The Nobel Prize in Chemistry 1999

The work of Professor Ahmed H. Zewail presented by

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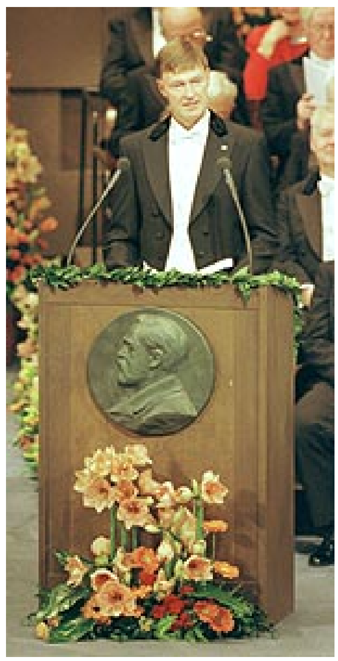
Prize citation: "for his studies of the transition states of chemical reactions using femtosecond spectroscopy"



Professor Bengt Nordén delivering the Presentation Speech for the 1999 Nobel Prize in Chemistry at the Stockholm Concert Hall.
Photo: Hans Mehlin, Nobel e-Museum

Your Majesties, Your Royal Highness, Ladies and Gentlemen,

We chemists want to understand molecules and their intrinsic essence, and to be able to predict what happens when molecules meet—do they attach weakly to each other or do they react passionately to form new molecules? Not least, we want to understand the complicated chemistry called life. Through a revolution in knowledge, molecules today take center stage in all fields, from biology and medicine through environmental sciences, and technology.

The heart of chemistry is the chemical reaction, meaning the breaking and formation of chemical bonds between atoms. How then do chemical reactions occur? We all know that they can proceed at different rates—compare the time it takes a nail to rust with explosion of dynamite! Alfred Nobel knew that reaction rates are important; dynamite reacts too rapidly to be used in cannons—they would blow up. He also knew that chemical reactions proceed at greater speed at higher temperatures, but he did not see why. This was, however, realized by the *docent* of physical chemistry in Uppsala, Svante Arrhenius. Inspired by the Dutch scientist Jacobus van't Hoff (the first Nobel Laureate in Chemistry, 1901), Arrhenius presented the first theory on reaction rates and an equation for their temperature dependence that has been used for more than a hundred years now. Arrhenius was himself awarded the third Nobel Prize in Chemistry (1903), but for different achievements.

Science has always strived to see smaller and smaller things and faster and faster events. Since the time of Arrhenius a number of methods have been developed to measure increasingly faster reaction rates, many of them rewarded with Nobel Prizes. However, no one had, until recently, been able to observe what actually happens to the reacting molecule as it passes through its so-called *transition state,* a metaphor for a kind of intermediate state of the reaction in which bonds are broken and formed. This remained a misty no-man's land.

The molecule passes the transition state as fast as the atoms in the molecule move. They move at a speed of the order of 1000 m/second—about as fast as a rifle bullet—and the time required for the atoms to move slightly within the molecule is typically tens of *femtoseconds* (1 fs = 10^{-15} seconds). Only few believed that such fast events would ever be possible to see.

This, however, is exactly what Ahmed Zewail has managed to do. Twelve years ago he published results that gave birth to the scientific field called femtochemistry. This can be described as using the fastest camera in the world to film the molecules during the reaction and to get a sharp picture of the transition state. His "camera" is a laser technique with light flashes of only a few tens of femtoseconds in duration. The reaction is initiated by a strong laser flash and is then studied by a series of subsequent flashes to follow the events. The key to his success was that the first femtosecond flash or starting shot, excited all molecules in the sample at once, causing their atoms to swing in rhythm. The first experiments demonstrated in slow motion how bonds were stretched and broken in rather simple reactions, but soon studies of more complex reactions followed. The results were often surprising, and the dance of the atoms during the reaction was found to differ from what was expected. Zewail's use of the fast laser technique can be likened to Galilei'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.

Ahmed Zewail is being awarded the Nobel Prize in Chemistry because he was the first to conduct experiments that clearly show the decisive moments in the life of a molecule—the breaking and formation of chemical bonds. He has been able to see the reality behind Arrhenius' theory.

It is of great importance to be able in detail to understand and predict the progress of a chemical reaction. Femtochemistry has found applications in all branches of chemistry, but also in adjoining fields such as material science *(future electronics?)* and biology. The retinal molecule is an example—a substance that you are all making use of at this very moment, namely to see with. It has been found that light causes this molecule to twist like a hinge around a well-greased bond, which sends a nerve signal to the brain. The reaction takes only 200 fs, which explains the eye's sensitivity to light.

Femtochemistry has radically changed the way we look at chemical reactions. A hundred years of mist surrounding the transition state has cleared.

Professor Zewail. I have tried to explain how your pioneering work has fundamentally changed the way scientists view chemical reactions. From being restricted to describe them only in terms of a metaphor, the transition state, we can now study the actual movements of atoms in molecules. We can speak of them in time and space in the same way that we imagine them. They are no longer invisible.

May I convey to you my warmest congratulations on behalf of the Royal Swedish Academy of Sciences and ask you to come forward to receive the 1999 Nobel Prize in Chemistry from the hands of His Majesty the King.