The Life of Henry Eyring

From Mines to Molecules!

Deepika Janakiraman

In this era of blurring boundaries between various disciplines of science and technology, Henry Eyring stands tall as one of the earliest examples. Starting with a degree in mining, to becoming one of the greatest theoretical chemists ever; it was a journey guided by passion and curiosity. Eyring's first brush with reaction kinetics came at the age of 23, after which his enthusiasm for the subject continued unabated. 'Potential Energy Surfaces', that he developed along with Polyani and his 'Activated Complex Theory', completely changed the face of reaction kinetics. This article will cover the exciting life of Eyring.

Deepika Janakiraman is an Integrated PhD student in the Department of Inorganic and Physical Chemistry, IISc, working with Prof. K L Sebastian. Her research interests are non-equilibrium statistical mechanics, biological physics and application of path integrals to problems in chemistry and biology.

1. Early Life and Schooling (1901–1919)

Eyring was born into a family of affluent ranchers on 20th February, 1901 in Colonia Juárez, a Mormon colony in northern Mexico. Though his ancestors had their roots in northern Europe, they settled down in Colonia Juárez after a series of migrations. Eyring had a very enjoyable early childhood in Mexico, complete with horse-riding, which he used to fondly recollect in his later years.

When he was barely ten years of age, the Mexican revolution began, which led to the propagation of anti-colonist sentiment throughout the country. Having originated from Europe, it was unsafe for Eyring's family to continue living in Mexico. In July 1912, they fled Mexico along with 5000 other colonists from Colonia Juárez and migrated to El Paso, a city in the state of Texas which was 100 miles away from Colonia Juárez. Hoping

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to return soon, the Eyrings carried only the bare minimum with them, leaving almost everything behind in Mexico. However, the situation did not imporve and they had to continue living in the United States thereafter. From richness and prosperity in Mexico, they were reduced to humble circumstances as refugees. These were trying times for young Eyring during which, he had to work in a departmental store as a cashier for $2 a week to support the family finances! After a year at El Paso, Eyring's family finally settled down in Pima, Arizona. They bought a small piece of land to do farming and reconstruct their lives.

Eyring had finished his fifth grade before leaving Mexico. He had to miss a year of schooling during his stay at El Paso. In Pima, he resumed his education and went to a church academy. He excelled in school and showed particular interest in mathematics and sciences; fields in which he would go on to become a pioneer.

2. College Years at Arizona (1919–1925)

After finishing school in 1919, Eyring's much admired science teacher advised him to take up either electrical or mining engineering. Eyring secured a $500 state fellowship and chose to do mining engineering, as per his teacher's guidance, in the University of Arizona. This handsome scholarship not only covered his personal and academic expenses, it also allowed him to send his family a decent sum of money. His years at the University of Arizona were pleasant. His tryst with mathematics continued and he wrote a detailed report on the theory of aerial tramway under the guidance of a mathematics professor. However, soon he began to see the severe risks associated with a career in mining. In the summer following his junior year, he worked as a miner in the Inspiration Copper Company in Arizona. Since Eyring was a prospective mining engineer, he was trained in various aspects of mining. During one such training in

the mine, he met with an accident where a boulder hit his foot and was badly injured. He also saw several of his coworkers getting injured, some even fatally. Though as a mining engineer he did not have to work in the mine actively, he still had to instruct his subordinates to go through the ordeal. Therefore, Eyring decided to change over to metallurgy after obtaining a degree in mining in order to have an accident-free career. He obtained a fellowship from the US Bureau of Mines to pursue a masters degree in metallurgy in 1923. He continued at the University of Arizona for his masters and his dissertation topic was 'The Separation of Heavy Sulphide Ores by Froth Floatation'.

After completing his masters degree in 1924, Eyring worked at United Verde smelter at Arizona. Though the job was interesting, the overpowering odour of sulphur dioxide in the furnaces, forced him to quit the job and return to the University of Arizona as a chemistry instructor. This proved to be an interesting turning point in Eyring's career. In addition, he was given the opportunity to broaden his knowledge of chemistry by attending various classes. He took several courses during this period which included an advanced physical chemistry course, two courses on organic chemistry and one on electrochemistry. He showed enough spark during these courses that his physical chemistry and electrochemistry instructors recommended him for a PhD at the University of Chicago and Berkeley respectively. Though both the universities offered him admission with a good scholarship, Eyring chose to go to Berkeley in the fall of 1925.

3. Graduation from Berkeley (1925–1927)

The academic environment in Berkeley suited Eyring perfectly. The chemistry department at Berkeley came under the influence of the great scientist, G N Lewis, the man behind Valence Bond Theory. He had a very intuitive approach towards science which he always backed

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up with solid experimental verification. Berkeley, as Eyring later said [1], was no place for scientific onlookers and the research in that place was rarely equalled. Eyring immensely benefited from various courses that he took during his tenure as a graduate student which ranged from thermodynamics to several courses in mathematics. The mathematics he picked up at Arizona and Berkeley proved to be very useful for him later on as a theoretical chemist. Eyring did his PhD under the guidance of G E Gibson. His research involved studying ionization energies and stopping powers[1] of various gases when bombarded with α-particles from a plutonium source. He later published this work in *Physical Review*, which was the first of those innumerable papers that he would later publish. Eyring being no stranger to hard work, finished his PhD in just 2 years, by the fall of 1927. It is very interesting to note that Eyring was the first student at Berkeley to work on radiation. Berkeley would later go on to become the seat of radiochemistry and produce great scientists like Glenn Seaborg.

[1] Stopping power is the amount of energy lost by a fast particle, which here is the α-particle, while passing through a unit path length of the gas.

4. Introduction to Kinetics at Wisconsin

After graduating from Berkeley, Eyring moved to the University of Wisconsin as a chemistry instructor. For a while, he continued his doctoral work on ionization energies and stopping powers. But soon, he took up a research position with Farrington Daniels to study the decomposition of N_2O_5 in various solvents. With this, Eyring started concentrating on reaction kinetics. Years later, Daniels wrote to Eyring [2], "I consider that one of my most important achievements in science was my success in getting you interested in the field of chemical kinetics." In addition to research, Eyring also had the good fortune of attending lectures on quantum mechanics by Van Vleck. With a sound mathematics background, Eyring found it very easy to understand the then newly developing theory. Eyring himself would go on to become one of the first scientists to apply quantum

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mechanics to chemistry. His stint at Wisconsin was fruitful not only professionally, but also personally. He met and courted Mildred Bennion who was a faculty member from the University of Utah on leave. The two got married in the summer of 1928. Their union lasted for 40 years and they had four children.

Eyring would go on to become one of the first scientists to apply quantum mechanics to chemistry.

By the second year at Wisconsin, things became a little sore for Eyring and he was at risk of his tenure being terminated abruptly. He later admitted that he had made some unfavourable comparisons between the academic environments of Berkeley and Wisconsin which were obviously not received kindly. In order to resolve the matter peacefully, Matthews, the chairman of the chemistry department at Wisconsin, recommended Eyring for the National Research Fellowship to conduct research in Germany, which would ensure that Eyring left Wisconsin. Eyring on his part, saw this as a great prospect to study reaction kinetics further and readily accepted the offer. He was initially slated to work with Bodenstein, who was famous for postulating chain reactions. However, since he was going to be away on leave, Eyring went to Kaiser–Wilhelm Institute in Berlin to work with Michael Polyani.

5. Association With Polyani

Kaiser–Wilhelm Institute too, like Berkeley, was a society of scholars where Eyring had the company of some of the finest physicists and physical chemists like Fritz Haber, Fritz London and Eugene Wigner. He started his research in Berlin with light-emitting reactions. He studied the reaction of a sodium vapour jet with a jet of chlorine which precipitated NaCl and emitted a bright light. From spectroscopic analysis of this emitted light, Eyring tried to establish the reaction mechanism. Though this problem was very interesting, Polyani and Eyring soon turned their focus towards developing an approximate potential energy surface for three interact-

Eyring and Polyani obtained an approximate potential energy surface for the reaction H_2(para) + H = H_2(ortho) + H which was the first use of a semi-empirical method in quantum chemistry.

ing hydrogen atoms in the reaction $H_2(\text{para}) + H = H_2(\text{ortho}) + H$. They used spectroscopic estimation of the attraction between two atoms and modeled the potential energy using Morse curves [3]. Thereby, they obtained an approximate potential energy surface for the reaction which matched reasonably well with the experimental findings. This was the earliest use of a *semi-empirical* method in quantum chemistry [4]. The use of Morse potential also allowed them to extend the method to different problems and also see the role of zero-point energy in reaction kinetics. During the end of a very fruitful term at Berlin, Walter Latimer from Berkeley visited Eyring. Impressed with Eyring's work, he strongly recommended Eyring's name to G N Lewis for the post of a lecturer at Berkeley. In the light of another faculty, J H Hildebrand, leaving Berkeley on a sabatical to Europe, the post was offered to Eyring. Thus, he found himself at his alma mater once again.

Berkeley was as vibrant as ever and Eyring, now armed with the knowledge of quantum mechanics, was set to continue the research on potential energy surfaces. His teaching responsibilities at Berkeley were light and there was ample time for research. He started investigating hydrogen–halogen reactions using theoretical means and concluded that hydrogen–iodine reaction was the only hydrogen–halogen reaction to proceed via a four-atom activated complex and the rest, proceeded via a three-atom activated complex. He presented this work in the meeting of the American Chemical Society in 1931 in a paper titled, 'Applications of Quantum Theory to Chemistry'. This paper garnered a lot of attention and Hugh Taylor from Princeton, invited him to his university to give two lectures on quantum mechanical calculation of reaction rates. This visit to Princeton for a couple of lectures turned into an offer to join them as a faculty member.

Eyring presented a very interesting paper titled `Applications of Quantum Theory to Chemistry' in the ACS 1931 meeting which eventually led to an offer from Princeton to join them as a faulty.

6. Active Years at Princeton (1931–1946)

In Princeton, where he remained for the next 15 years, he carried forward his research on reaction dynamics and worked on several problems. One of them was to extend London's procedure for calculating the potential energy surface for 4 electrons to any number of electrons. This would enable them to construct potential energy surfaces for molecules. Along with a student, George Kimball, he succeeded in developing a rather simple way of obtaining the secular equation for any number of electrons. This association lead to the classic text titled *Quantum Chemistry* by Eyring, Walter and Kimball. It is very interesting to note that this was the first textbook to have such a title and the discipline of quantum chemistry has now taken massive proportions. With his mathematical skill, he developed a procedure to calculate the resultant dipole for a molecule with many dipoles that lie along the bonds and rotate with respect to each other. Since this problem is exactly analogous to calculating the distance between the ends of a flexible chain, it has found wide applications in calculating effective lengths and thermodynamic properties of polymers.

The most noted contribution of Eyring is the 'Activated Complex Theory', which he proposed in 1935. According to this theory, he predicted the reaction rate to be a product of the concentration of activated complexes at the barrier top multiplied by the frequency of crossing the barrier ($k_{\mathrm{B}}T/h$). Activated complex was described to have a very fleeting existence situated at a point of no return on the potential energy surface. He submitted his work to the *Journal of Chemical Physics* only to be met with skepticism. One of the reviews read as follows,"I have given considerable thought to the problems involved, and...I have nevertheless become convinced that the method of treatment is unsound and the result incorrect." Eyring, known for his conviction

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and perseverance, sought for comments from his mentors, Taylor and Polyani. Their positive reviews lead to the acceptance of the paper titled 'The Activated Complex in Chemical Reactions'. It was a golden decade for the Frick Chemical Laboratory in Princeton from 1929-39. The place was abuzz with serious research and the presence of Eyring and his co-workers added to its richness with their activated complex theory and its wide range of applications.

Like many legendary scientists, the greatness of Eyring is marked by the breadth of his research. Collaborating with other scientists at Princeton, he worked on many interesting problems such as one-electron optical activity with E U Condon and temperature and pressure dependence of bioluminescence in bacteria with Newton Harvey. Eyring also worked on explosives during World War II and published a detailed review titled 'The Stability of Detonations' in *Chemical Reviews*. He is known for very fundamental analysis of any scientific problem and adaptability to different areas of research. So much so that when the Textile Research Institute was set up in Princeton, Eyring was asked to head the institute by Hugh Taylor. His training in engineering and some experience in the chemical industry proved very useful during this assignment. He gained considerable expertise in textiles and even co-authored a book on deformation kinetics of fibres.

7. Final Years at Utah (1946–1981)

In 1946, Eyring accepted the post of the dean of graduate school and a professor of chemistry in the University of Utah.

Life came a complete circle for Eyring in 1946 when Ray Olpin, the then president of the University of Utah, offered him deanship of the graduate school or the School of Mines. Eyring was initially reluctant to leave the familiar grounds of Princeton; however, he eventually moved to Utah at the behest of his wife, Mildred. She hailed from Utah and had already stayed away from her family for several years. She saw this as an opportunity

to connect with her roots and insisted that they relocate to Utah. Eyring, in turn, respected her wish and agreed to be the dean of graduate school and a professor of chemistry. Setting up a graduate school was a challenging task since the University of Utah had not offered any PhD degrees before his arrival. Being the administrator at the top, Eyring delegated the work to appropriate people and oversaw their progress. Such a policy of decentralization, allowed him to pursue his research actively. While continuing his work on reaction dynamics, Eying also started exploring some new avenues of research such as theory of liquids. He presumably got interested in liquids with the hope of extending his reaction rates for gases to liquids. He developed a theory where he described the liquid state as an intermediate between the solid and gaseous states, though the theory was not entirely correct.

Amidst all the academic activity, his wife Mildred was diagnosed with cancer 1964. Eyring cared for her devotedly and did everything he could, to ease her pain in her final days. While taking care of his wife, Eyring neglected his own symptoms of cancer. He was operated upon for a cancerous tumour in 1969 following which he had declining health. He was a devout Christian of Mormon faith and found great solace in religion during difficult times of his life. He married Winnifred Brennan in 1971, who remained his pillar of support to the very end. Eyring had a relapse of cancer a decade after its first diagnosis and breathed his last on 21st December, 1981.

8. Award and Accolades

As a scientist, Eyring saw the importance of casting a process in mathematical terms and examining it in great detail. Such a method of enquiry always has rewarding results since it is possible to get quantitative estimates and compare it with experiments. Throughout

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his career, Eyring retained his youthful enthusiasm and vigour. Eyring was one of the most prolific researchers ever. He had published over 600 papers in peer-reviewed journals and authored 9 books. He served for 20 years as the editor of the *Annual Reviews of Physical Chemistry* and co-edited *Physical Chemistry*: *An Advanced Treatise* and *Theoretical Chemistry*: *Advances and Perspectives*. For his contributions, he was offered membership in several prestigious academies such as the the Royal Chemical Society, National Academy of Science, American Association for Advancement of Science and American Chemical Society for which he even held the post of the president.

He was awarded several medals like the National Medal of Science (1966), Joseph Priestley Medal of the American Chemical Society (1975) and the Wolf Prize (1980). It is an irony that Eyring did not win the Nobel Prize for his path-breaking work. Several others like R Hoffman, J Pople and W Kohn, who have carried quantum chemistry forward were awarded the prize much after Eyring. It is widely said that the Swedish Academy did not realize the importance of Eyring's work in the 1930s and 40s. When they realized his seminal contributions, it was too late to award him the Prize. As a compensation, they awarded him the Berzelius medal in 1977. While awarding this medal to Eyring, King Karl Gustav of Sweden said to Eyring [5], "You are the true alchemist; you have turned the hydrogen atom into pure gold", and the gold continues to glitter to this day!

Address for Correspondence
Deepika Janakiraman
Department of Inorganic and Physical Chemistry
Indian Institute of Science
Bangalore 560 012, India.
Email: dvchem@gmail.com

Suggested Reading

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