Akira Tonomura

(1942–2012)

Physicist who pioneered electron holography.

Akira Tonomura changed the field of fundamental physics through microscopy. Like botanist Robert Brown before him, he opened up a new world to observation. In the nineteenth century, Brown's microscope revealed Brownian motion and the cell nucleus. In the twentieth and twenty-first, Tonomura's has shown us basic principles of the quantum landscape and its applications.

Over decades, Tonomura developed the extremely stable, phase-coherent electron beams needed for good holographic imaging, a technique that enables measurement of both the intensity and the phase of transmitted electrons. This allowed many 'thought experiments' of quantum mechanics to be done in practice, and revealed details of magnetic and electric fields at the nanoscale. Tonomura used electron holography to illuminate the wave-particle duality of electrons and to measure the magnetic fields of superconductors and other quantum effects under challenging conditions, earning him heroic status among electron microscopists. His achievements meant he was tipped several times for a Nobel prize. He died of pancreatic cancer in early May, at the age of 70.

Tonomura spent some of his early childhood in Hiroshima, Japan. Fortunately, his family moved away from the city two months before the fateful morning in early August 1945 when the nuclear bomb was dropped. Soon after graduating in physics from the University of Tokyo in 1965, Tonomura joined the central research laboratory of the Hitachi Corporation in Tokyo and, with crucial encouragement from the distinguished electron microscopist Hiroshi Watanabe, began his long career.

At that time, physicist Dennis Gabor, working at the engineering company British Thomson-Houston, based in London, had already proposed the idea of using holography to increase the resolution of electron microscopes, and the technique had passed some feasibility tests. The most immediate and spectacular applications of holography were in the field of light optics, in which it was used to create stunning three-dimensional images. This led to a Nobel prize for Gabor. Electron holography could advance no further until the invention of the electron biprism (a positively charged filament that

causes the electron paths on either side of it to cross) by Gottfried Möllenstedt at the University of Tübingen in Germany, where Tonomura worked briefly in 1973–4. Using this technology, Tonomura created the first

practical electron holography microscope for Hitachi in 1978.

Tonomura's microscope proved crucial in settling a controversy over a bizarre quantum phenomenon. The Aharonov–Bohm (A–B) effect states that the phase of an electron's wavefunction can be shifted by a nearby magnetic field, even if the electron doesn't pass through that field. This idea sits uneasily with the classical theories that were used to develop practical electron optics. Early experiments hinted at confirmation of the A–B effect, but critics argued that stray fields might have caused the observed phase shift. So Tonomura placed a ring magnet inside a superconducting sheath to eliminate any stray magnetic fields, and encased that within a copper layer to stop a passing electron beam from entering the magnetic field region. He then used electron holography to confirm the predicted phase shift between electron paths inside and outside the ring. This conclusive and elegant experiment of 1986 finally silenced the critics, and was immediately recognized beyond the world of electron microscopy as a remarkable tour de force.

Few electron holography microscopes outpaced the resolution of ordinary electron

microscopes as Gabor had envisaged, but Tonomura's use of holography to detect electron phases allowed him to pioneer and dominate the technique's practical application. In 1989, he scored a major success by imaging a magnetic vortex emerging from a superconducting film, and built on that with observations of vortices in various metallic and ceramic superconductors. Tonomura and others mapped magnetic fields in small particles, in magnetic tape and, most recently, in the skyrmion lattice — a periodic arrangement of magnetic vortices generated by a complex structure of electron spins. In quantum computing, observations of superconducting vortices are key to investigating the behaviour of these potential 'qubits'.

Tonomura combined stubborn persistence and experimental skill with imagination and excellent communication skills. He presented material with scrupulous care in publications and seminars. In a memorable Royal Institution lecture in 1994, he filled the strictly allotted one-hour time slot almost to the second. His images of magnetic phenomena were so striking that they were often on the cover of major journals. An Internet video of his version of the classic 'double-slit experiment' continues to demonstrate for many the central mystery of quantum mechanics (see go.nature.com/722hph).

It shows how electrons travelling through a biprism arrive at a detector one by one, as particles, but over time build up a wave interference pattern.

Tonomura's stellar reputation and powers of persuasion helped to secure financial support from the Japanese government for his ambitious ideas. In 2010, he was awarded the largest grant for an individual research project in the country's history (see *Nature* **464**, 966–967; 2010). He became seriously ill a year later. In the spirit of Gabor's original idea for boosting resolution, the project aims to use high-voltage electron holography to create 3D images of electron wavefunctions. Its future now depends on securing a leader as inspiring as Akira Tonomura. ■

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