Ahmed Zewail

1946–2016

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
Marcos Dantus

NATIONAL ACADEMY OF SCIENCES

AHMED **ZEWAIL**

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Elected to the NAS, 1989

By Marcos Dantus

Ahmed Zewail had a profound impact on chemistry and related sciences. His work on femtochemistry and later 4D microscopy furthered the measuring of the most fundamental processes in chemistry, biology, and physics. His research transformed how we think about chemistry, biochemistry, biology, and physics by providing direct observations of nature at the atomic scale and with ultrafast time resolution.

Zewail was born on February 26, 1946, in Damanhur, a city located 43 miles southeast of Alexandria, Egypt. He attended Alexandria University, where he earned B.S. (1967) and M.S. (1969) degrees. For his Ph.D. studies, he attended the University of Pennsylvania (Penn), where he worked for Robin Hochstrasser, graduating in 1974. He then completed a postdoctoral fellowship at the University of California, Berkeley (UCB), working under Charles Harris. He became an assistant professor at the California Institute of Technology (Caltech) in 1976, where he received tenure in 1978 and became full professor in 1982.

There have been many books and biographies written about Ahmed H. Zewail, including *A Voyage Through Time, Reminiscences of Ahmed H. Zewail*, and *Personal and Scientific Reminiscences: Tributes to Ahmed Zewail*. This biographical memoir focuses on the birth of femtochemistry and ultrafast electron diffraction. During this time, I had the good fortune of being a graduate student and postdoc in the Zewail group intimately involved in these important projects.

Zewail's early childhood, the effect that politics and wars in the Middle East had on him, and his arrival in the United States are described in detail in his autobiography, *A Voyage Through Time*. Briefly, his very supportive parents strongly encouraged his education. They had traditional values and attended the mosque regularly. Ahmed grew up in a

small community where everyone knew each other and where education was held in very high regard. If a student did particularly well, the entire community appreciated and celebrated the accomplishment. In addition, he had a very successful uncle who took special interest in him and spent time with him in the summers.

Ahmed attended Alexandria University, where he excelled in science. He became part of the "specials," equivalent to an honors class in the United States. He was then accepted for a master's degree at the same university, where he started work on spectroscopy. Upon completing his work, a number of professors encouraged him to travel to the United States for his Ph.D. studies. In 1968, the Apollo 8 mission's pictures from lunar orbit had become well known around the world and highlighted the achievements of U.S. scientists. The obstacles he overcame to leave Egypt included a requirement that the graduate fellowship offer from Penn be written without specifying his name. Therefore, he had to make sure all other honors students declined the offer, leaving him as the sole candidate. He then needed multiple signatures, which he acquired days before leaving.

Ahmed joined the research group of Robin M. Hochstrasser in 1969. Robin was one of the pioneers of laser spectroscopy in the United States. During this time, Zewail had to learn about science, instrumentation, and scientific writing and get used to a very different culture. Zewail published ten scientific papers with Hochstrasser, mostly focused on the high-resolution spectroscopy of triplet states. For those experiments, molecules were prepared in glassy substrates and cooled below 2 Kelvin. In most cases, a xenon lamp was the excitation source, but one publication contains the two-photon excitation spectrum of naphthalene obtained with a homemade tunable nanosecond dye laser. His culture and high regard for professors compelled him to offer a coffee to Prof. Hochstrasser every day after lunch. This led to several opportunities to talk about science and life in general. Hochstrasser's encouragement was a determining factor in Ahmed's decision to apply for postdoctoral positions at top universities in the United States.

Ahmed joined the group of Charles "Chuck" Harris at UCB in 1974. There, he continued his work on high-resolution spectroscopy of low-temperature molecules, using optically detected magnetic resonance methods similar to those he had used at Penn. However, the work with Chuck also included studying the coherence between dimers and the observation of coherent energy migration in solids. The work on coherence led to numerous conversations with Prof. Alex Pines at UCB, a leader in multi-dimensional nuclear magnetic resonance spectroscopy. Zewail and Harris connected over their shared Middle Eastern roots, and he once again found a mentor with whom he could talk exten-

sively about both science and his future. Chuck helped Zewail find a faculty position at a top university, because that would allow him to carry out cutting-edge science and have access to the best students.

Ahmed arrived at Caltech in 1976 and started his independent research with urgency. In order to make his startup funds go much further, he leased and, in some cases borrowed, the lasers and detection systems. He published one paper in 1976 and eight in 1977. This level of productivity in the first two years of an academic career was unprecedented, especially for a laser spectroscopist having to establish a laboratory from scratch. The early work focused on coherence among electronic states of molecules in cryogenic matrices and in the gas phase. Ahmed acquired lasers that were just becoming available from Spectra-Physics, including a continuous wave (CW) laser that pumped a narrow-line dye laser. The output was then modulated by an acousto-optic crystal. This arrangement made possible the creation of well-defined pulse sequences with which he could study photon echoes. The earliest research focused on coherence, dephasing, and energy transfer between molecules. By 1978 Zewail's laboratory included a molecular beam with which he could study coherence and energy randomization in supersonically cooled isolated molecules, and by 1979 he had a laser capable of generating pulses as short as 0.66 ps. During these early days, Ahmed was working in the lab most of the time, and his wife, whom he married just before leaving Egypt, had a full-time position and two daughters to care for. The stress on the relationship led, ultimately, to their separation. Ahmed decided that he would dedicate all of his time to science. This included working on manuscripts at his apartment with graduate students and postdocs until 3 a.m. and expecting the updated version before noon the same day.

In 1980, Zewail's laboratory was pursuing spectroscopic studies in gases, liquids, and solids. Research topics included high-resolution spectroscopy of triplet states, coherence and dephasing in solids and gases, rotational diffusion in liquids, luminescent solar concentrators (US patent 4,227,939), energy transfer in quasi-one-dimensional solids, intersystem crossing rates in solids, energy localization in solids, and torsional dynamics in DNA and RNA. During this time, Zewail organized a laser chemistry meeting at Caltech where he met Richard "Dick" B. Bernstein. Dick, a pioneer in the use of molecular beams for spectroscopy and the use of lasers for multiphoton ionization of molecules, had several conversations with Ahmed at the conference. It was during this meeting that Bernstein suggested Zewail should focus on fundamental aspects of lasers and chemistry, taking advantage of his expertise in molecular beams and picosecond lasers, and abandon all other research topics. Bernstein's suggestion was based on his

awareness of the tremendous potential of basic research into molecular dynamics and the possibility for laser-based control of chemical reactions. The 1980 shift in Zewail's research focus had a significant impact in the decades to come.

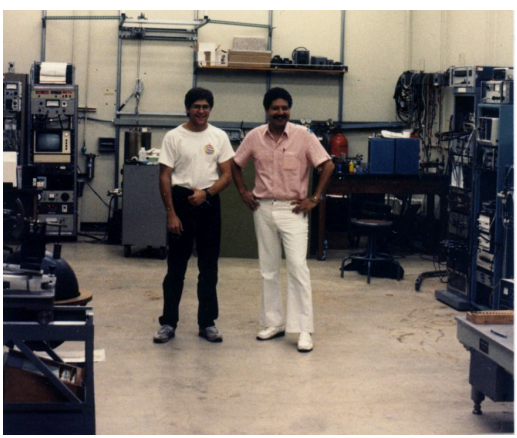
Four articles summarizing the Caltech Laser Chemistry meeting appeared in *Physics Today*.[1,2,3,4] In the first article, Zewail argues that the speed with which energy is redistributed in molecules implies that laser chemistry will require ultrafast laser pulses—with durations shorter than picoseconds.[1] In his own words, "With sufficiently brief and intense radiation, properly tuned to specific resonances, we may be able to fulfill a chemist's dream, to break particular selected bonds in large molecules." Letokhov's article on laser-induced chemical processes,[2] contains a similar thought: "If the excitation rate exceeds the rate of vibrational-energy equipartition we may hope to see mode-selective effects." The article by Richard Zare and Richard B. Bernstein discusses state-of-the-art state-to-state reactions. Toward the end, they present the observation of laser-assisted chemistry by Brooks and state, "Such studies may permit one to probe the structure of 'transition states' and to obtain direct information about the bond-making-bond-breaking process."[3] The fourth article, by Y. T. Lee and Ron Shen,[4] remarks, "Experiments with intersecting beams of photons and molecules can give detailed information on the dynamics of chemical reactions at the level of individual atoms and molecules." Another prescient quotation from Lee and Shen was "if mode-selective molecular dissociation is ever possible, it will need laser pumping in a mode fairly isolated from the other modes (presumably through frequency mismatch) and a very strong laser intensity for a very fast up-excitation."

The femtosecond lasers needed to achieve the experiments contemplated by the 1980 laser chemistry conference were being developed at Bell Telephone Laboratories (Bell Labs) by Erich Ippen and Charles V. Shank, who in 1976 began using the pump-probe method to study the recovery of a saturable absorber dye that revealed the role of intramolecular dynamics. By 1980, interest in femtosecond lasers and their applications in spectroscopy and chemistry were being realized.[5,6,7] Ben Greene was studying the femtosecond lifetimes of highly excited states of isolated molecules, molecular vibrations were becoming accessible by femtosecond impulsive excitation, and elementary biological processes such as changes observed in myoglobin and bacteriorhodopsin were being probed with femtosecond resolution. In 1980, T. Kobayashi and Shank discussed the application of subpicosecond optical techniques to molecular dynamics,[6] where pump-probe femtosecond experiments on gas and liquid phase showed ultrafast relaxation dynamics. In a 1983 article titled "Femtosecond spectroscopy and chemistry,"[8] Shank

and Green wrote, "This pulse width is on the order of molecular collision time." They discussed the use of femtosecond lasers in the areas of physics, chemistry, and biology. Quoting from that work, "With a direct time measurement, however, a primary observation can be unambiguously related to the dynamic phenomena of interest."

In the early eighties, Zewail focused his laboratories on picosecond dynamics in the gas phase. In one laboratory, experiments were being carried out on coherent vibrational and rotational spectroscopy of supersonically cooled molecules. In another laboratory, picosecond and sub-picosecond laser-induced chemical reactions were being probed. These efforts met with immediate success in the observation of vibrational coherence in anthracene,[9] energy randomization in increasingly complex molecules,[10] and the sub-picosecond measurements of bond dissociation.[11] Having worked on energy randomization in large polyatomic molecules cooled in molecular beams as an undergraduate student, I interviewed with Zewail in 1985. It was then that Ahmed told me that his dream was to measure how long it took to break a chemical bond. I told him that it was my dream to design such a laser laboratory.

In October 1985, Prof. Shaul Mukamel invited Zewail to a workshop on "Intramolecular Vibrational Redistribution and Quantum Chaos" sponsored by the Air Force Office of Scientific Research (AFOSR). At that meeting, Larry Davis and Larry Burggraf from AFOSR were present and liked Zewail's research presentation and direction. They asked him to submit a proposal related to work with femtosecond laser pulses. Zewail was funded to build a femtosecond laser laboratory dedicated to fundamental chemical processes. That summer Zewail asked me to design the femtosecond laser laboratory that later became known as Femtoland I. Dick Bernstein had joined Zewail's group as a Sherman Fairchild Scholar (1986-90) and helped determine the list of compounds to be studied in the new laboratory. Zewail hired Dr. Mark Rosker, who as a PhD student had published impressive work on femtosecond vibrational coherence dynamics using a



Contemplating the space where the first Femtosecond laser laboratory would be built. (Photo courtesy of Marcos Dantus.)

home-built femtosecond laser. Mark and I ordered all the optical components required to build an amplified femtosecond laser. The photodissociation of the triatomic molecule ICN was chosen as the target of our first experiment; the molecule had been studied using 300 fs pulses in the lab next door.[11] The laboratory space became available on Monday, December 1st, 1986. Amazingly, we had a "femtosecond laser lab warming party" on December 11, 1986, where visitors could see the newly built femtosecond laser in action. It goes without saying that Mark Rosker and I did not sleep much in those days. When we asked Ahmed for additional funds to build a molecular beam and purchase a spectrometer, he told us we had used up all of the funds and we had to run the experiment without additional purchases. I decided glassware was inexpensive, so we carried out the experiment in a glass cell and used a cardboard box to reject stray light. There were myriad technical difficulties to overcome; for example, we had to figure out how to generate femtosecond pulses centered at 388.9 nm to probe the nascent CN radical. We achieved that by mixing nanosecond 1064 nm pulses from the Nd:YAG laser and pumping the amplifier with the femtosecond 612.8 nm amplified pulses from the colliding-pulse-mode-locked laser in a nonlinear optical crystal to obtain the desired wavelength.

Late in February 1987, after having lunch with my wife, Mark and I returned to the laboratory and started scanning the delay between the pump and probe pulses in search of a signal. As the signal was being recorded point by point on the computer screen, we expected to see an exponential buildup of the signal. To our amazement, we observed a short-lived feature that rose and decayed within 200 fs. This feature was not the product or the reagent; it was the first direct observation of the intermediate species, or transition state of the reaction. I asked my wife, who was still in the lab with us, to call Ahmed and ask him to come to the lab urgently. We were all ecstatic. The following day was the first of many where we questioned and optimized everything related to this experiment. The observation was scrutinized over a period of five months. For example, Ahmed asked me to check the sample purity using five independent methods. We repeated the scans on multiple days and under different conditions. During the summer, Ahmed discussed our findings with professors J. C. Polanyi, R. B. Bernstein, R. S. Berry, R. Dixon, and J. P. Simons.

It is worth noting that there was an element of serendipity in the observation of transition states. Because we had no spectrometer in the laboratory, the probe laser was not tuned to detect the product of the reaction, namely the free CN radical, but instead to a longer wavelength. Therefore, we had inadvertently tuned the laser where neither

reagent nor product absorbed light. This also explained why our efforts to repeat the experiment with the shortest pulses and even longer wavelengths had failed. We figured out that we had the wrong wavelength once I borrowed a manually adjusted compact spectrometer from the lab next door and realized the probe laser was tuned a few nanometers redder than necessary. As soon as we tuned on-resonance with the free CN radicals, the signal was an order of magnitude stronger. The femtosecond ICN results were submitted and accepted for publication in June 1987. The first theoretical interpretation of the experiments[12] explained why tuning the laser pulses to redder wavelengths led to the observation of the transition state. In addition, it showed how the results could be inverted in order to learn about the potential energy surface governing the reaction dynamics. Semiclassical and quantum mechanical descriptions later were published by several groups. The summary of the first publication had a forward-looking statement worth quoting: "These FTS—femtosecond transition-state spectroscopy—experiments promise to provide real-time dynamics of TS—transition states—and intermediates in unimolecular and special bimolecular reactions."[12]

In order to give the reader a perspective of the magnitude of the achievement, I provide here a quotation from Y. T. Lee's 1986 Nobel Prize address:

> *If the motion of individual atoms were observable during reactive collisions between molecules, it would be possible to understand exactly how a chemical reaction takes place by just following the motion of these atoms. Unfortunately, despite recent advances in microscope technology that allow us to observe the static arrangement of atoms in a solid, we are still far from being able to follow the motion of atoms in the gas phase in real time.*

The first publication on what soon became known as femtochemistry[13] was followed by a number of papers describing the technique,[14,15] the time it takes to break a chemical bond,[16] coherent dynamics in the predissociation of NaI,[17] and the extension of the method to chemical reactions with a saddle point.[18] The first few years of femtochemistry were filled with tremendous success; every day there were new results revealing never-before-seen dynamic information. Despite the exciting findings being published by Zewail's research group, there was some dissent in the physical chemistry community. There were some who argued that Zewail was spending exorbitant amounts of money on experiments that were not teaching us anything that was not already known. The arguments went further, implying that one could either simply convert frequency-resolved data into

the time domain by Fourier transformation, or that in the worst case, we were simply convoluting the cross-correlation of the femtosecond laser pulses. I was concerned about the ongoing criticism and had a conversation with Zewail about this. He looked at me with a grin and told me not to worry—we would keep exploring the most interesting reactions in chemistry and one day the critics would realize that they had gravely underestimated the impact femtosecond lasers would make in chemistry.

In addition to the experimental achievements, one can identify two additional aspects that set the femtosecond spectroscopy measurements from Zewail's group apart from those of other laboratories. First, Ahmed had carefully selected the molecules to be studied, starting from simpler ones and advancing to more complex molecules. This progression implied that each publication had one key observable with few, if any, confounding aspects, such as solvent response, solvatochromic shift, and intermolecular energy transfer. Second, Zewail had the ability to describe an observation in the simplest of terms. For example, he would explain a problem using a classical or semiclassical model before discussing the problem at a quantum mechanical level. The scientific impact of the work in Zewail's group was recognized early on with the King Faisal Award for science in 1989 and the Wolf Prize in 1993. It was at the festivities for the King Faisal Award in Saudi Arabia that Ahmed fell in love with Dema Faham, whose father had won the King Faisal Award in Literature. They married later that year at Caltech, and the celebration was capped by a laser show that we prepared using equipment from the laboratory.

Ahmed's focus on fundamental chemical processes in the gas phase was in full effect during the early femtochemistry days. His discipline was such that when Dr. Robert M. Bowman and I observed the most beautiful vibrational coherence, which we speculated was coherent phonon dynamics in a solid film, and brought it to Ahmed's attention, he told us without equivocation that his focus was on fundamental chemical processes in the gas phase and that he would not look at the results. Heartbroken, Bowman and I pursued the project in our scarce spare time and finally discovered that the signals were from iodine (I_2) vapor and not from solid-state phonon dynamics. Ahmed, who had worked with I_2 vapor before, was very happy and this led to a number of additional publications.[19,20] In the summer of 1990, when femtochemistry was blossoming, Dick Bernstein suffered a heart attack while attending a meeting of the U. S. and Soviet academies of science in Leningrad and passed away a few days later on July 8, 1990. Ahmed, who had been traveling with Dick and who was a very close friend, was devastated.

Early in 1991, Ahmed started planning the next step for femtochemistry. This time, the goal was to use electron diffraction to follow all atoms involved in a chemical reaction with femtosecond time resolution. This project had the challenge of generating the short electron pulses and detecting a sufficient number of diffracted electrons at each pump-diffraction time delay in order to provide the most complete "molecular movie." One of my out-of-field, required Ph.D. proposals was the use of electron diffraction in tandem with a molecular beam in order to obtain structural information for molecules and clusters with sub-Angstrom resolution. This was a continuation of a proposal I had written for my candidacy exam in 1987 on the same topic. When I heard that the AFOSR, this time Michael Berman, had funded Ahmed to create the first ultrafast electron diffraction (UED) instrument, I asked him if he would allow me to lead the project. I stayed at Caltech as a postdoc from 1991 to 1993 to oversee that work. The project benefited from an outstanding graduate student, Charles Williamson, and a postdoc, Dr. Scott Kim. The technical challenge of the project is summarized as follows: we needed to improve electron detection by eight orders of magnitude. This challenge was solved through a collaboration with the Jet Propulsion Laboratory. We were able to find James R. Janesick, the person in charge of the charge coupled device (CCD) detectors that were incorporated into cameras of the NASA CRAF/Cassini mission. In 1991, these one-megapixel back-thinned CCDs were unique because of their quality, resolution, and size. Moreover, they had two quadrants blocked by an aluminum layer to protect them from light. We used these quadrants to catch the main electron beam and the unprotected quadrants to detect the precious few scattered electrons. The design of the electron gun was based on ultrafast streak cameras pioneered by Rentzepis, Sibett, Ischenko, and Alfano. Additional inspiration was gained during visits in May 1991 from Prof. John D. Ewbank, who had written about instrumentation for time-resolved electron diffraction, and M. Y. Shelev, a designer of picosecond streak cameras. We followed the design of H. E. Elsayed-Ali, which involved a photocathode with a thin film of gold to be excited by an ultraviolet femtosecond laser pulse. The experiment required us to generate 260 nm femtosecond pulses to activate the photocathode in order to generate a focused beam of femtosecond electron pulses that had to be synchronized with the pump laser. We also had to characterize the instrument response. By 1992 we were publishing results from this new instrument.[21,22] This instrument would later start producing transient molecular structures that were instrumental in determining reaction mechanisms.

Femtochemistry gained recognition, in part, through an international conference organized by Prof. Jörn Manz in 1993. This conference highlighted contributions from a

Receiving the Nobel Laureate Signature Award. (Photo courtesy of Marcos Dantus.)

variety of femtochemistry researchers and theorists. Starting with the first conference in 1993, femtochemistry conferences have been held every other year and have usually followed Ahmed's preference for having no parallel presentations and leaving sufficient time for discussion. By the late 1990s, graduate student and then postdoc Dongping Zhong in Zewail's group helped to expand femtochemistry studies into the liquid phase, addressing fundamental aspects related to electron transfer, isomerization, and nucleophilic substitution reactions, and these studies were being carried out on larger molecules, including iron-sulfur proteins. During that time, a second-generation UED instrument was being built. Zewail's group was one of the most productive and innovative groups doing ultrafast chemistry in the world, and scientists, students, and postdocs from all over the world wanted to join the action. Zewail was awarded the Nobel Prize in 1999 for the development of femtochemistry. Everyone, including Ahmed, was surprised that no other pioneer in the development or use of femtosecond lasers to study chemistry, physics, biology, or spectroscopy was included.

The Nobel Prize significantly increased the number of talks Ahmed was invited to give, many of which he could not decline. In many cases the newfound fame and the sense of accomplishment afforded by such a prize leads to a decline in productivity. However, Ahmed responded to the prize with the energy of an assistant professor. He set out new bold scientific challenges, such as bringing the ability to create molecular movies to the biological world, in his own words, "to be able to see the machinery of life in action." This work required taking electron microscopy instruments and outfitting them with the methods used to develop ultrafast electron pulses. The range of topics being addressed by femtochemistry continued to expand, including an insightful contribution into the dynamics of water in biological recognition.[23] Zewail's forays into the area that became known as four-dimensional electron microscopy (4D UEM) are nothing short of spectacular.[24,25] In fact, there were rumors that they nearly led to a second Nobel Prize. From

the beginning he imagined applying this new tool to study interfaces, surfaces, and nanocrystals, self-assembly, and 2D crystalline fatty-acid bilayers. His dream was to use 4D UEM to image a living cell, a project for which he obtained an $18 million grant from the Gordon and Betty Moore Foundation in 2005.

Despite all the demands from a large scientific group, editorship of the *Chemical Physics Letters* journal, writing an average of twenty scientific papers per year, teaching, and giving more than twenty invited lectures per year, Ahmed had a sense that he could do much more for the world. He had two principal concerns: unimpeded scientific advancement and education for all in the world. These two themes were highly correlated in Ahmed's mind. Unimpeded scientific research requires freedom of thought and expression—he saw that many conflicts arise when people have lost the freedom to think and express themselves—as well as education that fosters investigation and the search for truth. Education, therefore, was the key to raising people out of poverty and bringing prosperity to poor countries.

Ahmed wrote an influential article in 2001 titled "Science for the Have Nots," in which he highlighted the fact that only one-fifth of the world's population enjoys the benefit of life in the "developed world." His prescription for bringing prosperity to the world included eliminating illiteracy, allowing for freedom of thought, and recognizing the important role that science and technology can play in the betterment of society. During the early 2000s Ahmed proposed to then-President Hosni Mubarak the creation of an Egyptian science and technology institution modeled after Caltech. This dream became a reality in the Zewail City of Science and Technology, which opened its doors in 2013. In a *Wall Street Journal* editorial written by Zewail and David Baltimore in 2008 in response to the refusal of presidential candidates Barack Obama, Hillary Clinton, Mike Huckabee, and John McCain to participate in a science debate, they wrote "We need to fund the America Competitiveness Initiative and double the National Science Foundation's budget for basic research." Ahmed also wrote an essay titled "Science for the Haves" in 2012. In this article Ahmed criticized the emphasis of broader impacts in scientific proposals for basic research. He considered curiosity-driven research to be the natural seeding ground for technologies that later have a major impact on society and worried that early emphasis on applications would eventually starve innovation. The same year he published an essay titled "Curiosity Begets Curiosity," in which he expressed his regret that "curiosity-driven research is no longer looked upon favorably." He was disturbed by the trends that still pervade scientific funding today. He wrote,

> *In much of academia today, however, curiosity-driven research is no longer looked upon favorably. Research proposals must address broad relevance to society and provide transformative solutions even before research begins. Professors are writing more proposals, reducing the time available for creative thinking, and increasing numbers of academics are involved in commercial enterprises.*

Ahmed expanded his vision of education and the impact that science and technology have on society to include the Middle East and world peace. I happened to be present at one of his early speeches on this topic at Oxford University in 2007, where the femtochemistry conference was being held that year. The presentation was given in the evening following a special invitation by the Islamic Community of Oxford. After gracious salutations, Ahmed began his presentation with a memorable statement, which I paraphrase here:

> *I am Egyptian, and I am American, I am a Muslim and I am a scientist, and I see no contradiction or conflict in my mind. So, don't let the media or anyone else say that there is a conflict or a division among us."*

In one statement Ahmed pointed out the divisiveness of the media and leaders in many countries. He felt that that every person is capable of great achievements provided that they have access to education and that they work hard. At the presentation, a young Egyptian woman described all the difficulties she had faced leaving her family to pursue a scientific education at Oxford and the cultural difficulties she was facing. Ahmed recognized the difficulties but promised that with hard work she would become successful, and then, that everyone would celebrate her achievements and be much more accepting. Ahmed made multiple trips per year to Muslim-majority countries, where he promoted education reform and investments in science. For an Egyptian journal he wrote, "The only thing that will carry Egypt forward in the coming period is scientific thinking" and "I don't see that there is a contradiction between science and religion whatsoever. Science looks into facts."

Ahmed served on the President's Council of Advisors on Science and Technology (PCAST) from 2009-13. He was also named Middle East Science Envoy by President Obama as part of a program to foster science and technology collaborations between the United States and nations throughout the Middle East, North Africa, and South and Southeast Asia. Zewail often reminded the Arab world that the Middle East was historically a place of learning. He wrote,

A part of the world that pioneered science and mathematics during Europe's Dark Ages is now lost in a dark age of illiteracy and knowledge deficiency." He continued, "With the exception of Israel, the region's scientific output is modest at best.

Among other honors, Zewail received the King Faisal International Prize (Saudi Arabia, 1989), Wolf Prize (Chemistry, 1993), Peter Debye Award (1996), E. Bright Wilson Award (1997), Tolman Award (1997), E. O. Lawrence Award (1998), Franklin Medal (United States, 1998), Paul Karrer Gold Medal (1998), Nobel Prize for Chemistry (1999), Fellow of the Royal Society (United Kingdom, 2001), Albert Einstein World Award of Science (2006), Othmer Gold Medal (2009), Priestley Medal (2011), and Davy Medal (2011). Zewail received honorary degrees from forty universities around the world and was elected as a member of many professional academies and societies, including the National Academy of Sciences (USA), the American Philosophical Society, the Royal Society of London, and the Swedish, Russian, Chinese, and French Academies. He received the Grand Collar of the Order of the Nile (Egypt), Knight of the Order of Merit (Egypt), Knight of the Legion of Honor (France), Officer of the National Order of Merit (France), Grand Cordon of the National Order of the Cedar (Lebanon), Grand Officer of the National Order of the Republic of Sudan (Sudan), Commander of the Order of the Republic (Tunisia), and Grand Officer of the Order of Zayed (United Arab Emirates).

In March 2015 I met with Ahmed at Caltech and we made plans for the femtochemistry conference that would take place in Mexico in 2017. Together with Prof. Jorge Peon, a former Zewail postdoc, we organized a memorable conference. Zewail was very excited about the selection of Cancún, where good science would meet with a nice location. Unfortunately, on August 2, 2016, Zewail died from complications from an illness he had battled for several years. His untimely death came at a time when his dream of 4D microscopy was coming to fruition, with Angstrom spatial resolution and the possibility of attosecond time resolution.[26] His passing represents a major loss to science, as well as to scientific education and scientific research around the world. We are left to wonder about the unusual combination of culture, education at home, charisma, enthusiasm, intensity, focus, resilience, clarity of vision, urgency, courage to attempt the impossible, help from wonderful mentors, postdocs, students, and luck that led to his remarkable contributions.

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