AHMED ZEWAIL—FATHER OF FEMTOCHEMISTRY

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Abstract*:*

Ahmed Hassan Zewail was an Egyptian scientist who won the Nobel Prize in Chemistry in 1999 . He was known as the ***Father of femtochemistry*** *,studies of chemical reactions on extremely short timescales . Zewail held the Linus Pauling Chair as professor in chemistry and was the Physical Biology Centre director for the UST or the Ultrafast Science and Technology, all at the prestigious school of California Institute of Technology.*

Key Words: Femtochemistry, ultrafast.

Ahmed Hassan Zewail was an Egyptian scientist who won the Nobel Prize in Chemistry in 1999 – the first of his race to win such accolade in the field of science. He was known as **the Father of Femtochemistry** because of his marvelous work in studies of chemical reactions on extremely short timescales.

Ahmed Zewail was born in Damanhour, Egypt on the 26th of February, 1946. Zewail was educated at the University of Alexandria where he received his Bachelor's and Master's degree. He then worked for two years as an instructor. Zewail moved, with his wife, to the United Sates to finish his Doctorate (PhD) degree under his mentor, Robin Hochstrasser at the University of Pennsylvania. He was supervised by Charles B. Harris at the University of California, Berkeley. Zewail then completed a post-doctoral fellowship for two years. He was appointed assistant professor of chemical physics at the California Institute of Technology (Caltech) in 1976, and he stayed at Caltech for the remaining of his career. In 1982 Zewail became a naturalized resident of the United States. He was awarded the first ever Linus Pauling Chair of Professor in Chemistry in 1995 and held that position until his death.

Ahmed Zewail's main work was as a pioneer and a leader on femtochemistry – an area of physical chemistry that studies the chemical reactions that occur in just a matter of femtoseconds. The actual atomic motions involved in chemical reactions had never been observed in real time despite the rich history of chemistry over two millennia. Chemical bonds break, form, or geometrically change with awesome rapidity. Whether in isolation or in any other phase, this ultrafast transformation is a dynamic process involving the mechanical motion of electrons and atomic nuclei. The speed of atomic motion is ~1 km/second and, hence, to record atomic-scale dynamics over a distance of an angström, the average time required is ~100 femtoseconds (fs). The very act of such atomic motions as reactions unfold and pass through their transition states is the focus of the field of femtochemistry. With fs time resolution we can "freeze" structures far from equilibrium and prior to their vibrational and rotational motions, or reactivity.

In over a century of development, ultrafast pulsed-laser techniques(1) have made direct exploration of this temporal realm a reality. Spectroscopy, massspectrometry, and diffraction play the role of "ultra-high-speed photography" in the investigation of molecular processes. A femtosecond

laser probe pulse provides the shutter speed for freezing nuclear motion with the necessary spatial resolution.The pulse probes the motion by stroboscopy, i.e., by pulsed illumination of the molecule in motion and recording the particular snapshot. A full sequence of the motion is achieved by using an accurately timed series of these probe pulses, defining the number of frames per second.

For molecules, there exist three additional requirements in order to study the motion. First, we need to clock the motion by defining its zero of time, also accurate to tens of femtoseconds. Second, the motion must be synchronized since millions of molecules are typically used in the recording of molecular

motion. Third, molecular coherence must be induced to localize the nuclei. These requirements are satisfied by using a femtosecond pump (initiating) laser pulse, in what is referred to as a pump-probe configuration. For femtosecond studies, where femtosecond control of relative timing is needed, the laser pump and probe pulses are produced in synchrony, then the probe pulse is diverted through an adjustable optical path length. The finite speed of light translates the difference in path length into a difference in arrival time of the two pulses at the sample; 1 micron corresponds to 3.3 fs. The individual snapshots combine to produce a complete record of the continuous time evolution—a motion picture, or a movie—in what may be termed femtoscopy. The intra-pulse pump–dump effect, first proposed theoretically (3), has been demonstrated experimentally quite recently (4). It was also shown that ultrashort chirped laser pulses can be used for laser-controlling photodissociation processes of NaI and CO (5).

Applications of femtochemistry(2) have spanned the different types of chemical bonds—covalent, ionic, dative and metallic, and the weaker ones, hydrogen and van der Waals bonds. The studies have continued to address the varying complexity of molecular systems, from diatomics to proteins and DNA. Studies have also been made in the different phases of matter: gases and molecular beams; mesoscopic phases of clusters, nanostructures, particles, and droplets;

condensed phases of dense fluids, liquids, solids, surfaces and interfaces; and in sibling fields of femtoscience such as femtobiology. The applications of femtochemistry can be extnded to complex inorganic reactions of organometallics. Organometallic compounds have unique functions and properties which are determined by the dynamics of metal–metal (M–M) and metal–ligand (M–L) bonding. The timescales for cleavage of such bonds

determine the product yield and the selectivity in product channels. They also establish the nature of the reactive surface: ground-state versus excited-state chemistry. Similarly, the dynamics of chlorine atom production from OClO has been studied, a reaction of relevance to ozone depletion.

One reaction studied by Zewail is the decomposition of cyclobutane to two ethylene molecules. Zewail has shown that the reaction mechanism involves

the breaking of one of the carbon–carbon bonds in cyclobutane to produce a tetramethylene intermediate.The intermediate exists for approximately 700 fs

and then decomposes into two ethylene molecules. Techniques similar to Zewail's approach are now widely used in chemical research and are being applied to problems such as elucidating the mechanism for energy conversion in chlorophyll (photosynthesis) and understanding the way human eyes detect light.

When molecules are studied in the gas phase, interactions between neighboring molecules can be neglected. However, a vast range of chemical phenomena occurs preferentially or even exclusively in a liquid environment. When a reaction occurs in a condensed phase, the theoretical problem becomes significantly more complex. This difficulty is because motion of the surrounding molecules leads to fluctuations in the structures and energy levels of neighboring molecules, thereby promoting or hindering thermally activated processes in these systems. Understanding molecular motions and how they couple to the reaction coordinate is, therefore, crucial for a comprehensive description of the underlying microscopic processes. This problem is particularly challenging because molecules exhibit strong mutual interactions, and these interactions evolve on the femtosecond time scale because of random thermal motion of the molecules. In essence, understanding the dynamics of a molecular system in the condensed phase, boils down to a problem of non-equilibrium statistical physics. Combined with an impressive increase in computational capacity, recent developments in theoretical methodology such as molecular dynamics (6), path integral approaches (7), and kinetic equation approaches for dissipative systems (8) have enlarged dramatically the scope of what is now theoretically tractable.

While Zewail was continuing his studies on the redistributions of vibrational energy, he began new studies and works on more brief time resolutions for molecules showcasing diverse rational motions and chemical processes..In 1991 Zewail designed the four-dimensional (4D) ultrafast electron microscope to help understand the complexity and nature of physical, chemical and biological transformations. His book 'The 4D Visualization of Matter' was published in 2014.

It seems that on the femtosecond to attosecond timescale we are reaching the “inverse” of the Big Bang time, with the human heartbeat “enjoying” the geometric average of the two limits. The language of molecular dynamics is even similar to that of cosmos dynamics. Cosmologists are speaking of energy

landscapes and transition states for the Big Bang and universe inflation. Perhaps we are approaching a universal limit of time.

Over his lifetime Zewail published over 600 papers and 14 books, including “The Chemical Bond: Structure and Dynamics” in 1992 and “Physical Biology: From Atoms to Medicine” in 2008.In 1999 Ahmed Zewail received the Nobel Prize for Chemistry, he was the third Egyptian national but first in the field of science to win this prize. He received many different awards and recognitions from his works and experiments. His accolades were awarded by renowned institutions and he received the Grand Collar of the Nile, which is Egypt's highest honour.

Zewail's dedication to science also led to political work. During the 4th of July, 2009 speech held at Cairo University, the President of the United States, Barack Obama, announced a new program of Science Envoys as part of the fresh start between the people from the United States and the Muslims all over the world. And in January the following year, Bruce Alberts, Elias Zerhouni, and Ahmed Zewail became the first ever science emissaries to Islam. Zewail was selected as a member of the American PCAST or the Presidential Council of Advisors in Science and Technology from 2009 to 2013. This is an advisory group of America's pioneering and leading engineers and scientists who give advice to the President and Vice President and put together guidelines in the areas of science, technology, and invention or innovation.

Zewail also had a profound sense of history in general, but the history of science in particular. Zewail, frequently reminded that, for 700 years, the language of science was Arabic. He pointed out that, in around AD1000, Alhazen had invented the camera obscura, and that this Arab scientist's Book of Optics greatly influenced later European natural philosophers, including Galileo. He also drew attention that, in his native city, Alexandria, Hero had invented the principle of the jet engine (long before Frank Whittle); and that Aristarchus had suggested that the earth circulates the sun some 19 centuries before Copernicus.

In 1991, Zewail enthralled members of the Royal Institution of Great Britain with his scintillating account of his laser femtochemistry work. During the course of it he showed a spectacular image of Akhenaton (the father of monotheism, 14th century BC) and drew attention to “the first known image that depicts that light travels in a straight line”. Ahmed Hassan Zewail, scientist, born 26 February 1946; died 2 August 2016 .He is survived by his wife, Dema (nee Faham), a doctor, whom he married in 1989, and four children, Maha, Amani, Nabeel and Hani.

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