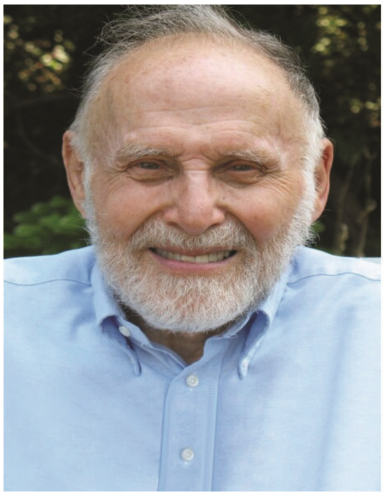
Arthur Ashkin (1922–2020)

The American physicist Arthur Ashkin was awarded the 2018 Nobel Prize for Physics at the age of 96. Recognition of Ashkin's merit by the Nobel Committee created a historical precedence, and he was the oldest recipient as of 2018 (ref. 1). John B. Goodenough won the Nobel Prize in Chemistry the following year at the age of 97.

Ashkin, known as 'Art' to many of his close friends and colleagues, was born in Brooklyn, New York, USA, on 2 September 1922. His parents, Isadore and Anna (née Fishman), were immigrants from strife-ridden Odessa, which was then part of the Soviet Union and is now part of Ukraine. Ashkin was the third of four children. One of his elder siblings, Gertrude, died at an early age. He had an elder brother, Julius, and a sister Ruth. Ashkin grew up in Brooklyn, and studied at the James Madison High School. He graduated in 1940, and then joined Columbia University and worked in the Columbia Radiation Lab. This laboratory specialized in experimental short wavelength microwave magnetron studies and was founded by Prof. I. I. Rabi along with his former students and other colleagues. At that time, Ashkin was working on the production and design of magnetrons for the radar systems of the US military. He was drafted to serve the US military under the 'Selective Service System (Military draft)' during World War II. Fortunately, later he was classified in the 'Enlisted Reserve Category', and was able to continue his work in the lab. After the war, he completed his undergraduate B.S. degree in physics from Columbia University in 1947.

Next, he joined Cornell University as a graduate student to focus on the experimental verification of the relativistic formulation of quantum electrodynamic theory[2]. His decision to attend Cornell was strongly influenced by his older brother Julius who was already working there as a nuclear scientist. Julius was part of the very famous 'Manhattan Project', and worked with two Nobel Laureates, namely Hans Albrecht Bethe (Nobel Prize for his work on stellar nucleosynthesis in 1967) and Richard Feynman (Nobel Prize for his fundamental work on quantum electrodynamics in 1965); both of whom were then at Cornell[3]. In 1952, Ashkin obtained his doctoral degree in nuclear physics from Cornell University for his thesis entitled, 'A measurement of positron–electron scattering and electron–electron scattering', under the able guidance of Dr W. M. Woodward.

Ashkin then joined AT&T Bell Laboratories (now Nokia Bell Labs), first at Murray Hill, New Jersey, and then at Holmdel, New Jersey. AT&T Bell Labs, at that time, was home to a world-famous microwave research facility. Ashkin joined this facility before moving into laser research when the nascent field took off.



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Forces of light were always extremely fascinating to young Ashkin. Theodore Harold Maiman, an American engineer and physicist, invented and successfully demonstrated the laser on 16 May 1960. Laser is originally an acronym for 'light amplification by the stimulated emission of radiation'. Maimam built the world's first-ever operational laser. For this, Maiman flashed white light into a ruby cylinder, which had high chromium content. The cylinder absorbed the green and blue light, and emitted red light such that the generated wavelength of the narrow beam of monochromatic light was approximately 694 nm. Stimulated emission let the photons multiply, and eventually, an intense beam of coherent photons moved unidirectionally. This incident light was called laser as amplification of light occurred as a result of stimulated emission of radiation. This groundbreaking discovery soon became a boon to the fields of science, technology, and medicine. Ashkin, always fascinated by the radiation pressure of light, started developing this new field, with a focus on nonlinear optics. He, along with Gary Boyd, demonstrated CW (continuous wave) second harmonic and parametric amplifiers.

In 1963, Ashkin became the head of the Laser Science Research Lab of AT&T Bell Labs, and his research interests veered towards laser sciences and the interplay of optical forces and matter. He started working extensively on various optics-related fields like nonlinear optics, optical fibres, parametric oscillators, parametric amplifiers, and laser trapping, to name a few.

In 1966, a research group in Bell Labs discovered the photorefractive effect, and Ashkin was an integral part of that work. This effect refers to the transient change in the properties of a crystal due to passage of a laser beam. By this time, with Boyd, Ashkin also reported the first-ever observations of nonlinear optical effects through his research with CW laser, namely 'harmonic generation' and 'parametric amplification'.

In the 1970s, Ashkin, along with Erich Ippen and Rogers Stolen, established the field of fibre nonlinear optics. Their work led to a clear understanding of residual noise in optical communication fibres. In the same year, Ashkin also finalized the mechanism to trap dielectric particles in a stable condition, for the first time, using only the forces of radiation pressure. Within a few years, he was successful in demonstrating the tangible effects of radiation pressure forces on atoms. In 1980, Ashkin improved the optical traps or tweezers to measure charge of an electron in collaborative work with John Bjorkholm and Richard Freeman. He also worked with Steven Chu (one-third recipient of the 1997 Nobel Prize in Physics for 'development of methods to cool and trap atoms with laser light') and others at Bell Labs. This collaborative work led to the atom cooling and single-beam dipole trapping discoveries in 1985 and 1986 respectively.

Ashkin worked in Bell Laboratories for the entirety of his 40-year professional career, and retired in 1992. It was in Bell Labs where Ashkin's ingenious discovery of 'optical trapping (tweezer)' happened and history was created. He is called the 'father of optical trapping' for his invention of optical tweezers in 1986, which later led to his half share of the Nobel Prize.

The news of the world's first successful optical trapping of atoms found its place as a front-page article of the *New York Times* on 13 July 1986; though his initial work on levitating particles with radiation pressure was rejected by the internal review committee at Bell Labs.

Recollections of Ashkin are often tied to the Nobel Prize of Chu in 1997 (ref. 4). When Chu joined Bell Labs, Ashkin, James Dziedzic and John Bjorkholm had detailed discussions with him about their thoughts and work on atomic trapping in the 1970s and early 1980s (ref. 5). In a series of papers at AT&T Bell Labs, Ashkin worked with Chu, Hollberg, Bjorkholm and Cable on cooling and trapping of atoms. Chu suggested that the optical trapping of atoms should be restricted to the optical molasses experiment. It involved simultaneous atomic cooling and trapping. This was a crucial thought behind the eventual success of the optical trapping experiment.

In 1970, Ashkin started working on accelerating and trapping tiny dielectric, transparent, bead-like particles in air or water using the radiation pressure of light. Light beams have energy and momentum, which is termed as 'radiation pressure'. Radiation pressure can be apportioned into optical gradient and scattering forces. Hence a focused laser beam had the capability to move microscopic matter using radiation pressure.

The invention of the single-beam dipole trap, which later became familiar as the optical tweezer trap, was a landmark scientific achievement. The optical tweezer trap consisted of a single focused Gaussian beam and was easily manoeuvrable. Tweezer traps can also be used to study light scattering. Using two separate traps and two particles, each particle and their combinations can be studied.

Ashkin used a magnifying lens set-up to focus a single laser on capturing and controlling extremely small objects like molecules, atoms, proteins, viruses and bacteria. The beads used were 0.59 to 2.68 μm in size. Later, he used two counter-propagating laser beams instead of a single laser, which could trap and move a tiny particle. Ashkin's invention of the optical tweezer has been extraordinarily useful for biophysicists. It was a fabulous technological advance for the understanding of single-molecule biophysics. Ashkin and collaborators were able to show for the first time a stable optical trap to control and hold atoms, molecules, bacteria, red blood cells, viruses, etc., without hurting them. This led to studies on the mechanism by which infectious organisms attack healthy cells. Tweezers use lasers to push small particles towards the centre of the laser beam (due to the optical field gradient) and hold them there. Using CW coherent light beams, high-intensity laser gradients can be achieved. Particle sizes of tens of nanometers to tens of micrometers were soon being used. For trapping tobacco mosaic virus (TMV), his group used a yttrium/aluminium garnet laser instead of the previously used green laser (at 5145 Å) to create a damage-free environment for the living cells. This much-needed change prevented damage to the living cells, thus enabling him to study how trapped molecules could move organelles around within cells. Thereafter Ashkin worked with different types of cells of various shapes and sizes, e.g. protozoa, diatoms, algae, etc.

Ashkin's invention of optical trapping and manipulation of neutral particles using the forces of radiation pressure from lasers was a major breakthrough in the fields of atomic physics, biophysics, other biological fields and chemistry. Initially, the size of the trapped spheres was in tens of micrometres down to tens of nanometres, and how work around the world is aimed at increasing the size range at which the traps are viable. Atoms and molecules used were in the huge temperature range of hundreds of degrees kelvin down to a nanokelvin. The presence of strong gradient forces on particles in laser beams gave birth to the idea of optical trapping. Perhaps the most fertile area of study has been that of topics connected to biology. The optical trap has been shown to be both non-invasive as a probe, while also being sensitive and discriminating. A single, independent, non-invasive beam of light could hold small particles at a fixed position. By controlling some parameters like temperature, pressure, pH, etc. the separation of a particular particle was possible in a controlled trap. Direct optical manipulation was possible for large individual molecules like a tubule or TMV. For smaller molecules like DNA and RNA polymerase, attachment to small, transparent, dielectric spheres, known as handles, was practised for optical manipulation.

Ashkin was a part of the team that was the first to perform laser cooling of atoms known as 'optical molasses' in 1985. The idea of Bose–Einstein condensates (BECs) in atomic vapour arose naturally after Ashkin's demonstration of cooling and trapping atoms. Ideally, BECs occur by the cooling of identical bosonic atoms to a point in space, such that the de Broglie wavelengths of two adjacent particles, λ_{db}, overlap and couple. In other words, BEC is a state (or phase) of bosonic matter, which is formed at low density and at a very low temperature, almost at absolute zero temperature. Particles in this phase form a single coherent state, which is comparable to photons in a coherent laser beam. In 1995, Anderson *et al*., for the first time, successfully devised an experimental set-up to achieve BECs in atomic vapours using optical methods. BECs have atoms in a single coherent atomic state. Physicists study BECs to understand quantum effects and many-body physics.

In 1987, while experimenting with trapping and scattering of TMV, Ashkin and Joe Dziedzic discovered that there were two modes of trapping. First was 3D-trapping, where the bacteria were trapped freely in space and the second one was 2D-trapping, where the bacteria were at the bottom surface of the sample cell. The second type of trapping was done with the help of a 1D mechanical force trapping. This observation established optical tweezers to be a viable technology for biological sciences.

Ashkin was well respected in his field. He authored a popular laser science book titled *Optical Trapping and Manipulation of Neutral Particles using Lasers* and also held 47 patents. He had a total of 105 published papers; among them, 61 were about radiation pressure on small particles.

Ashkin had a very fulfilling family life. He met Aline, while he was studying at Cornell University and eventually got married to her. She was a chemistry teacher in Holmdel, New Jersey and their marriage lasted over sixty years, spanning Ashkin's whole life. They had three children, Michael, Daniel and Judith. They are also blessed with five grandchildren and two great-grandchildren.

Ashkin was a nature enthusiast and was very fond of different types of flora and fauna. He bought a huge plot of land in New Jersey to have a proper garden. This interest of Ashkin inculcated a strong inclination towards nature in his son, Michael's mind. Michael went on to become a well-known American artist and is a Professor and chair of the Department of Art in the College of Architecture, Art and Planning at Cornell University. Michael Ashkin accepted the 2018 Nobel Prize in Sweden on behalf of his father in the Nobel Prize Ceremony held by the Royal Swedish Academy of Sciences.

Ashkin was elected as a member of the US National Academy of Engineering in 1984 and the US National Academy of Sciences in 1996. He was a fellow of the Optical Society of America (OSA), the American Physical Society (APS), the Society of Photographic Instrumentation Engineers (SPIE), and the American Association for the Advancement of Science (AAAS). He was also inducted as a 'Life Fellow' of the Institute of Electrical and Electronics Engineers (IEEE). In 1987, he received the Quantum Electronics Award from IEEE. He received the Charles and Tones Award from the OSA in 1988. OSA also conferred on him the Frederic Ives Medal/Jarus W. Quinn Award in 1998. Ashkin was inducted into the American Optical Society, the Institute of Electrical and Electronic Engineers, and the American Association for the Advancement of Science. In 2013, he was also inducted into the American National Inventor's 'Hall of Fame'. Ashkin was also elected fellow of the American Physical Society (APS). He was a recipient of the Keithley Award of APS in 2003. He also received the prestigious Harvey Prize of Technion – the Israel Institute of Technology in 2004.

Ironically, Ashkin mentioned in one of his interviews that he never took any formal courses on optics, neither at Columbia University nor at Cornell University. After 40 years of an extensive, and productive research career in AT&T Bell Labs, Ashkin retired; but he never stopped working. He was gifted some equipment from Bell Labs on his retirement and continued research in the basement of his residence. Research in the very last leg of his illustrative career as a world-class scientist and innovator involved manipulating light with reflective concentrator tubes to produce affordable solar power. He could not be present at the Nobel Prize ceremony in Sweden due to health reasons. In the many invited lectures that he delivered after receiving the Nobel Prize, Ashkin mentioned that he believed in the fact that harnessing and utilizing solar power would shape the world's future and sustenance.

Ashkin died on 21 September 2020 at the age of 98, in his residence at Rumson, New Jersey. He is survived by his wife, three children, five grandchildren, and two great-grandchildren.

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Indra Bir Singh (1943–2021)

The sad demise of Professor Indra Bir Singh in the early hours of 11 February 2021 stunned the entire geological community in India and abroad. Indra Bir was proud of his alma mater Lucknow University which provided him the platform to contribute to various aspects of Earth Sciences. With his death, the world has lost an internationally well recognized geologist with broad interests in Earth Sciences. He is survived by his wife Janak and two sons Shwetabh and Arunabh, both working abroad.

Indra Bir was born in Lucknow on 8 July 1943 in the western UP family of Chaudhri Atar Singh and Ram Kumari. He had his early schooling in a neighbourhood school – Mansa Din Shukla Inter College and attended the Govt Jubilee Inter College for High School (class X) examination. He joined Intermediate Course in Lucknow Christian College in 1956. His collegemates included some of the later year highly successful geoscientists like Nirankar Prasad (Canadian

Geological Survey), Sayyed Abbas Jafar (Aligarh Muslim University, Birbal Sahni Institute of Palaeobotany and ONGC), Satya Prakash Rastog (GSI) and Avinash Chandra (Director General of Hydrocarbons). I happened to be his class fellow as well in Class XI. Two of his close class friends at the college became leading oncologists in US (Manatosh Banerjee) and top orthopaedic surgeon of India (D. K. Taneja).

Indra Bir studied Geology in Lucknow University and obtained M.Sc. (Spl) degree in 1962. He joined Oil and Natural Gas Commission. He worked in Director's Cell briefly under B. G. Deshpande where he had the company of Aditya Chaubey, Laxman Singh, Bindesh Srivastava and Avinash Chandra, who in later years earned considerable laurels in the field of petroleum exploration. In 1963, he left for higher studies in the Technical University, Stuttgart. He worked under the supervision of Aldinge