HENRY EYRING: A MODEL LIFE*

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Introduction

Henry Eyring was eminently quotable: of the many things he was credited with saying, a quote repeated by his student Joseph O. Hirschfelder in 1966 aptly describes the work ethic of this insightful and prolific scientist (1):

> A scientist's accomplishments are equal to the integral of his ability integrated over the hours of his effort.

Henry Eyring, with over 620 publications (2) and an H-index of 66 (3), was clearly both able and hard working. Eyring produced work that continues to directly influence scientific thought decades after its initial publication. He worked hard, thought deeply about the questions that caught his attention, respected the people around him, and produced work that redefined how the rates of chemical reactions were understood and modeled. One quantitative measure of the quality of that work is its continued relevance. Eyring's papers were cited 347 times in peer-reviewed journals in 2008, 27 years after his death (3). In fact, Eyring's work has been cited more than 225 times annually, every year since 1959 (3).

Henry Eyring's transition state theory, widely known as Absolute Rate Theory (ART), was initially published in 1935 (4). ART is recognized as one of the most important developments in chemistry in the twentieth century. The theory states that the mean lifetime of the activated complex is definite and controls the rate of a chemical reaction, and Eyring applied an unconventional combination of thermodynamics, quantum mechanics, and statistical mechanics to calculate the rate and concentration of crossing that potential energy barrier. Despite the accolades he received for ART, Eyring remained engaged, hard working and humble throughout his life. He applied the principles of physical chemistry to broad-ranging questions that fired his imagination, but also taught introductory chemistry, passing his love and understanding of chemistry on to others, even during the final stages of his terminal illness. Approaching the world driven by childlike curiosity and an enduring belief that the truth is simple, he produced a body of work that continues to inform scientists from freshmen to senior researchers.

Biography

Henry Eyring was born at Colonia Juàrez in Chihuahua, Mexico in 1901, a first son and one of 18 children (2, 5, 6). When the successful ranching family was forced to desert their holdings and return to the United States during the Mexican Revolution, eventually settling in Pima, Arizona in 1914, Henry and his siblings learned how to work hard (5, 6). Hard work bred success; many of the Eyrings went on to prominent careers, including a university presidency and two other full professorships (E. M. Eyring, personal communication).

Upon completing high school in Thatcher, Arizona, Henry departed for the University of Arizona, where he earned an undergraduate degree in Mining Engineering (1923) and a Master's degree in Metallurgy (1924). Work experiences in both mining and metallurgy spurred Eyring to explore other fields of science, and he completed a Ph.D. in chemistry at the University of California at Berkeley under the supervision of Professor George Ernest Gibson. The focus of his Ph.D. research was the

Table 1. Selected events in the life of Henry Eyring

Year	**Event**
1901	Born in Chihuahua, Mexico
1912	Family departs Mexico, fleeing the revolution
1914	Family resettles in Pima, Arizona
1923	B.S. in Mining Engineering at the University of Arizona
1924	M.S. in Metallurgy at the University of Arizona
1927	Ph.D. in Chemistry at the University of California, Berkeley
1930-31	National Research Foundation Fellow at the Kaiser Wilhelm Institute, Berlin, Germany
1931-1946	Assistant, Associate and Full Professor of Chemistry at Princeton University
1935	Publication of "The Activated Complex in Chemical Reactions" in the Journal of Chemical Physics
1936	Publication of "Viscosity, Plasticity and Diffusion as Examples of Absolute Reaction Rates" in the Journal of Chemical Physics
1944	Publication of *Quantum Chemistry* (Wiley, NY)
1946-1981	Dean of Graduate School, Professor of Chemistry, and Distinguished Professor of Chemistry at the University of Utah
1963	President of the American Chemical Society
1965	President of the American Association for the Advancement of Science
1966	Awarded the National Medal of Science
1973	Publishes Paper #500
1979	Awarded the Berzelius Medal
1980	Awarded the Wolf Foundation Prize in Chemistry
1980	Dedication of the Henry Eyring Chemistry Building at the University of Utah
1981	Dies in Salt Lake City, Utah

ionization and the stopping power of various gases for α-particles from polonium (5).

In 1930 Eyring began work with Michael Polanyi at the Kaiser Wilhelm Institute in Berlin, funded by a national research fellowship. Together, Polanyi and Eyring developed a method for approximating the potential surface of a chemical reaction that combined theoretical calculations with empirical results (5). The combination of theoretical and empirical approaches is a recurring theme in Eyring's research (2). Eyring and Polanyi's application of quantum mechanics to chemistry garnered an invitation for Eyring to return to Berkeley for a year as a lecturer. During that year (1931), Henry and Mildred Eyring's first son Edward was born in Oakland, California (5).

Henry Eyring next moved to the Chemistry Department at Princeton University, where he remained for 15 years, earning the title of full professor. This very productive period included the publication of Eyring's two most cited papers, "The Activated Complex in Chemical Reactions" (4) and "Viscosity, Plasticity and Diffusion as Examples of Absolute Reaction Rates" (7), and of the standard text *Quantum Chemistry* (8). Two more sons Henry (1933) and Harden (1939) were born during this time (2, 5, 6).

Professor Eyring, invited to establish the Graduate School at the University of Utah, relocated with his family to Salt Lake City in 1946. During the period from 1946 to 1981, he continued to direct a prolific and highly collaborative research group (paper 500 was published in 1973) (6), served as the President of the American Chemical Society (1963), served as President of the American Association for the Advancement of Science (1965) (2, 5, 6), and published "Faith of a Scientist," a collection of essays on the topic of reconciling faith and science (9).

Henry Eyring's broad-ranging scientific contributions were recognized by his peers many times. His honors included the Newcomb Medal in 1932, election to the National Academy of Sciences (USA) in 1945, the National Medal of Science in 1966 (presented by President Lyndon B. Johnson), and the Wolf Foundation Prize in Chemistry in 1980 (2). Eyring was particularly proud of the Berzelius Medal, presented by King Gustaf of Sweden in 1980. This medal is presented only once every 50 years by the Royal Swedish Academy of Science (2, 6). In 1980, when the chemistry building at the University of Utah was named in his honor, the 79-year-old Dr. Eyring responded with a speech including a quote combining his good humor with his abiding work ethic (10):

> I'll keep working as long as I can find my way to the chemistry building and somebody there will let me in. Now that my name is on the building, it should be a lot easier.

Figure 1 – Mildred Eyring in Berlin, 1930. *The image is from the personal collection of E.M. Eyring.*

Professor Eyring kept that promise. In the final year of his life, he taught undergraduate chemistry, maintained an active research program, and collaborated on three new books (2). He died in December, 1981.

Some key events in Henry Eyring's life are listed in Table 1. Figure 1 is a photograph of Mildred Eyring taken by Henry Eyring in 1930 in Berlin. Figure 2 is a photo of Eyring with his three sons in Princeton in the winter of 1939 - 1940. More complete biographies of Henry Eyring can be found in print (2, 5, 6) and on the internet (11, 12).

Continued Impact of Absolute Rate Theory

Henry Eyring's most influential idea was the Absolute Rate Theory, first published in 1935 in the *Journal of Chemical Physics* (4). Eyring summarized the paper as follows (13):

> I showed that rates could be calculated using quantum mechanics for the potential surface, the theory of small vibrations to calculate the normal modes, and statistical mechanics to calculate the concentration and rate of crossing the potential energy barrier. This procedure provided the detailed picture of the way reactions proceed that still dominates the field.

The activated complex has a fleeting existence of only about 10^{-13} sec and is situated at the point of no return or of almost no return. It is much like any other molecule except that it has an internal translational degree of freedom and is flying apart. This concept describes any elementary reaction involving the crossing of a potential barrier. If the activated state is really a point of no return, there is no perturbation of the forward rate by the backward rate, so that the rate at equilibrium applies unchanged to the rate away from equilibrium.

In simple terms, this theory holds that atoms and molecules can collide and combine to form an unstable, high-energy complex. When the molecules fall out of this high energy state, they may do so as new and different molecules, or in their original states. The energy required to reach the activated state must be available if the molecules are to change into something new. This idea, which was radical when it was proposed in 1935, is now so firmly established in scientific thinking as to seem intuitively obvious. The papers published to explain the theory remain relevant and useful today. Their principles can be found in any introductory chemistry textbook, and their content continues to be regularly cited in the peer-reviewed literature. The two most influential publications describing ART were published in the *Journal of Chemical Physics* in 1935 and 1936 (4, 7) and were cited in the literature a total of 140 times in 2008 (3).

Continued Impact of Childlike Curiosity

As a graduate student at the University of Utah, one of the authors (S.M.K.) had the opportunity to spend time with Henry Eyring. What S.M.K. observed from these interactions was that Eyring was driven by childlike curiosity. In saying this, it is important to distinguish between two very different adjectives. Eyring was *childlike*, an adjective which describes some of the most valued characteristics of children: trust, guilelessness, curiosity, and openness. He was by no means *childish*, an adjective suggesting immaturity and silliness (14, 15). As Henry Eyring described himself (16):

> I perceive myself as rather uninhibited, with a certain mathematical facility and more interest in the broad aspects of a problem than the delicate nuances. I am

> more interested in discovering what is over the next rise than in assiduously cultivating the beautiful garden close at hand.

Eyring's curiosity made him extraordinarily open to new fields of thought and exploration. He loved to think about new problems that caught his imagination. He himself illustrates this point with an oft-told story of walking through a rose garden at Princeton with Albert Einstein during the Second World War. The garden had been replanted with field crops. Professor Eyring plucked a sprig and asked Professor Einstein to confirm what it was, but Einstein didn't know. Eyring sought out a gardener, who replied: "It is soybeans." Einstein was too busy thinking about other things, but for Eyring, "what gain[ed] attention [wa]s not just propinquity, but interest." (17, 18).

Figure 2 – Hal, Harden, Henry and Ted Eyring in Princeton during the winter of 1939 to 1940**.** *The image is from the personal collection of E.M. Eyring.*

One outcome of Eyring's broad scientific curiosity was effective collaboration with scientists from many disciplines. He published extensive work in the field of physical chemistry but also contributed to the disciplines of astrophysics, biochemistry, biology, chemical education, geology, medicine, molecular biology, and textiles (2).

Eyring's curiosity was not universally admired. Some colleagues, in nominations prepared for various awards, including the Nobel Prize, made comments that reveal a subtle contempt for his simple and curiosity-driven approach to scientific problems. The authors of the comments cited below express reservations about Eyring's approach to scientific problems, despite his obvious success (19):

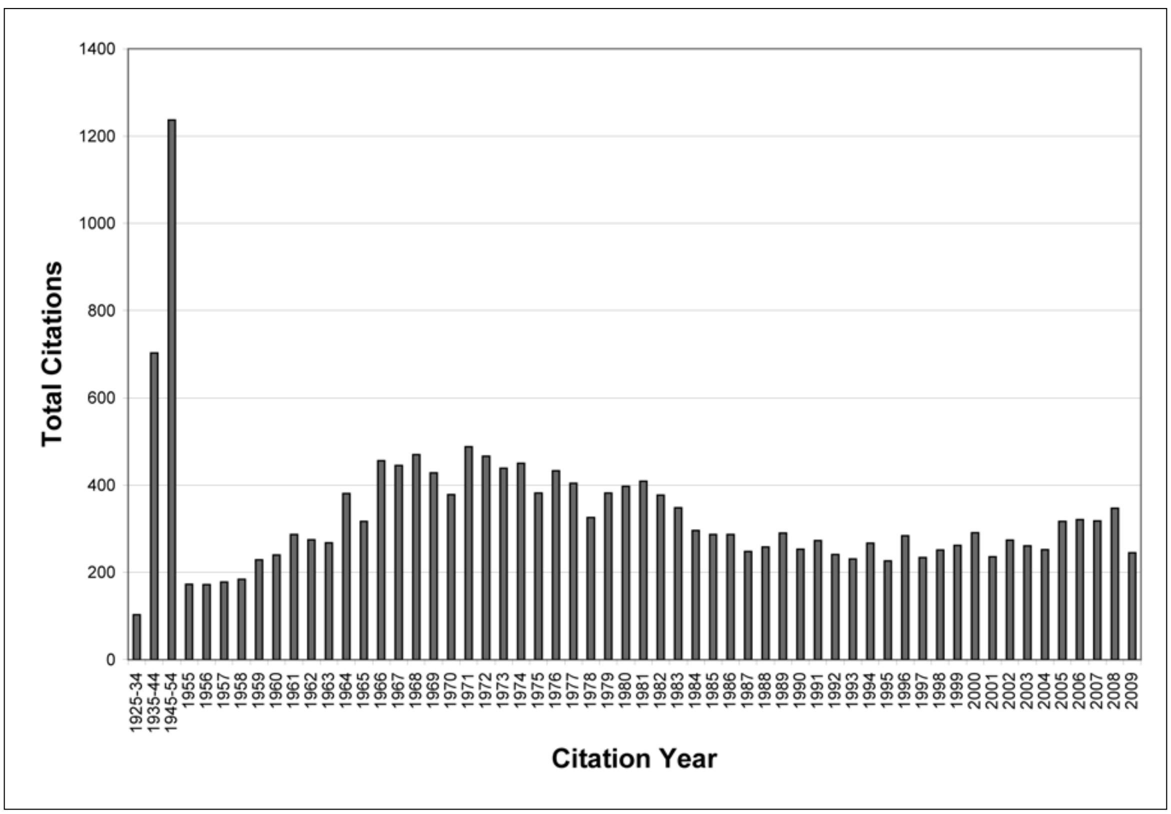

Figure 3. Annual research citations for Henry Eyring**.** *This citation history was generated from statistics that were accessed August 2, 2009 from the Web of Science (TM), a Thomson Reuters Citation atabase (Thomson Reuters, 2009), and is based on the 488 publications icluded in the Web of Science (TM) Dstinct Author Setfor Henr Eyrn*

Table 2. Citation statistics for the 10 most-cited publications of Henry Eyring*

Publication Name	2005	2006	2007	2008	2009	Total Citations	Average Citations per Year
Combined Citations for all Publications	**317**	**321**	**318**	**347**	**245**	**19525**	**229.71**
J.Chem.Phys., 1936	51	52	47	61	35	1530	20.40
J.Chem.Phys., 1935	58	70	55	79	57	1528	20.37
P.N.A.S. USA, 1952	3	7	9	3	4	789	13.60
J.Phys.Chem., 1954	32	20	19	26	17	551	9.84
Z.Phys.Chem, 1931	11	10	11	6	11	425	5.00
Chem. Rev., 1935	14	17	11	14	12	338	4.51
Phys. Rev., 1932	0	3	4	1	1	327	3.85
J.Chem.Phys., 1937	5	5	4	5	4	313	4.17
J.Phys.Chem., 1937	3	4	2	2	0	306	4.08
J. Phys. Colloid Chem., 1949	1	4	2	3	2	298	4.89

**Statistics were accessed August 2, 2009 from the Web of Science (TM), a Thomson Reuters Citation database (Thomson Reuters, 2009). Citation totals are based on the 488 publications included in the Web of Science (TM) Distinct Author Set for Henry Eyring.*

> His approach to every problem is fresh, original and frequently unorthodox. He tends to discover the facts rather than read what others have found.
>
> He paints with a broad brush. It is interesting that it comes out so well.

The continued impact of Eyring's scientific contributions would suggest that following his childlike curiosity and applying himself to the questions that interested him constituted an effective strategy. Figure 3 shows Eyring's annual research citations. His citations reached a level of 229 per year in 1959 and have remained very high ever since, even though his last papers were published in 1982 (3). Table 2 summarizes the recent and total citations for Eyring's most cited publications. Despite the length of time since these influential papers were first published, they clearly remain relevant to researchers (3).

Truth is Simple

Eyring, a man who believed that veracity and simplicity were closely related, advocated in one author's (S.M.K.) presence that if something was true, it could be expressed in simple terms. This is not to say that Eyring's scientific contributions were simplistic. On the contrary, his work is sophisticated and complex, although he was a proponent of simplicity.

Simple Truths in Research

Although not all scientists possess the mathematical skill required to understand the details of Eyring's work, the simply stated core truth of his Absolute Rate Theory provides a good starting place to think about how chemical reactions work. In the preface to *Quantum Chemistry* published in 1944, Eyring wrote (20):

> No chemist can afford to be uninformed of a theory which systematizes all of chemistry even though mathematical complexity often puts exact numerical results beyond his immediate reach.

This remains true today.

Henry Eyring's thoughts on model building and hypothesis design also remain relevant across many disciplines. In his own words (21):

> 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, even if the theory must be modified, can be useful.
>
> A well designed model can be proved or disproved, debated, tested, and improved. No matter what field of science, a simple approach to model building can be very powerful.

Simple Truths in Teaching

Professor Eyring was a teacher who asserted that deep and sophisticated understanding of complex material is a prerequisite to a simple explanation of that information. One principle that he passed on to his family was that (22):

> If you can't explain something to an eight-year-old, you don't really understand it yourself.

Eyring often used analogies to explain complex ideas to nonscientific audiences and to students from outside the field of chemistry. His simple explanations made a scientific understanding of the principles of chemistry accessible to a broad range of people and inspired great praise from his students (6). Eyring also inspired learning in his sons. Edward, seen in Figure 4 as a toddler watching the eclipse, became a Professor of Chemistry. Hal is currently First Counselor in the First Presidency of The Church of Jesus Christ of Latter-Day Saints, while Harden was Assistant Commissioner of Higher Education for the State of Utah upon his retirement in 2009 (E.M. Eyring, personal communication).

Figure 4 – Sharing his scientific curiosity. *Edward (left) and Henry (right) Eyring view an eclipse in 1932. The image is from the personal collection of E.M. Eyring.*

Simple Truths in Faith

Henry Eyring was an unapologetic man of faith. Though it may not have been respected by all his colleagues or supported by all of his fellow believers, Eying also took a simple, but not simplistic, approach to reconciling faith and science. Eyring believed that, although faith and science might seem to be in conflict, this apparent conflict did not negate either human pursuit, but simply underscored the incomplete human understanding of both. For him both true science and true religion are concerned "with the eternal verities of the universe" (23). In his own words (24):

> Is there any conflict between science and religion? There is no conflict in the mind of God, but often there is conflict in the minds of men.

For Eyring, apparent contradictions between scientific results and the teachings of his faith community would be resolved by an eventual understanding of the truth (25):

> I am a dedicated scientist and the significant thing about a scientist is this: he simply expects the truth to prevail because it IS the truth. He doesn't work very much on the reactions of the heart. In science, the thing IS, and its being so is something one cannot resent. If a thing is wrong, nothing can save it, and if it is right, it cannot help succeeding.

Simply Respecting Everyone: Brother Amott, USPS, Ph.D.

Eyring encouraged his students to treat everyone with respect (1) and clearly led by example. When he was the Dean of the Graduate School at the University of Utah, the U.S. Postal Service delivered the mail directly to the Dean's Office, twice each day. The mailman who delivered the Dean's mail for 20 years, known to the Dean's secretaries as Brother Amott, always stopped to speak to the Dean and his influential and hard working secretaries. When it came time for the mailman to retire, Eyring decided to exercise his authority and arrange for Brother Amott to receive an honorary doctorate directly from the Office of the Dean, in recognition of his service to the University of Utah, in particular to the Graduate School. This story, which typified Professor Eyring's respect for others, caught the imagination of the Salt Lake City press and caused quite a stir (E. M. Eyring, personal communication).

Conclusion

Professor Eyring published over 600 scientific articles and more than a dozen textbooks over his 50-year career (2). He established the Graduate School at the University of Utah and educated countless graduate and undergraduate students (2, 5). He wrote essays and texts reconciling the pursuit of scientific knowledge with faith in God (9, 24). His collaborators included biologists, chemists, physicists, and medical researchers. He thought broadly, and brought innovative questions and solutions to the many fields that inspired him. Eyring's work continues to be actively cited in the research literature, nearly 28 years after his death (3).

Eyring was hard working and insatiably curious. He was also a proponent of simplicity. As one author (S.M.K.) learned from time spent with Professor Eyring (26):

Henry Eyring saw himself as simple. Great ideas come from simple people. It is simple ideas that can actually change the world. Henry Eyring instinctively knew the truth when he saw it. You know the truth when you see it. The truth is always simple. The lesson of Henry Eyring's life is that simple people, just like you and me, can change the world. We do it a little bit every day. And we have the potential to change the world much more, if we can better understand and use our unique gifts.

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