. In the same year, Werner Heisenberg published a mathematical quantum theory later shown to be equivalent to Schrödinger's.

Best of all, in 1928 the brilliant young British scientist Paul Dirac published a generalised version of quantum theory that was consistent with the theory of relativity, gave a theoretical foundation for electron spin and, astonishingly, predicted the existence of antimatter, or electrons of opposite charge.

The new theory threw up many difficult questions. Are electrons and photons particles or waves? What does Schrödinger's wave represent physically?

The best answers were gathered by Bohr, Weisenberg and others in what became known as the Copenhagen interpretation, after the university at which they were based. They suggested that the state of a quantum system is defined only when a measurement is made; that Schrödinger's wave is simply a measure of the probability of a given state being observed; and that whether an object behaves as a particle or as a wave depends on how it is observed.

This interpretation marked a paradigm shift in our ideas about the nature of reality and remains essentially unchanged today. The strange implications of the new theory did not slow the development of novel applications for it.

One of the first applications of the new theory was in understanding the conduction of electricity in solids called semiconductors. Following the manufacture of the first semiconductor electric amplifier, or transistor, in 1947, valve technology was soon replaced by circuits made up of tiny semiconductor amplifiers and switches, which formed the basis of today's electronics industry.

A second discovery was the light amplifier, or laser, created by stimulating huge numbers of particles leaping simultaneously from one quantum state to another. Nowadays, laser technology is used in anything from medical surgery to bar-code recognition and has revolutionised telecommunications.

Future applications may include photonics - the use of light and optical switches instead of electricity and electronics. Quantum physics may deliver the next generation of superfast "quantum" computers.

And what of the theory itself? Modern experiments in particle accelerators have overwhelmingly confirmed the strangeness of the quantum world and produced a host of elementary particles (and antiparticles) predicted by quantum theory.