Arthur Ashkin

(1922–2020)

Physicist who won Nobel for optical tweezers that trap atoms and proteins.

Arthur Ashkin was the father of optical trapping. Using focused laser beams, he manipulated particles ranging in size from atoms to cells and their components. In 2018, aged 96, he shared the Nobel Prize in Physics for "optical tweezers and their application to biological systems". He also made pioneering discoveries about the forces that light exerts. Ashkin – 'Art' to most of us – died on 21 September, aged 98.

Today, optical tweezers are indispensable to biology. They can measure movement with a precision equal to the diameter of an atom, or the force generated by using the chemical energy of a single molecule of the energy-carrying molecule ATP.

Ashkin was born in Brooklyn, New York, to immigrant parents from what is now part of Ukraine. He and his older brother Julius taught themselves physics and calculus, and cobbled together financial contributions from their extended family to go to Columbia University in New York. When the United States entered the Second World War in his second year, Ashkin's mentor Sidney Millman convinced the army to let him stay at Columbia to work on radar technology.

For his PhD at Cornell University in Ithaca, New York, Ashkin measured the angular dependence of electron–electron and electron–positron scattering accurately enough to verify the full quantum electrodynamic (relativistic) theory. Then, invited by Millman, he went to Bell Laboratories in Holmdel, New Jersey, where he stayed until his retirement in 1992. At first, he worked on microwave physics. After Theodore Maiman demonstrated the laser in 1960, Ashkin worked in this new field and, with Gary Boyd, made important advances in non-linear optical devices.

Since childhood, Ashkin had been fascinated by the forces due to light. In the mid-1960s, he heard Eric Rawson at the University of Toronto in Canada describe how tiny dust particles were trapped in a light beam inside a helium–neon laser cavity. Later, Rawson showed the effect is due to the radiometric force. This is the force that causes the black and white vanes in a Crookes radiometer, encased in a partially evacuated glass bulb, to rotate, as the result of the thermal interactions with the residual gas molecules, but in the opposite direction to the scattering force due to photons recoiling from the vanes.

Intrigued, Ashkin focused a laser beam

NOKIA BELL LABS

onto latex spheres micrometres in diameter immersed in water. The water cooled the spheres, eliminating the thermal radiometric force, but the particles were still drawn into the high-intensity beam. Ashkin showed that the particle acts as a tiny lens that alters the momentum of the light. This rate of change of momentum creates an equal but opposite force on the particle that attracts it to higher light intensity.

> **"His infectious passion for exploring optical forces changed the course of many scientific careers."**

Ashkin also investigated the optical forces on atoms. He demonstrated the atomic version of lensing – the 'dipole force' – with John Bjorkholm and Richard Freeman. In 1978, he proposed that a combination of the scattering and dipole forces could trap atoms. He highlighted an atom trap made of two opposing laser beams, but also proposed "the conceptually simplest trap" of one focused laser beam.

By 1980, the experimental work on atom trapping had stopped, but Art remained steadfast. He piqued my interest after I moved to Bell Labs at Holmdel in 1983. In 1985, my research team, with Art and Bjorkholm, showed that light could cool atoms to less than a thousandth of a degree above absolute zero by using an 'optical molasses' created by three counter-propagating sets of laser beams. The basic idea had been proposed a decade earlier by Theodor Hänsch and Arthur Schawlow.

We showed that optical molasses slowed atoms enough for optical forces to trap them. Art, Bjorkholm and I tried, but failed for several months, to demonstrate a large-volume trap proposed by Art. We rejected the single focused beam because the tiny trapping volume would contain, at most, a few atoms in a cloud of millions. But we eventually realized that thousands of atoms near the trap would rapidly diffuse into the focal region and remain cold and trapped.

Holding atoms cooled to just above absolute zero in a single beam was analogous to trapping micrometre-sized polystyrene spheres in water at room temperature. Once he realized this, Art quickly showed that 0.025–10-μm diameter polystyrene particles in water could be trapped in the one beam. A few months later, we trapped atoms. Ironically, all the ingredients for the optical-tweezers trap were established by Art in 1970.

In 1987, Art came into my lab with eyes sparkling and declared, "Steve, you're not going to believe this, but I discovered LIFE!" He had found that bacteria growing in his experimental set-up could be optically manoeuvred. When the light was turned off the bacteria swam away, but by steering the focal spot of the laser they could be recaptured. By 1990, several researchers were using optical tweezers to trap particles, atoms, single cells, organelles, and individual biomolecules by attaching them to polystyrene spheres.

The elegance and creativity of Ashkin's ideas were extraordinary. He remained indefatigably enthusiastic about science, working in his home basement into his nineties. He happily taught many biophysicists how to duplicate the optical-tweezers trap. His infectious passion for exploring optical forces changed the course of many scientific careers, mine included.

Steven Chu is the William R. Keenan Jr professor of physics and professor of molecular and cellular physiology at Stanford University, California. He was a fellow department head with Ashkin at Bell Labs from 1983 to 1987. In 1997, he received a share of the Nobel Prize in Physics for laser cooling and atom trapping.
e-mail: schu@stanford.edu