Ahmed Hassan Zewail (1946–2016)

At the ceremony in Stockholm in December 1999, when Ahmed Zewail was the sole winner of the Nobel Prize in Chemistry that year, Bengt Norden (Chalmers University of Technology), a member of the Nobel Committee introduced the recipient with the following words:

"Zewail's use of the fast laser technique can be likened to Galileo's use of his telescope, which he directed towards everything that lit up the vault of heaven. Zewail tried his femtosecond laser on literally everything that moved in the world of molecules. He turned his telescope towards the frontiers of science."

To appreciate the magnitude of the advance that Zewail introduced to chemistry, one has to ponder the minuteness of the time intervals that he could routinely employ with his special lasers: a femtosecond is a millionth of a billionth of a second, or one second divided by ten to the power of fifteen. By brilliantly deploying such small time intervals to carry out ultrafast photography of atomic movements of both inorganic and organic molecules in the gas phase, Zewail brought about a revolution in chemistry and related sciences. He showed how to track the course of the atomic movements that take place in chemical reactions—he could explore the dynamics, in unprecedented detail, of individual atoms involved at the instant of rupture or formation of chemical bonds.

To place this advance, which Zewail achieved in the 1980s and 1990s at the California Institute of Technology (Caltech), into perspective, we recall that in the late 1960s, researchers worldwide operated on time scales of micro- or nanoseconds. There are as many nanoseconds in a second as there are seconds in a man's life. But a femtosecond is so much smaller: it is to a second as a second is to 32 million years.

I first got to know Zewail in Santa Barbara at the Molecular Crystals International Symposium in 1977. At that event, Zewail disclosed his strategy for tackling coherence in molecular and crystal systems. To address the questions related to spectral inhomogenieties in solids he outlined how, using lasers, he could capitalize on the concept of coherence. Up until the advent of his work, chemists were convinced that it was practically impossible to monitor the atomic movements involved in the so-called transition states when reactants were converted into products. Zewail did not let this stop him. He set out to do so as a young assistant professor without tenure at Caltech, having first delved deeply into concepts of coherence previously clarified by the Hungarian-American physicist Eugene Wigner. From the late 1970s onwards, Zewail's work led inexorably and rectilinearly to his reward in Stockholm.

Being the uniquely gifted experimentalist and versatile theoretician that he was, in 1991 Zewail embarked on another major scientific venture: he designed a new type of electron microscope that, through dexterous use of ultrafast laser pulses and the photoelectric effect, created a stream of ultrafast electrons repeated on a femtosecond scale (see figure for the change of the molecular structure of pyridine over time). This later enabled him to chart the movement of atoms in solids and on their surfaces, and in biological material such as amyloid fibrils a thousand million times as fast as had been done by electron microscopists hitherto. His so-called 4D electron microscope—three dimensions of space and one of time—is now transforming the whole corpus of physical, biological, medical and engineering science. The Nobel Laureate Roger Kornberg, in commenting on Zewail's most recent book *The 4D Visualization of Matter* describes it as "a chronicle of an extraordinary journey of invention and discovery". Many believed that Zewail was on the course to win a second Nobel Prize.

Born in the town of Damanhur in the Nile Delta in 1946, as a teenager he roamed freely in that region of his beloved Egypt, and he became, within a few short decades, successor at Caltech to the greatest chemist of the twentieth century, Linus Pauling. Like Pauling, Zewail was destined to shape much of modern science. He took his initial degree in the University of Alexandria, and also gained a masters degree there before joining the group of Robin Hochstrasser at the University of Pennsylvania. After his PhD in Philadelphia, he worked for two years as IBM Fellow in the group of Charles B. Harris at the University of California, Berkeley. He was then appointed as a junior faculty member at Caltech, where he stayed for the rest of his extraordinary life.

Apart from the Nobel Prize, he was the recipient of numerous other honors, including the Albert Einstein World Award, the Robert Welch Award, the King Faisal Prize, the Franklin Prize, and the Wolf Prize. He was awarded honorary doctorates from fifty universities. Like Marie Curie, Mendeleev, and Faraday he is one of the few scientists to hold honorary doctorates from both the Universities of Oxford and Cambridge. He was a Foreign Member of the Royal Society and of most other national academies in the world. He was particularly proud to be a Fellow of the American Philosophical Society, founded by Benjamin Franklin in 1743. In 2009, President Obama appointed him to the Council of Advisors on Science and Technology and in the same year he became the first US Science Envoy to the Middle East. In 2013 the Secretary General of the United Nations, Ban

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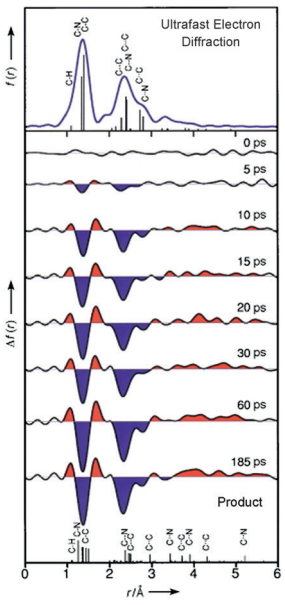

Ki-moon, invited Zewail to join the UN Scientific Advisory Board.

Zewail was profoundly interested in raising the scientific and technological profiles of Egypt and other Middle Eastern countries, and he wrote numerous articles in major newspapers in the US, UK, and Egypt, advocating procedures that could be used to help young people and the "have-nots" in the Third World (for a recent Essay, see *Angew. Chem. Int. Ed.* **2013**, *52*, 108). For the past several years, he took almost daily interest in the establishment of Zewail City of Science and Technology, now in the process of completion on the outskirts of Cairo. Zewail was decorated with the Order of the Grand Collar of the Nile, Egypt's highest state honor and was appointed a member of the Legion d'Honneur by the President of France. For several years, along with the Belgian Nobel Laureate Christian de Duve, he played a leading role in the L'Oreal–UNESCO Awards for Women in Science.

Author of some 600 papers and 14 books, one of which I co-authored with him, he has left a lasting legacy for generations of future natural philosophers. In the summer of 2009, I spent four whole weeks in Caltech and a week in Yosemite National Park with Zewail's extended family. It was during this period of intense interaction that I grew to learn more about Ahmed and his intellectual stature, and I can testify to two things that made him so unusual as a scientist: first, he combined in a singular manner patience, passion, pertinacity and perspicacity. Second, he described his work in beautifully elegant and memorable ways: every sentence and every illustration of every paper of his was the product of deep contemplation and lucubration.

Zewail also had a profound interest in history in general, but the history of science in particular. My Eurocentric views of who discovered what were often corrected by Zewail, who reminded me that, for 700 years, the language of science was Arabic. He pointed out that, during his time in Baghdad in 1000 AD, Al Hazen (latinized as Alhacen) had invented the camera obscura. He also drew to my attention that Aristarchus of Samos, who had spent some time in Zewail's beloved Alexandria, had suggested that the earth circulates the sun some 18 centuries before Copernicus, and pointed out that Eratosthenes, the Librarian in Alexandria, proved that the earth was spherical and calculated its circumferences with amazing accuracy 1700 years before Columbus sailed on his epic voyage.

In 1991, Zewail enthralled members of the Royal Institution of Great Britain with his thrilling account of his laser femtochemistry work. In the course of it he showed a spectacular image of Akhenaton (14th Century BC) and drew attention to "The first known image that depicts that light travels in a straight line" (see picture).

Zewail had many admirable qualities, including his prodigality of output; his general celerity of action; the technical virtuosity of his experimental methods; the profundity of thought of his theoretical exercises; his efficiency in mentoring students and scholars; his remarkably enterprising ventures in fundraising, especially for the establishment of Zewail City; and his concerns about the "have-nots", especially the millions of children worldwide who receive no education. He discussed his activities in the latter topic, as well as the development of 4D electron microscopy in a most memorable talk at the 125th Anniversary Symposium for *Angewandte Chemie* in Berlin in 2013.

Zewail's unique legacy to natural science is that he made a multitude of wide-ranging, far-reaching, uplifting, and long-lasting contributions. He is survived by his Syrian-American wife Dema, who is a doctor, and his four children Maha, Amani, Nabeel, and Hani.

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