NATIONAL ACADEMY OF SCIENCES

# WARREN KENDALL LEWIS

*1882—1975*

*A Biographical Memoir by*

HOYT C. HOTTEL



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*August 21, 1882–March 9, 1975*

BY HOYT C. HOTTEL

WARREN KENDALL LEWIS, through his coordination of chemistry, physics, and engineering into an independent discipline to serve the chemical industry, has been called the father of modern chemical engineering. Although his contributions to basic chemical engineering principles and to chemical processing during a life of ninety-two years were many and solid, his hallmark was intense stimulation of hard thinking in others—his students, research associates, and industrial contacts. His applied chemical research and books were important, but aggressive teaching and demand of straight thinking were Lewis's characteristics most remembered by his associates of two generations. "Doc" would bring to the solution of a problem, whether educational or industrial, a sound, well-organized knowledge of physics and physical chemistry. His capacity for expression was superb and his dedication to the objective of finding the answer was obvious and intense. In any discussion, whether on science or engineering or social problems, he loved to lecture and to question.

Born on a farm in Laurel, Delaware, on August 21, 1882, Lewis transferred in his high school days to Newton, Massachusetts, for better schooling. There he met Richard C.

Tolman, later to become as able and original in his area, statistical mechanics, as Lewis would become in his; friendship and mutual respect developed. (In London during World War II Dr. Tolman spoke to me with warmth and admiration about Lewis.) In 1901 Lewis entered the Massachusetts Institute of Technology, intending later to improve farming with his engineering background. His association with William H. Walker, head of the chemical engineering option in MIT's Chemistry Department, changed his objective. He was awarded a fellowship for study in physical chemistry in Breslau, Germany. On the award of his Sc.D. degree in 1908, he returned to MIT for a year as a research associate in applied chemistry; this was followed by a year as a chemist for a tannery in New Hampshire. Then, in 1910, Lewis accepted an MIT appointment as assistant professor. His son, H. Clay Lewis, tells the story of a conversation he had years later with his father's former employer: "I told Lewis I would double his salary if he stayed in leather. He said, 'No'. I then said I would triple his salary. He said 'No'. I then said to him, 'I suppose there is no amount I can offer that will keep you from going to MIT'. Doc said, 'I guess so!'" In 1914 Lewis became full professor under Walker, and in 1920, when the Chemistry Department's engineering option of thirty-two years' standing was split off, Lewis was made head of the new Department of Chemical Engineering at MIT. After thirteen years as head he resigned in order to have more time for his teaching and research. In 1948 he became professor emeritus.

## BOOKS

In the period before 1920 Lewis recognized the need for a more unifying philosophy of education in chemical engineering. Stimulated by Arthur D. Little, he worked with Walker and William H. McAdams in identifying and quantifying what they called the "unit operations" of the chemical industry—distillation, vaporization, separation processes, heat transfer, combustion, absorption, fluid flow, filtration, and so on. In 1923 that effort produced the classic *Principles of Chemical Engineering* by Walker, Lewis, and McAdams (Edwin R. Gilliland was coauthor of the third edition in 1937). The book powerfully stimulated the evolution of chemical engineering as a profession, and it encouraged the creation of new chemical engineering departments worldwide. Parallel to that effort was the publication by Lewis of many papers on unit operations. How more effectively to use material and energy balances on a single chemical species was the motivation for Lewis's next book, *Industrial Stoichiometry* (1926), written jointly with A. H. Radasch; in 1954 the book was expanded, with coauthorship by H. Clay Lewis. Lewis's early work on leather tanning and on the vulcanization of rubber got him interested in colloidal phenomena, and his later research on clay, textiles, and plastics expanded that interest and produced a book, written jointly with L. Squires and G. Broughton, *The Industrial Chemistry of Colloidal and Amorphous Materials* (1942).

## SOME OF LEWIS'S RESEARCH ACTIVITIES

So many areas of applied research interested Lewis that it is difficult to guess which interested him most; distillation was certainly high on his list. He had early become a consultant on petroleum problems and was soon aware of the higher level of sophistication on distillation in the alcohol industry than in petroleum. Existing patents on separating petroleum fractions showed a gross deficiency in the basic physics and physical chemistry of separation, and Lewis typically dedicated himself to putting fractionation by rectification on a sound basis. One story of events in that area in the 1920s is typical Lewis: The department's Applied

Research Laboratory had contracted to expert a lawsuit involving fire in piping carrying oxygen, and had got Lewis to agree to be an expert witness. Studying the problem, he found that a side issue unimportant to the subject case presented a distillation problem he could not solve. He buried himself in the problem, and on the train to where the case was to be tried he was so lost in his new problem that the laboratory staff began to worry, and assigned to one of its younger members the full-time job of keeping Doc from working on his distillation problem rather than studying the coming court case. Lewis published thirteen papers on distillation and nine on evaporation; nineteen of his eighty-one patents were on distillation.

The movement of underground oil to a well's borehole excited Lewis's imagination, and he made valuable contributions to the modeling of flow through oil sands, the prediction of oilfield life, and methods of increasing oil recovery. But his most important contribution to the petroleum industry, measured either in dollars or in military value, came out of his interest in fluidized powders and the control of their movement in a chamber. Lewis in his early days in petroleum had contributed to thermal cracking as a means of increasing the fraction of crude petroleum that ended up in the volatility range of gasoline. Then came catalytic cracking, which enormously increased the gasoline yield and its antiknock quality but was plagued with troublesome problems such as control of temperature of the massive bed of pellets on the surface of which the chemical reaction generates heat and loss of catalytic activity due to the deposition of carbon on the pellet surface. Lewis saw that preparing the catalyst in fine-particle form and suspending it in the petroleum vapors to be cracked could solve the problems. In a continuous process he saw that the catalyst could be partially removed at one point, cleaned by oxidation, and returned at another point, and that the temperature could be far more readily controlled. The first full-scale unit began operation in 1942; fluid-bed cat cracking produced high-octane aviation fuel, giving Allied planes greater speed than Axis models with engines designed for lower-octane fuel. Substantially all cracking today uses the fluid bed, representing a multibillion dollar investment. Many other chemical reactions are today carried out in fluid-bed systems.

## WARTIME ACTIVITIES

Lewis's high ethical standards and deeply religious temperament did not prevent his large effort in both world wars. In World War I, first in the Bureau of Mines and later in the Chemical Warfare Service, he was in charge of research on gas defense, correlating and directing the work of various laboratories and aiding in the reduction to practice of the results in the manufacture of protective devices by the Gas Defense Production Division. In World War II Lewis served as executive officer of the Chemical Engineering Department's many military research activities. He was also a consultant to the federal Office of Scientific Research and Development and an advisor to the Office of Production Research and Development. In April 1940 Arthur H. Compton was asked by Vannevar Bush, director of the wartime Office of Scientific Research and Development, and the National Academy of Sciences to chair a committee to assess the military value of uranium. Two academy reports and indecisive discussion of the consequence caused Bush and Conant in the autumn of 1941 to enlarge the Compton committee by two members, "this time to include W. K. Lewis, a chemical engineer with an outstanding reputation for estimating the potential success at industrial scale of laboratory processes"[1] and George Kistiakowski, a Harvard chemist and expert on explosives. By early spring of 1943 Los Alamos physicists were busy laying plans for their laboratory work, and "(General) Groves appointed a review committee—W. K. Lewis again, an engineer named E. L. Rose, who was thoroughly experienced in ordnance design, van Vleck, Tolman, and one other expert—to follow planning and to advise."[1] In January 1943 Philip Adelson and Ross Gunn had proposed thermal-diffusion as a partial enricher of uranium, and a year later construction finally began on a small plant. By the spring of 1944 Oppenheimer had become aware of the effectiveness of thermal-diffusion as a complement to gaseous diffusion, had convinced Groves, and was contrite for having lost time. In May "Groves appointed a committee of men thoroughly experienced by now in Manhattan District troubleshooting: W. K. Lewis, Eger Murphree" (an expert on thermal diffusion who had served at MIT under Lewis) "and Richard Tolman."[1] Clearly, in both wars Lewis's engineering know-how and decision-making ability were highly prized by many organizations.

## HIS AGGRESSIVE TEACHING

Lewis's contributions to the chemical industry loom large but they pale in comparison with his Herculean capacity to teach, whether students, faculty, or industrial associates. His teaching methods were phenomenal, varying greatly but always stimulating and intense, sometimes dramatic, and not infrequently showing a talent for acting. But they drove home Doc's demand for clear analysis, his impatience with sloppy thinking, and, if a problem involved industrial application, the importance of action. Sometimes Doc would come into the classroom, take off his coat, roll it into a bundle, deposit it, and turn to a student with a riveting glare and ask a broad question. To a poor answer he might reply, "You damned dumb-bell, don't you see that," and so on, sometimes with a little sermon. Among countless stories told about Doc's teaching, here is one told a generation after it happened by the last recipient in a class period of Doc's succession of put-downs of student answers to his questions, shouted from a raised platform in a large classroom: "Can anyone here name a single infallible law of Nature?" Silence, then a pointed finger, "You there, first man in the first row! Can't you name one?" Pause. Then, "Conservation of matter." Doc, "Cosmic rays blow your law of conservation to Kingdom Come. Next man!" Finally the pointing finger got to the teller of this story, who blurted out, "The law of constant proportion." Doc, "Did you ever hear of isotopes?" Then he leaned down and forward until his face was within 12 inches of the student's and shouted with such intensity that his mouth was not under proper control, "Isotopes are things that *spit* at the law of constant proportion." In telling the story the teller did not forgive; instead, he thanked Doc for a lesson never forgotten. Some comments from Walter G. Whitman, who followed Lewis as chemical engineering department head at MIT: "There was nothing more important (to Dr. Lewis) than kindling the spark for accomplishment. . . . (His) methods have seemed unorthodox and even harsh to many on first acquaintance. . . . But as the student learns to meet that challenge to his intelligence and imagination, he acquires unsuspected powers and confidence. He also learns that Doc can become a patient guide. . . ." One more story: When a lecturer of students gets badly mixed on a quantitative derivation, the gracious and student-time saving action is to admit being mixed, promise a straight derivation next session, and go on with the lecture. Not for Doc; he feared an apology would be misinterpreted as indicating being wrong rather than just temporarily being confused. Doc's teaching assistant, Robert L. Hershey, later a faculty member and superb teacher and still later a du Pont vice-president, was sitting in the back row of a large classroom where Doc, at the blackboard on a thermodynamics derivation, got going in a circle. Hershey left through the rear door, entered the front one, and handed Doc a paper as he commented, “A telegram for you, Dr. Lewis.” Doc glanced at the paper, pocketed it, and went on, with his derivation clarified. Doc’s use of strong statements to make a point often got him into an argument with students or faculty associates. Characteristically, he would say, “I’ll bet you a dollar to a doughnut” (five cents in the early 1920s). R. E. Wilson, one of Doc’s faculty associates and later president of Standard Oil Company of Indiana and still later Atomic Energy Commissioner, would set scientific traps for Doc and sometimes win. Every spring he would send Doc a copy of a page out of his IRS return in which he reported “$xx won from W. K. Lewis on dollar-to-doughnut bets.” Sixty years after the event causing its transfer, an old-fashioned dollar bill, larger than the present one, was received by MIT from a surviving relative of a student who had won a dollar-to-doughnut bet from Lewis and carried it in his wallet throughout his life.

## CONSULTING

Lewis’s teaching ability was a main factor in his consulting contacts with industrial researchers or planners. Harold C. Weber, a faculty associate of Doc, told a story of their joint visit to National Carbide Company, where they discussed several problems related to carbon, including B batteries. Lewis dominated the discussion. As they left the conference, Doc turned to Harold and said, “Weber, what the hell is a B battery?” Weber later said that Doc could stretch a small bit of factual knowledge about a problem farther than anyone he knew. That was illustrated in a 1928 conference at Humble Oil Company which I had the honor to join. Doc and Robert T. Haslam took me with them to Texas for consulting on several problems in their area and one in mine. At the conference were several young men I knew who had studied under Doc and were now on Humble's research staff. I expected the chairman, Mr. Wise, general manager and later on the board of Standard Oil Company of New Jersey, the holding company for Humble and other subsidiaries of Standard Oil, to dominate the meeting. He outlined the first problem, and Doc immediately made some comments that got a lively discussion going. Mr. Wise presented the second problem area, and Doc at once spoke up and said what the problem was about. One of his former students immediately replied, "Doc, that isn't it. The problem centers on (so-and-so)." Mr. Wise encouraged the younger man, and discussion went well. On the third problem Doc again started the discussion, and again one of the younger men disagreed. The whole conference went that way, with Doc occasionally supplying inputs but always supplying stimuli. With the fairly prevalent youngster's misconception of how big corporations become big I had expected Mr. Wise to dominate the conversation. Instead, he stayed in the background. It was also clear that the Humble staff knew far more about what inputs were important to the discussion than Doc, and even clearer that by any standards Doc was the most valuable man at the conference.

## THE ENGINEER IN SOCIETY

Taking a strong position on the problems of society was characteristic of Lewis. His belief in the important role the engineer had played over the centuries in raising the living standards of humanity was expressed frequently; he saw engineering as a noble activity. Such a discussion might lead to his almost religious fervor in defending the principle of a free competitive economy, or profit as the measure of industrial success. He could become eloquent on the validity of that measure, pointing out that the principle of free competition combined with profit to measure success promoted individual contributions to the common welfare at minimum cost. Then he would add, "I see no viable alternative to the profit system; I have nothing but contempt for the profit motive." Lewis was devout, high principled, a deacon in his church, but not outwardly religious. He never hesitated to mix his beliefs about ethical principles or free industrial competition with his teaching of engineering. He believed the engineer, by not taking more of a lead in society's problems, was overlooking an opportunity to render a public service greater than any he had contributed in the past.

At the end of World War II, MIT appointed a Committee on Educational Survey. With Lewis as chairman and Jay Stratton one of the members the committee made a long-range study of the MIT's curriculum and educational policy. One of the significant results was the establishment of the School of Humanities and Social Sciences, a deficiency about which Lewis had commented for decades and had the support of Stratton. His legendary ability for clear and forceful report writing was one of the reasons for the committee's success in guiding the evolution of MIT during the critical years after World War II and for the next two decades. In the nearly fifty years since the committee's formation two similar ones have written reports which refer to the principles enunciated by the Lewis committee.

Warren K. Lewis was elected to the National Academy of Sciences in 1938. He was the recipient of the many honors listed below; but he is chiefly honored by the vivid memory of his personality and principles in the minds of engineers and others who had the privilege of knowing him.

## AWARDS AND HONORS

Perkin Medal of the Society of Chemical Industry (British), 1936
Member, American Academy of Arts and Sciences
Member, National Academy of Sciences, 1938
Lamme Medal of the American Society of Engineering Education, 1947
Priestley Medal of the American Chemical Society, 1947
President's Medal for Merit, 1948
Gold Medal of the American Institute of Chemists, 1949
New England Award of the Engineering Societies of New England, 1950
First American Chemical Society Award in Industrial & Engineering Chemistry, 1956
American Petroleum Institute Gold Medal for Distinguished Achievement, 1957
Founders Award, American Institute of Chemical Engineers, 1958
Member, National Academy of Engineering, 1965
John Fritz Medal of 5 Engineering Societies, 1966
Honorary Member, Institute of Chemical Engineers (British)
President's Medal of Science
Warren K. Lewis Award of the American Institute of Chemical Engineers
Establishment of the Warren K. Lewis Professorship in Chemical Engineering at MIT, 1969
Honorary Sc.D. degree, University of Delaware, 1937
Honorary D.Eng. degree, Princeton University, 1947
Honorary Sc.D. degree, Harvard University, 1951
Honorary Sc.D. degree, Bowdoin College, 1952

## NOTE

1. R. Rhodes, *The Making of the Atomic Bomb.* New York: Simon & Schuster (1986).

## SELECTED BIBLIOGRAPHY

Dr. Lewis published 3 books, 81 patents, and about 125 papers between 1909 and 1959. This bibliography omits many papers which guided chemical engineering teaching worldwide.

1909

The theory of distillation. *J. Ind. Eng. Chem.* 1(8):522-33.

1916

The principles of countercurrent extraction. *J. Ind. Eng. Chem.* 8(7):825-33.

1919

Controlling factors in gas-mask design. *Proceedings of the 8th Annual Safety Congress of the National Safety Council.*

1922

The efficiency & design of rectifying columns for binary mixtures. *J. Ind. Eng. Chem.* 14(6):492-7.

1923

With W. H. Walker and W. H. McAdams. *Principles of Chemical Engineering.* New York: McGraw-Hill. (Third edition coauthored with E. R. Gilliland.)

With W. H. McAdams. Factors in the design of absorption apparatus. *J. Am. Gas Assoc.* 5:754-65.

1926

With A. H. Radasch. *Industrial Stoichiometry.* New York: McGraw-Hill. (Second edition coauthored with H. C. Lewis in 1954.)

1927

With E. D. Ries. Influence of reaction rate on operating conditions in contact sulfuric acid manufacture. II. *Ind. Eng. Chem.* 19(7):830-7.

1928

With P. K. Frölich. Synthesis of alcohols higher than methanol from carbon monoxide and hydrogen. *Ind. Eng. Chem.* 20(4):354-9.

With H. D. Wilde. Plate efficiency in rectification of petroleum, *Trans. AIChE* 21:99-126.

1931

With J. Q. Cope and H. C. Weber. Higher hydrocarbon vapors. I. Generalized thermodynamic properties of higher hydrocarbon vapors. *Ind. Eng. Chem.* 23:887-92.

1932

With G. L. Matheson. Studies in distillation design of rectifying columns for natural and refinery gasoline. *Ind. Eng. Chem.* 24(5):494-8.

1933

With C. D. Luke. Vapor-liquid equilibrium of hydrocarbons at high pressures. *Ind. Eng. Chem.* 25(7):725-7.

Physical laws of perfect solutions applied to properties of mixed petroleum hydrocarbons. *Oil and Gas J.* 32(20 Oct.).

1934

With L. Squires. The structure of liquids and the mechanism of viscosity. *Refin. Natur. Gas. Manuf.* 13(12):448.

1936

Rectification of binary mixtures. *Ind. Eng. Chem.* 28:(4):399-402.

1937

With L. Squires and R. D. Nutting. Mechanism of rubber vulcanization with sulfur. *Ind. Eng. Chem.* 29(10):1135.

1942

With L. Squires and G. Broughton. *Industrial Chemistry of Colloidal and Amorphous Materials.* McMillan.

1949

With E. R. Gilliland and W. C. Bauer. Characteristics of fluidized particles. *Ind. Eng. Chem.* 41:1104-17.

With E. R. Gilliland and G. McBride. Gasification of carbon by carbon dioxide in fluidized powder bed. *Ind. Eng. Chem.* 41:121-26.

1950

With E. R. Gilliland. Conversion of hydrocarbons with suspended catalyst. U.S. Patent No. 2,498,088.

With E. R. Gilliland, B. Chertow, and W. P. Cadogan. Absorption equilibria: hydrocarbon gas mixtures. *Ind. Eng. Chem.* 42:1319-26.

1951

With E. R. Gilliland and W. P. Sweeney. Gasification of carbon: metal oxides in a fluidized powder bed. *Chem. Eng. Prg.* 47(5):251.

1952

The place of chemistry in the liberal arts curriculum. Report to Alumni, Bowdoin College, Sept., 1952. "Bowdoin College 1802-1952", p. 45.

1957

Engineering as a profession. *Tech. Rev.* (MIT), p. 351.