AHMED H. ZEWAIL

26 FEBRUARY 1946 · 2 AUGUST 2016

It is often proclaimed that a stylist is someone who does and says things in memorable ways. From an analysis of his experimental prowess, his written contributions, his lectures, and even from the details of the illustrations he used in his published papers or during his lectures to scientific and other audiences, Ahmed Zewail, by this or any other definition, was a stylist par excellence.

For more than a quarter of a century, I interacted with Ahmed (and members of his family) very regularly. Sometimes he and I spoke several times a week during long-distance calls. Despite our totally different backgrounds we became the strongest of friends, and we got on with one another like the proverbial house on fire. We collaborated scientifically and we adjudicated one another's work, as well as that of others. We frequently exchanged culturally interesting stories. We each relished the challenge of delivering popular lectures. In common with very many others, I deem him to be unforgettable, for a variety of different reasons. He was one of the intellectually ablest persons that I have ever met. He possessed elemental energy. He executed a succession of brilliant experiments. And, almost single-handedly, he created the subject of femtochemistry, with all its magnificent manifestations and ramifications.

From the time we first began to exchange ideas, I felt a growing affinity for his personality and attitude. This was reinforced when I told him that, ever since I was a teenager, I had developed a deep interest in Egyptology and a love for modern Egypt. On several occasions during my visits to Cairo, we were able to spend time together in that magical city. At first, from the early 2000s onward, we were often accompanied by a lady who was a professor of chemistry at the American University in Cairo (AUC), Jehane Ragai, who later (in 2010) became my wife. Only a few years ago, Ahmed, his wife Dema, Jehane, and I had dinner together in Cairo, at about the time when the constructional work for the Zewail City of Science and Technology was getting underway. Happy days!

I welcome this opportunity to sing Ahmed's praises, and I begin by drawing attention to his Nobel Lecture, "Femtochemistry: Atomic-Scale Dynamics of the Chemical Bond Using Ultrafast Lasers." The 1999 reprint from *Les Prix Nobel* consists of 100 pages of extraordinarily beautiful vignettes and illustrations: there are 36 figures, most of them consisting of color illustrations that could be incorporated, without change, into standard university texts. The whole article is redolent of deep scholarship; it mingles historical appreciation with frontier scientific achievements, and some of the portrayals in his article, typified here by Figure 1, are worthy of being used as tapestries on the walls of science museums and other temples of scholarship.

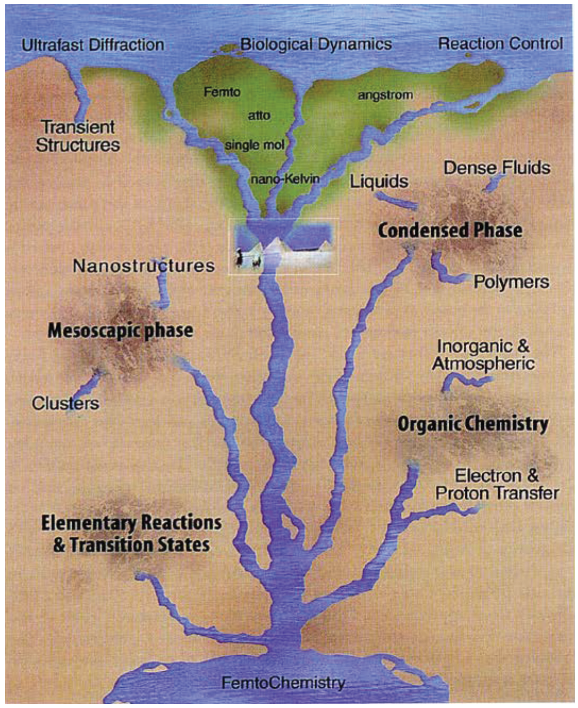


FIGURE 1. A figure from Ahmed Zewail's Nobel Lecture, reprinted from *Les Prix Nobel* (1999).

The version of his Nobel Lecture that appeared in *Angewandte Chemie International Edition* is the largest ever such Nobel article; it occupies some 43 pages. The excitement and background debts to early collaborators (e.g., Robin M. Hochstrasser, Charles B. Harris of Berkeley, Richard B. Bernstein, John C. Polanyi, Fred C. Anson, Rudolph A. Marcus, John D. Roberts, Peter Dervan, Jackie Barton, Harry Gray, Vince McKoy, and all his collaborators at Caltech and elsewhere), as well as the doubts and triumphs associated with frontier research, are beautifully chronicled in this magnum opus.

Two years after winning the Nobel Prize, Ahmed, along with his able colleague, Spencer Baskin, published a summarizing account of his work, entitled "Freezing Atoms in Motion: Principles of Femtochemistry and Demonstration by Laser Stroboscopy," in 2001 in the *Journal of Chemical Education* (vol. 78, no. 6) that was targeted at pedagogues. It exhibits the same exhilarating attributes as his Nobel Lecture, but the illustrations are presented in a manner that is immediately usable by high school teachers.

Having had countless conversations with him, and having written a book together as well as a recent research article, I feel impelled to enumerate briefly the qualities that I admired in Ahmed. These include his: prodigality of output; general celerity of action; technical virtuosity of his experimental skills; profundity of thought of his theoretical excursions; efficiency in mentoring students, scholars, and visiting scientists; and remarkable enterprising ventures in fundraising, especially for the establishment of Zewail City, during the course of which he mobilized the energies of many of his fellow countrymen.

Ahmed was also deeply committed to alleviating the plight of the "have-nots," not only in his native Egypt, but elsewhere in the Middle and Far East. He worked hard in the causes of the underprivileged, the underdogs, and especially the millions of children worldwide who receive no education.

I first got to know Ahmed in Santa Barbara at the Molecular Crystals International Symposium in 1977, to which we had each been invited to give plenary lectures by Mostafa El-Sayed. At that event, Ahmed disclosed his strategy for tackling coherence in molecular and crystals systems. In retrospect, we can now see that those early endeavors by the young Caltech assistant professor—without tenure at the time—constituted the first steps in his rectilinear path to Stockholm in 1999. (Of my lecture at that symposium, Ahmed was later to write, "To this day, I can recall the way John presented his work and particularly the way he handled the Chair of his session. In a pre-emptive strike designed to secure more time for himself he said: 'Mr Chairman, I am about to finish', meaning he needed another five minutes or more!") It was not until 1990, at a Royal Society Discussion Meeting in London on "Fast Reactions," that I had the opportunity of speaking again to Ahmed. I had already read many of his publications, which clearly indicated that he was well on the way to interrogate transition states in chemical conversions involving the rupture and creation of bonds—work that had already elicited worldwide acclaim.

I engineered a private discussion with him at that Royal Society meeting and I showed him a photograph (Figure 2). I pointed out to him that, in 1826, Michael Faraday had initiated a series of Friday Evening Discourses at the Royal Institution, at which eminent men and women of science gave popular lectures to intelligent lay audiences. I also drew to his attention that Faraday, James Clerk Maxwell, J. J. Thomson, Lord Rayleigh, and Ernest Rutherford had given Friday Evening Discourses there. Would he be willing to come and give us an account of his work? I told him also that George Ellery Hale of Caltech had given a Discourse on solar vortices and their magnetic effects in 1904; that R. A. Millikan had spoken on cosmic rays in the 1930s; that

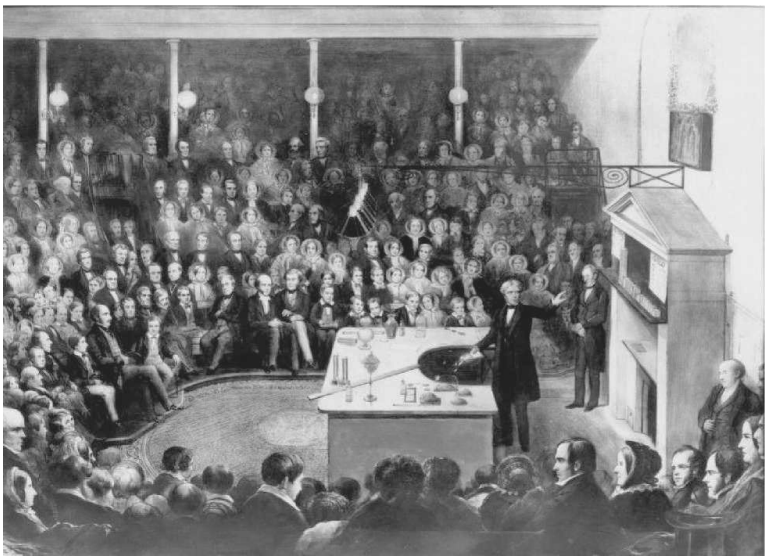


FIGURE 2. Michael Faraday delivering the Royal Institution Christmas Lectures in 1856, with Prince Albert in the chair (seated directly opposite him). By kind permission of the Royal Institution.

Linus Pauling, in 1948, had described the nature of the forces between biological macromolecules; and that yet another Caltech scientist, Murray Gell-Mann, had spoken on elementary particles in the 1960s.

To convince him further that he should accept an invitation to perform, I also mentioned that other famous Americans, like Margaret Mead, A. H. Compton, Roald Hoffmann, and Edwin Hubble had given Discourses at the Royal Institution. Ahmed agreed. And, in early 1991, it was a pleasure to entertain Dema and Ahmed in the Director's Flat for dinner before whisking him away to relax in solitary confinement in the Lecturer's Room prior to his appearance in the Lecture Theatre. (Faraday believed that, before delivering any important lecture, the speaker should relax on his or her own in a quiet room for at least 15 minutes. That tradition is still maintained.)

When Ahmed entered the darkened theatre, he was overwhelmed by the magnitude of the audience. The auditorium was, in English parlance, jam-packed. His opening words were, "This large crowd must be under the impression that the Egyptian speaker tonight was to be Omar Sharif!" He proceeded to give an enthralling account of his work, in such charming and exhilarating terms that he brought members of his audience almost to the brink of ecstasy. The first slide that Ahmed showed that night transported the audience to ancient Egypt and reminded them that Egypt is the "cradle of civilization."

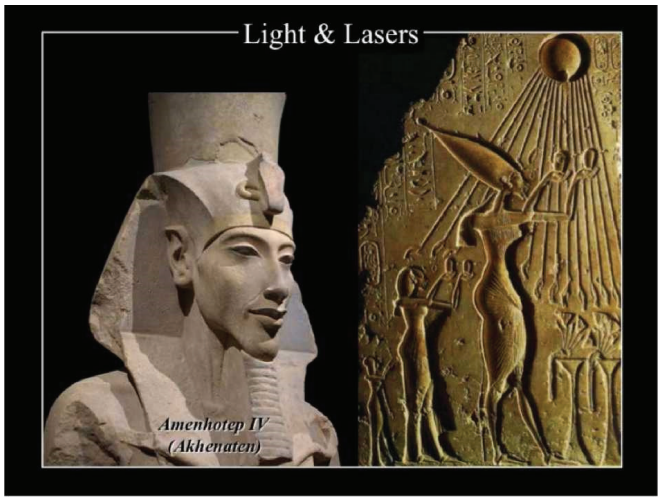


FIGURE 3. The first slide shown by Ahmed Zewail at his Friday Evening Discourse at the Royal Institution, April 1991.

Humankind's first efforts in art, agriculture, architecture, astronomy, medicine, and dentistry, not to mention civil constructions like temples, obelisks, statues, and pyramids, were taken on the shores of the Nile. His slide (Figure 3) had the image of Akhenaten (the father of monotheism) alongside the beautiful picture of the sun's rays emanating from the sun god, Atum. Ahmed said, "This is the first known image that depicts that light travels in a straight line."

Also in 1991, Ahmed and his colleague J. C. Williamson published an extremely important paper on femtosecond diffraction in the *Proceedings of the National Academy of Sciences of the United States of America*. The News and Views editor of *Nature* invited me to write a commentary on it, which I did in June of that year. The Williamson-Zewail paper was revolutionary, since it paved the way to dynamic electron microscopy. In my conclusion, I said that this work at Caltech was likely to lead to the dawn of a new era in crystallography and microscopy. And indeed it has done so. Zewail's *4D Electron Microscopy* has transformed the whole corpus of physical, biological, medical, and engineering science, bringing forth a succession of results of unprecedented importance and beauty. Zewail's 4D electron microscopy work has enhanced time-resolution by ten orders of magnitude. It is little wonder that the Nobel Laureate, Roger Kornberg, in commenting on Zewail's last book, *The 4D Visualization of Matter* (2014), describes it as "a chronicle of an extraordinary journey of invention and discovery."

In 2006, the American Philosophical Society at Philadelphia celebrated the tercentenary of the birth of Benjamin Franklin. Ahmed's lecture on "Franklin's Vision" on that occasion was a masterpiece. It encapsulates much of his philosophy, and it presages his later crucial work as an emissary for President Obama. His opening paragraphs are below:

> ON THIS SPECIAL OCCASION of the Tercentenary, I am especially delighted to speak in honor of a polymath and an American icon, Benjamin Franklin. Since his death in 1790, Franklin has been revered, memorialized, and made into an educational, financial, and political icon. Through his collective work this sage has climbed to the apex of human endeavor in the sciences, public service, and statesmanship in international relations. Such great heights for a man of wit and wisdom are reached by very few in the world, both then and now.
>
> I have real connections to Franklin, though not biological in nature. My first science home in America, the University of Pennsylvania, was founded by him; the pre-Nobel recognition I received from the Franklin Institute [w]as the medal in his name; and election to this August Society has indeed strengthened my bonds to Franklin's home of knowledge and to Franklinian ideals of "promoting useful knowledge." In my office I have his bust for a daily reminder of what it means to be a scientist in service of society and a citizen of the world at large.
>
> For me personally, Franklin is a hero, not only for his unique and remarkable scientific contributions in the 1700s, but also for his humanitarian vision and his belief in the power of learning. He best used his own power as an accomplished scientist to influence world politics and peace. Perhaps the greatest of all of his achievements was his efforts to secure America's independence and peace with England. Today, it is Franklin's vision, with his spirit of compromise and eloquence, that we need in order to reach a dialogue and peace in our troubled world.
>
> Some attribute the origin of calamity and conflict to a clash of civilizations. I do not. Being a cultural product of both "East" and "West" with a voyage of confluence, not clash, I do not find a fundamental basis for the so-called "clash of civilizations." What is important is to emphasize cooperation, not confrontation, and to understand that we live in an interdependent "flat world" (in the words of Thomas Friedman) that cannot be peacefully sustained with huge disparities in wealth and conspicuously inconsistent policies. Let me quote what Franklin said more than two centuries

> ago in *Poor Richard's Almanac*: "Who is wise? He that learns from everyone. Who is powerful? He that governs his passion. Who is rich? He that is content."
>
> These words radiate vision, thought, and humor. Franklin added, "Who is that? Nobody." True, perhaps, but an important point is that being rich and powerful has meaning and responsibility, and that hegemony, if we are wise and learn from history, does not work in the end.
>
> But this is not the "Franklin's vision" that I will be discussing in the remaining time. Rather, I would like to ask how, at the atomic and molecular level, did Franklin actually see?

Ahmed then proceeded to give a brilliant account, intelligible to lay folk, of the atomic and molecular events involved in vision.

As is well known, Ahmed was eternally indebted to his early education and upbringing in Alexandria, Egypt. By a happy coincidence at the Franklin Tercentenary, there was another famous scientist-mathematician of Arab stock, Sir Michael Atiyah (former president of the Royal Society and of the Royal Society of Edinburgh, Fields Medalist, and arguably one of the world's foremost mathematicians; see Figure 4). He was, like Ahmed, educated in his pre-university days in Alexandria and Cairo.

In December 2007, Ahmed Zewail masterminded a three-day symposium held in Cambridge to celebrate my 75th birthday. He gave one of his spectacularly gripping lectures to open the event, attended by many of Cambridge's premier scientists; Sir Brian Pippard and Archie Howie, each former Heads of the Cavendish Laboratory; Lord Martin Rees, President of the Royal Society; David Buckingham, Sir Colin Humphreys, and Lord Jack Lewis; and most of the major figures in solid-state, materials, and surface chemistry of Europe and Asia. The lecture was another of Ahmed's greats—and it was much talked about in Cambridge in subsequent years. Figure 5 shows Jehane Ragai sandwiched between Ahmed and me at that event. She is one of tens of millions of Egyptians who rejoice in Ahmed's phenomenal achievements.

In the summer of 2008, I spent four whole weeks in Caltech and a week in Yosemite National Park with the Zewail family and the families of Dema's brother and sister. My purpose in doing so was to write a monograph with Ahmed on *4D Electron Microscopy: Imaging in Space and Time*, a venture that emerged partially as a result of the Robert A. Welch Symposium in Houston, held in October 2007, on "Physical Biology: From Atoms to Medicine," where I had presented a talk on

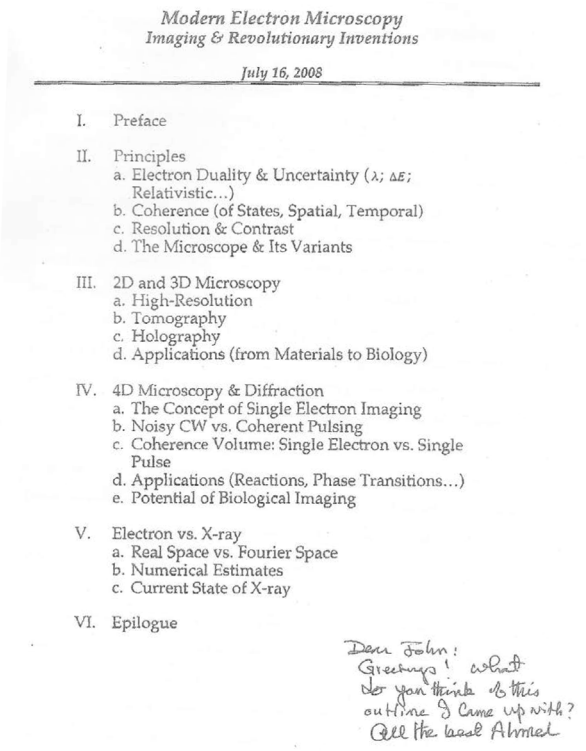
FIGURE 4. Ahmed Zewail, Sir Michael Atiyah, and Sir John Meurig Thomas at the APS Franklin Tercentenary Celebrations, April 2006.

FIGURE 5. Ahmed Zewail, Jehane Ragai, and John Meurig Thomas at the University of Cambridge, December 2007. By kind permission of Nathan Pitt, University of Cambridge.

"Revolutionary Developments from Atomic to Extended Structural Imaging."

Another factor that brought Ahmed and me together in this way was the set of short scientific reviews that I had written earlier, extolling the virtues of the remarkable succession of breakthroughs that the Zewail team had accomplished at that time.

Together in the Noyes Building we worked with frenetic zeal and obsessive commitment. To avoid irresistible temptations—like discussions with Jack Roberts (always illuminating)—we rarely went to the



Modern Electron Microscopy
Imaging & Revolutionary Inventions

July 16, 2008

I. Preface

II. Principles
a. Electron Duality & Uncertainty (λ; ΔE; Relativistic…)
b. Coherence (of States, Spatial, Temporal)
c. Resolution & Contrast
d. The Microscope & Its Variants

III. 2D and 3D Microscopy
a. High-Resolution
b. Tomography
c. Holography
d. Applications (from Materials to Biology)

IV. 4D Microscopy & Diffraction
a. The Concept of Single Electron Imaging
b. Noisy CW vs. Coherent Pulsing
c. Coherence Volume: Single Electron vs. Single Pulse
d. Applications (Reactions, Phase Transitions…)
e. Potential of Biological Imaging

V. Electron vs. X-ray
a. Real Space vs. Fourier Space
b. Numerical Estimates
c. Current State of X-ray

VI. Epilogue

Dear John!
Greetings! what
do you think of this
outline I came up with?
All the best Ahmed

FIGURE 6. Ahmed Zewail's suggested framework for our joint book, *4D Electron Microscopy: Imaging in Space and Time* (Imperial College Press, 2010).

Athenaeum for lunch. It was during this period of interaction that I grew to learn more about Ahmed and his intellectual stature.

Shortly before I arrived in Caltech in 2008, Ahmed had grown so excited about the prospect of our composing a monograph on 4D electron microscopy together, that, in July of that year, he faxed me a tentative draft of the content of our intended monograph. Figure 6 is a copy of this draft, which again illustrates Ahmed's incredible energy and vision. In the course of my numerous discussions with Ahmed over the years, I also acquired other insights into what propelled him with such brilliant intensity: his love of knowledge for its own sake; his unique combination of patience, passion, pertinacity, and perspicacity; and his profound interest in history generally, but the history of science in particular.

My Eurocratic view of who discovered what and where was often corrected by Ahmed, who reminded me that for 700 years the language of science was Arabic. He pointed out that in Cairo, in 1000 AD, the

Iraqi-born Al Hazen had invented the camera obscura and that this Arab scientist's "Book of Optics" greatly influenced later European scientists, such as Galileo. He also drew to my attention that, in his beloved Alexandria, Aristarchus had suggested that the earth circulates the sun some 18 centuries before Copernicus. Ahmed also recalled that Eratosthenes, the librarian in Alexandria, proved that the earth was spherical and calculated its circumference with amazing accuracy 1,700 years before Columbus sailed on his epic voyage. Ahmed also rejoiced that it was in his native city, Alexandria, that Hero invented the principle of the jet engine (long before Frank Whittle).

While working alongside Ahmed, and during my continual interaction with him over the years, I also discovered that his knowledge of the fundamentals of physics and chemistry were exceptional. (I did not know about the Kapitza-Dirac effect—even though it originated in Cambridge—until I met Ahmed). He executed his work in an enviably dispatchful manner, and each paper or book was the product of intense contemplation and lucubration.

Looking back again at the writing of our monograph on 4D electron microscopy, I vividly recall the rapidity with which Ahmed picked up new ideas. I had been working in chemical electron microscopy for some 40 years. Concepts and ideas that took me a fair time fully to comprehend were acquired by Ahmed as swiftly as the blinking of the biblical eye. When one contemplates the contents of his most recent monograph, *4D Visualization of Matter*, it is staggering to think that he mastered so comprehensively and so expeditiously the multiple facets of "static" electron microscopy, and added to them so magnificently the time domain. I cherish the fact that, in a small way, I helped him conquer new vistas in temporal and spatial electron microscopy, and I was touched when, in his "Acknowledgements" to *4D Visualisation of Matter* he remarked, "Besides our intellectual bonds and common interests, John was the first to see clearly the significance of the 4D imaging developments over the past decade."

During his after-dinner speech on the occasion of my 75th birthday, seated close to the German Chancellor, Angela Merkel (Figure 7)[1], Ahmed said of me: "He has written many obituaries and given eulogies of distinguished scientists to salute their contributions to science and society. I have repeatedly told John to write my obituary in advance. . . ."

There is a sad irony associated with the fact that, owing to a favorable dispensation of providence, I was, in effect, thanks to the

1 By a happy coincidence, one of my former collaborators who presented a paper at my celebratory symposium was the famous computational chemist, Professor Joachim Sauer, of Humboldt University, Berlin. It was our good fortune that his wife, the German Chancellor, Dr. Angela Merkel, was able to join us at the celebratory dinner on December 15, 2007.

FIGURE 7. Ahmed Zewail, Angela Merkel, and John Meurig Thomas at John Meurig Thomas's celebratory dinner in Peterhouse, Cambridge on December 15, 2007. By kind permission of the University of Cambridge.

invitation from President Rosenbaum of Caltech, able to give a verbal account of my admiration of Ahmed at the Gala Dinner held in Caltech on February 26, 2016, when much of what I have written above was communicated verbally in his presence.

There are numerous memories of Ahmed which will remain with me for as long as I live. Two, rather trivial ones, are of interest in this collection of tributes. The first deals with his endearing competitive spirit. In his scientific work, his desire to be the best is largely responsible for his enduring brilliance. But, even in small things, he strove to surpass. The example I quote here pertains to the inscriptions he and I each wrote in the copy of our book *4D Electron Microscopy* that was presented to Jehane, my wife (see Figure 8).

Shortly after our book appeared in December 2009, I presented Jehane with an inscribed copy. A month later, when Jehane went to a function in Cairo at which Ahmed was due to speak, she asked him to add his inscription also. He willingly obliged, but said to her jokingly, "This is both longer and composed in better English than John's inscription."

The other vivid memory I have centers on Ahmed's infectious sense of humor. We were both in an audience at an international meeting, when the speaker, an eminent scientist, started to talk about "the genius of the carbon atom." Ahmed, on hearing this, turned to me and remonstrated, "Carbon is inanimate! It cannot exhibit genius! We shall soon be talking about the genius of this chair."

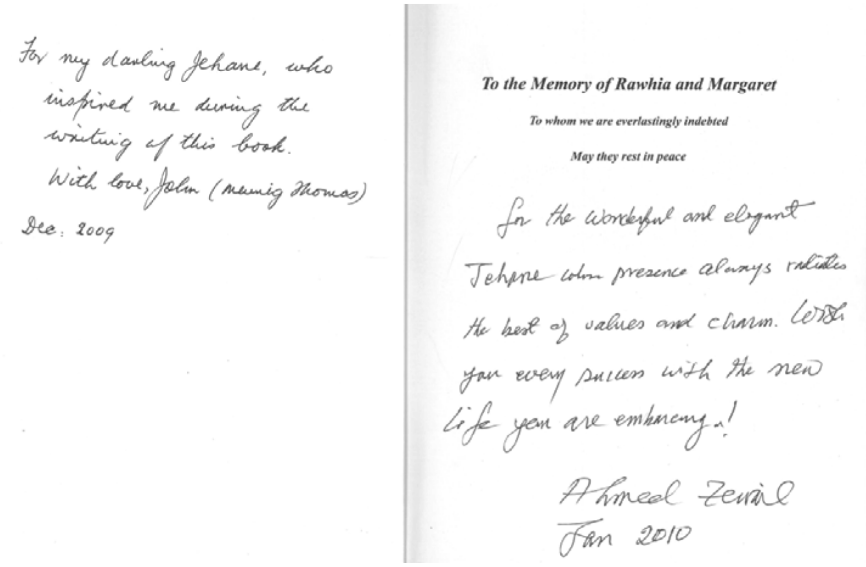


FIGURE 8. Inscription made by John Meurig Thomas (December 2009) and by Ahmed Zewail (January 2010) on the inside cover of the Zewail-Thomas monograph on electron microscopy (2010). "For the wonderful and elegant Jehane whose presence always radiates the best of values and charm. Wish you every success with the new life you are embracing! Ahmed Zewail, Jan 2010." I had written, "To my darling Jehane, who inspired me during the writing of this book."

Quite apart from the myriad extraordinary things that Ahmed accomplished as a scientist, educator, creator of a new City of Science, ambassador of science, statesman, and family man, he was a life-enhancing person. He was a joy to be with. Even now, not long after his passing, I feel tempted, as if I were in a time warp, to share with him new, mutually interesting facts—like the discovery I made recently while reading about the life of the great American Egyptologist, James Henry Breasted, that the 104th Psalm of the Hebrews shows a notable similarity to the hymn composed by the Pharaoh Akhenaten.[2] His great sense of humor and his genuine friendship to one and all will never be forgotten.

In view of the fact that his scientific and administrative work was imbued with a sense of compelling urgency, it is fitting that I should end this tribute by reverting to Ahmed's lecture on Franklin's vision that he gave at the American Philosophical Society. Ahmed ended that talk as follows:

2 See Jeffrey Abt, *American Egyptologist: The Life of James Henry Breasted and the Creation of His Oriental Institute* (Chicago: University of Chicago Press, 2011), 110.

Benjamin Franklin understood the importance of time and its centrality to our lives. Of time and life he said (*Poor Richard's Almanac*, 1746), "Dost thou love life? Then do not squander time, for that's the stuff life is made of."

Elected 1993

John Meurig Thomas
University of Cambridge

Author's Note

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