HENRY EYRING
1901–1982

The Editorial Committee dedicates this volume to the memory of Henry Eyring in honor of his association with the *Annual Review of Physical Chemistry* for 20 years. Professor Eyring served as Editor from 1956 to 1976. His personal contributions to science were as broad as the amazing scope of physical chemistry portrayed in this volume. His work and memory live on.

We are pleased to have the opportunity to publish in the following pages the memoir by Professor Joseph O. Hirschfelder.

HENRY EYRING, 1901–1982*

Henry Eyring was a great scientist who dared to be innovative. His theory of absolute reaction rates has been used to explain the behavior of a wide range of biological and chemical systems. His interests included all natural phenomena. Indeed, he contributed in major ways to the theory of liquids, optical rotations, molecular biology, mutations, aging, and cancer.

In recognition for his research Eyring received a large number of awards, including the 1949 Bingham Medal, the 1980 Wolf Prize in Chemistry, the 1979 Berzelius Gold Medal of the Royal Swedish Academy of Sciences, the 1975 Priestley Medal of the American Chemical Society, and in 1966 the National Medal of Science, in addition to many other honors.

From 1931 to 1946 Eyring was professor of chemistry at Princeton. Then, because of his devout faith in the Mormon religion and in order to please his wife, he moved to the University of Utah, where, in the period 1946–1982 he became dean of the graduate school, Distinguished Professor of Chemistry, and professor of metallurgy.

According to family genealogists, *Eyring* is reputed to be the name of the pagan God of Light, and the German family from whom Henry descended is said to have adopted that name when they accepted Christianity (1).

Henry was born in the Mormon community of Colonia Juarez 100 miles south of the American border in the state of Chihuahua, Mexico. His father was well-to-do and owned a 10,000-acre fenced ranch where he raised 600 head of high grade shorthorn Durham cattle and 100 head of horses—the bull calves were sold to upgrade the herds of Spanish longhorn cattle. As long as Henry could remember he rode horses. Once when he was three years old (2), he fell off into a river. As soon as he was fished out, he cried, "Put me back on my horse!" Henry was always very independent and self-confident.

Henry was also kind and thoughtful. For example, I remember that he advised me to "be nice to the guys on the way up so that they will be nice to you on the way down." He recalled gratefully the care he received when, at the age of four, he nearly died of typhoid fever: "I learned then how important it is to care about people even if they are small and may not seem very important" (1).

Quite suddenly, when Henry was 11, the Eyrings, together with 4800 colonists from their area, were forced by the Mexican revolution to leave their homes and all of their belongings and flee to the United States. Thus

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the Eyring family became poor, and little Henry got a job working in an El Paso department store for $2 for a six-day week. After a year or so the Eyrings moved to Pima, Arizona, where the father purchased a farm with a small down payment. Most of the farm was covered with mesquite, which had to be cleared by hand and with the help of a team of horses. Thus from necessity Henry learned to work hard and long hours.

Henry worked his way through the University of Arizona by working in a copper mine as a timberman. On one occasion a large rock fell on his foot, crushing it and disabling him for a short time (1). On another shift three fatal accidents occurred. After getting a BS in mining engineering, Henry applied for and was awarded a US Bureau of Mines fellowship to do graduate work in metallurgy, which he thought would be safer than mining. However, after getting an MS in metallurgy at the University of Arizona, he spent the summer taking samples from blast furnaces in a smelting operation and got his lungs full of sulfur fumes. He then decided to leave metallurgy and he accepted an invitation of an instructorship in chemistry at Arizona for the year 1924–1925. The following year he received fellowships from both the Universities of California and Chicago to continue his graduate studies in chemistry. Since the Berkeley fellowship paid $750 per year and the Chicago fellowship was for $700, Henry went to Berkeley (3).

Eyring was very happy at Berkeley. He wrote (1): "Graduate students mingled with outstanding scientists who entertained no doubt that intelligent research was the most important activity in the world. This contagion infested everyone. Individual success in research was accompanied by shedding of any undue veneration for the embalmed science of the past!" His one regret was that course work was not stressed at Berkeley (3). During the course of his PhD studies he took seven courses in mathematics (his favorite subject), only two in chemistry, and none in physics. In his first attempt at research he bombarded a vacuum tube containing hydrogen at low pressure with an 11 M.E.V. high frequency Tesla discharge. Result: a broken vacuum tube. In 1927 he earned a PhD under the direction of Professor George E. Gibson. His thesis was on the ionization, stopping power, and straggling of alpha particles from polonium passing through different gases.

On the basis of his Berkeley PhD and G. N. Lewis's recommendation, Eyring secured a lectureship in chemistry at the University of Wisconsin, and he taught a physical chemistry laboratory course. During that year he met a charming girl, Mildred Bennion, who was on leave from the University of Utah, where she was chairman of the women's physical education program. In the spring Henry bought a canoe and frequently took Mildred for rides on Lake Mendota. In the fall they were married, and the canoe, having served its purpose, was sold! The following year (1928–

1929), Eyring worked at the University of Wisconsin as the research associate of Farrington Daniels, experimenting on the rate of decomposition of N_2O_5 in a wide range of solvents. This was the beginning of Henry's active interest in chemical kinetics. During his second year at Wisconsin, Eyring was stimulated by the physics lectures of Professor John H. Van Vleck on the new developments in quantum mechanics.

Then, in 1929, Eyring was granted a National Research Fellowship to work with Professor Polanyi at the Kaiser Wilhelm Institute in Berlin. At this time Bonhöffer and Harteck in Germany were making front-page news with their experimental studies of the rate of conversion of *para* to *ortho* hydrogen, $H_2(para) + H \rightarrow H_2(ortho) + H$. On the basis of the new quantum mechanics, it should be possible to calculate the activation energy for this reaction. Sugiura (4), using the method of Heitler and London, had made numerical calculations of the energy of interaction of two hydrogen atoms; and Fritz London had just presented a paper for the sixtieth birthday of Professor Haber showing how it was possible to approximate the potential energy of a 3- or 4-atom molecular system. Eyring & Polanyi substituted Sugiura's calculations into London's equation for the energy of a 3-atom system, and found that it did not agree with the experimental *ortho-para* reaction results. It was at this point that Henry showed his genius for devising semiempirical approximations. Eyring & Polanyi finally used Morse curves and spectroscopic data to estimate the attractions between pairs of atoms as functions of their separation. The Sugiura calculations were also used as a guide in apportioning the bonding energy between Coulombic and exchange integrals. The result was the Eyring-Polanyi potential energy surfaces, which were used for many years to explain the activation energy of not only the *ortho-para* conversion but a large number of 3- and 4-atom reactions.

Soon after Eyring returned to the United States, he explained in a talk at an American Chemical Society meeting that a mixture of hydrogen and fluorine would not explode because (according to his theoretical estimates) the activation energy of $H_2 + F_2 \rightarrow 2HF$ was too large. Hugh S. Taylor (subsequently Sir Hugh), the chairman of the Princeton chemistry department, who was in the audience, knew (on the basis of little known experiments) that Henry was right. Accordingly he invited Eyring to Princeton as a lecturer. Henry soon scaled the academic ladder to become a full professor. During Eyring's Princeton years (1931–1946) he enjoyed a very stimulating collaboration with Hugh S. Taylor, which resulted in a whole progression of important discoveries.

Princeton was a fabulous place in the 1930s. Many famous physicists, such as Einstein, von Neumann, Wigner, Ladenburg, came there to get away from Hitler. Furthermore, Dirac, Pauli, Schrödinger, Slater, and others spent a great deal of time there. I was fortunate to do the chemistry part of my physics and chemistry double doctorate under the direction of Eyring.

Working with Eyring was a lot of fun. He was full of ideas, and thoroughly enjoyed his work; we worked together every night until I was ready to fall asleep. In those days Eyring got the inspiration for most of his research by assiduously studying the literature. Every morning he would pop some new idea for his students to criticize—it was the job of the graduate students to discover which ideas were sound and which were erroneous. Most of his ideas needed modification and reworking—this gave us a good lesson in how discoveries are made!

In 1934, Eyring made his most important discovery, his theory of absolute reaction rates. It was an epoch-making, Grand Concept! His equation (5),

$$\text{Rate constant} = \kappa(kT/h)\exp(-\Delta G_{act}/RT)$$
$$= k(kT/h)\exp((-\Delta H_{act} - T\Delta S_{act})/RT), \qquad 1.$$

extends the concepts and terminology of thermodynamics and statistical mechanics to all sorts of rate processes. Equation 1 implies that there is a single rate-determining bottleneck which is characterized by a free energy of activation—it is immaterial whether the bottleneck is largely in the potential energy (as in small molecule gas phase chemical reactions) or whether entropy considerations play an important role in characterizing the bottleneck (as in the case of most biological reactions). Of course, it should be clearly recognized that Eq. 1 is only intended to apply to single steps of complex rate processes. It has been argued that Eyring's theory follows logically from previous work of Pelzer & Wigner (6) but that paper and all of the other previous treatments of reaction rates considered particular examples and did not anticipate the possibility of there being a formulation that was universally applicable. The only part of the Eyring theory that is not simple and elegant is the catch-all factor κ, which Eyring included in order to account for those systems which pass through the activated state and turn around and come back. (In 1935, Eyring said that whenever he thought of κ, he thought of women drivers! In 1982, he would not dare to think such a thing, let alone to say it!) However, it is the factor κ which is used to account for the very small transmission coefficients that occur in quantum mechanical tunneling. One of the reasons the theory of absolute reaction rates has been so useful is that it is usually easy to make a good estimate of the entropy of activation corresponding to an assumed reaction mechanism—then use a comparison between the observed and the estimated entropies to determine the correct mechanism! Unlike the Arrhenius reaction rate theory, Eq. 1 can explain either extremely slow or extremely fast reactions.

The Theory of Absolute Reaction Rates was so different from any of the previous collision rate formulations that Harold Urey, the Editor of the *Journal of Chemical Physics,* rejected Eyring's manuscript (5) for publication. Fortunately, Hugh S. Taylor persuaded Urey to change his mind, provided that Eyring would add an explanation of how to use his theory to calculate the rate of collisions between two rigid spherical molecules! Thus Eyring added an appendix with this explanation.

In the 1950s Ilya Prigogine followed in Eyring's footsteps in his theories of the thermodynamics and statistical mechanics of irreversible processes, when he assumed that instantaneous configurations of molecular or macroscopic configurations possess meaningful thermodynamical properties even though they are not at equilibrium. This concept and Prigogine's formulation are leading to a better understanding of biologically important chemical reactions that are periodic in both time and space, the theory of turbulence, etc.

One of Eyring's first applications of the theory of absolute reaction rates was to the viscosity, plasticity, and diffusion in liquids. This led to his free volume and significant structure theories of liquids.

Then in 1942, Henry collaborated with Professor Frank Johnson to explain some puzzling problems associated with bioluminescent bacteria. This was the beginning of Eyring's great interest in biological and medical problems.

Eyring's Princeton days came to an end in 1946, when he was asked to become dean of the Graduate School at the University of Utah and build up the chemistry and metallurgy departments. As much as Henry liked Princeton, his family and church ties to Utah were too strong to reject this offer. He accepted this challenge and did an amazing job thereafter of building up the graduate research program at Utah into one of the strongest in the country.

In 1977 Eyring wrote (2):

> As I look back over my research efforts, I would characterize my contributions as being largely in the realm of model building. To test a model it is usually advantageous to cast it in mathematical form so that quantitative predictions can be used to compare calculations with experimental findings. Ideally, agreement should be quantitative and complete. Unfortunately, this never happens in the real world. Even Newtonian mechanics must be amended in the realms of relativity and quantum mechanics.
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> In model building it is convenient to start out with the following hypotheses: (*a*) There is always a model that will explain any related set of bonafide experiments. (*b*) Models should start out simple and definite enough that predictions can be made. (*c*) A model is of limited value except as it correlates a substantial body of observable material. (*d*) Models that suggest important new experiments can be useful, even if the theory must be modified.

The Eyring philosophy that I remember best is: "Always ask yourself how might the phenomena occur. Make a Gedenks-model. It will suggest the proper groupings of variables—and this is usually a big help in semiempiricizing." Typical of Eyring's skill at model making is his explanation of why the coefficient of sliding friction is very nearly equal to one-half for most substance: Suppose that the surface is sinusoidal (like corrugated cardboard), with height $z = \sin(\pi x)$, then in order to slide an object from a trough at $x = -1$ to its next trough at $x = 3$ (or a distance of four units), it is necessary to lift the object two units from the trough of $z = -1$ to the crest of $z = 1$.

Henry Eyring had three sons: Edward Marcus, who has followed in his father's footsteps and is now a professor of chemistry at the University of Utah; Henry Bennion, who earned his PhD in business administration and served as president of Ricks College until 1977, and since then has become the commissioner of Mormon Church education; and Harden Romney, who for many years has been the assistant commissioner of Utah's higher education system.

Henry's first wife, Mildred Bennion Eyring, died in 1969 after a long illness; after two lonely years Eyring married Winifred Brennan Clark, a devout Mormon who shared Henry's philosophy.

In 1976 Eyring explained his religious feelings (3): "I know I am never alone in the world. I think you could not describe my feeling in any other way. I'm convinced that this life is meaningful and that it wouldn't make sense without a continuation after death. For me, the idea of living again is a reality. This feeling of not being alone gives meaning to life. I feel that there will eventually be justice. This belief allows understanding of the gallantry of men who, for instance, stay at their posts in time of disaster, such as when a ship is sinking. Or those who help lift the burdens of other people at great sacrifice. This aspect of life has a meaning that I think transcends every other kind of meaning. I try to live up to my ideals, and even though I fail at times, I tremendously admire those around us who have this sense of duty. In the vastness of the universe we are not alone but are really looking to a Higher Power. Religion is a living, real thing for me. I don't see how it is possible to be happy without it. The idea that one is a brother to one's neighbor and the obligation that we have to lift the burdens of those around us are more important than material things. Happiness is more a function of worthwhileness than the possession of material things."

JOSEPH O. HIRSCHFELDER

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