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OF

LEO HENDRIK BAEKELAND

1863–1944

BY

CHARLES F. KETTERING

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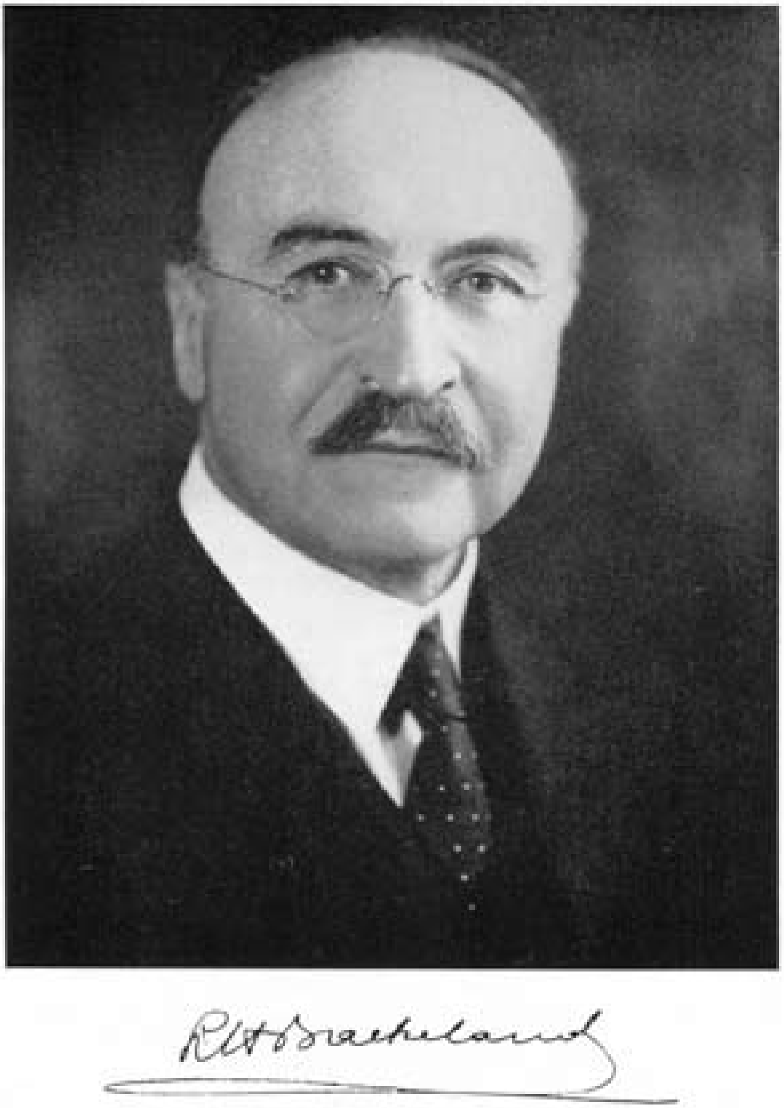

LEO HENDRIK BAEKELAND

1863–1944

BY CHARLES F. KETTERING

Leo Hendrik Baekeland was born in Belgium, in the Flemish city of Ghent, on November 14, 1863. He was a son of Charles and Rosalie (Merchie) Baekeland, a Belgian family of moderate circumstances. Entering school at the age of 5, he passed through the elementary schools and the Atheneum, a government high school. When old enough he entered the Ghent Municipal Technical School, where he attended evening classes in chemistry, physics, mechanics, and economics, and won a medal in each of the four subjects.

Young Baekeland was such a promising student that the City of Ghent awarded him a scholarship in the University of Ghent, and he entered that university in 1880 at the age of 17. He was the youngest member of his class, but the most brilliant. In 1882 he graduated from the university as a Bachelor of Science. In two years more, or in 1884 at the age of 21, he gained the degree of Doctor of Science, maxima cum laude. Furthermore, with the aid of the City Scholarship he had received, and by teaching and serving also as a lecture assistant, he supported himself while in the university. Baekeland was inspired to do this, and so to relieve his parents of his support, he said later, by having early heard the story of Benjamin Franklin and having learned from it that a boy in humble circumstances could make his way altogether by his own efforts.

In the university Baekeland studied the natural sciences and specialized in chemistry. A boyhood interest in photography was one of the things which interested him in chemistry and which attracted him to it as a major. In some of his early experiments on photography young Baekeland had needed silver nitrate. He had no money to buy it, but he did have a watch with a silver chain which his father had given him. So he took the chain off his prized watch and dissolved it in nitric acid. There was copper in that solution too, but young Baekeland worked out, as one of his earliest chemical operations, a plan for removing the copper from the silver solution.

It was at the University of Ghent that Kekule had taught and it was there in 1865 that he announced his classical theory of the structure of benzene. Some years before Baekeland's time, however, Kekule had left Ghent for Bonn, and his chief assistant, Theodore Swarts, had taken his place as senior professor of chemistry. And it was under Professor Swarts that Baekeland studied.

In 1887 Baekeland was appointed professor of chemistry and physics at the Government Higher Normal School of Science in Bruges. He did not stay long at Bruges, though, for his own University of Ghent soon offered him a post as assistant professor. He gladly accepted that offer, and soon afterwards, in 1889, he was promoted to associate professor.

One of the reasons for Baekeland's desire to return to Ghent was that he had fallen in love there with Celine Swarts, the charming daughter of his professor of chemistry, Theodore Swarts, and his wife Nina (Plateau) Swarts. The two young people were married on August 8, 1889, and the marriage proved a particularly happy one. In later years at a gathering to do him honor, Baekeland said, "You have talked here tonight about my many discoveries. But you haven't mentioned my greatest discovery—a discovery I made when I was still a student. That great discovery was a woman who is here with us tonight—my wife." Aside from the contributions she made to the success of her husband, which were many, Mrs. Baekeland became famous in her own right, notably as a painter in oils.

In a competition among the alumni of the four Belgian universities who had graduated during the preceding three years Baekeland won in 1887 first prize in chemistry. That gave him the title of laureate in chemistry, a gold medal, and a traveling fellowship. And so, in 1889 when he was 26 years old, Baekeland visited University College, London, Oxford University, and the University of Edinburgh. After that, accompanied by his young wife, Baekeland sailed to the United

States, where he planned to spend some time in continuing his researches, particularly in the chemistry of photography. Baekeland's native city of Ghent was a center for the manufacture of photographic dry plates, an industry started there in the 1880's by Van Monkhoven. Monkhoven had taken an interest in young Baekeland, and with his encouragement Baekeland began early to experiment with photography and with the chemistry of its processes, and to try to extend the knowledge in the field.

Upon his arrival in New York, Baekeland made the acquaintance of Richard A. Anthony of E. and H. T. Anthony and Company, manufacturers of photographic materials. And through Richard Anthony he was introduced to C. F. Chandler, professor of chemistry at Columbia University, who was a chemical consultant to the Anthony Company and who also, as an enthusiastic amateur photographer, was then editing the *Photographic Bulletin* published by that company. Professor Chandler, being impressed by the capabilities of Baekeland, persuaded him to remain in the United States and to apply his talents to the solution of chemical problems in industry. Accepting the advice of Prof. Chandler, Baekeland cabled his resignation from the faculty of the University of Ghent. The Minister of Education of Belgium, in accepting Baekeland's resignation, authorized him to retain as an honorary title that of Associate Professor at the University of Ghent.

In 1891 the E. and H. T. Anthony and Company offered Baekeland an excellent position as chemist in their factory, which offer he accepted. It was the Anthony Company, makers of photographic dry plates and bromide paper, which afterwards joined with the Scoville Company to form the Ansco Company.

In 1893, however, two years after he had begun to work for the Anthony people, Baekeland resigned his position to become an independent consulting and research chemist. Chiefly he planned to devote his time to developing a number of chemical processes which he had devised; and, as he said later, he made the mistake of scattering his attention on too many subjects at the same time. But at that stage a serious illness came upon him. And that brought him to a decision which he expressed in these words:

> While I was hovering 'twixt life and death, with all my cash gone and the uncomfortable sentiment of rapidly increasing debts, I had abundant time for sober reflection. It then dawned upon me that instead of keeping too many irons in the fire, I should concentrate my attention upon one single thing which would give me the best chance for the quickest possible results.

The one thing which Baekeland decided to do after his recovery was to found in Yonkers, with the financial and managerial assistance of Leonard Jacobi, the Nepera Chemical Company, and to begin to manufacture on a small scale photographic papers and chemicals. One of those papers was named "Velox," and it was destined later on to become very widely used indeed and to yield a financial return which set Baekeland free and put him in position to make other outstanding discoveries. Baekeland had begun ten years before, while still a student at Ghent, the research which culminated in Velox paper; but he had not previously appreciated its commercial importance. What he had found out was that, in preparing a silver chloride emulsion, the customary "ripening" process and the subsequent washing step had a disastrous effect upon the emulsion in respect to the tone and the general gradation of the image, especially in the shadows. By preparing silver chloride in a special colloidal condition and omitting altogether the customary washing step, Baekeland made a distinctly superior photographic paper, and one which printed much faster than older papers. Prints were made by exposing for a short time to artificial light and then developed at a little distance from the same light, which was a distinct improvement over the slow and unreliable method of "sun printing" then in use. Because of the different processing Velox paper required, however, it did not meet with general favor at first; and for that reason, coupled with the depression of 1893, the new company passed through some very difficult times. Baekeland spoke once of that period as "several years of hard work, with never a single day of rest, and ever wondering whether I would pull through or not." He said further:

> I had been too optimistic in believing that the photographers were ready to abandon the old slow processes of making photographic prints. I had to find out then how difficult it is to teach anything new to people after once they got use to older methods. . . . Even my best friends tried to dissuade me from continuing my stubborn efforts. I had also not foreseen manufacturing difficulties, but I gradually managed to overcome them.

Largely through use by amateurs—who, as Baekeland said, "began to give themselves the trouble of reading and following our printed directions"—the sales of the new paper gradually grew, and by 1899 the business had become so successful that the Eastman Kodak Company bought out the interests of Baekeland and Jacobi on very liberal terms.

It was while he was manufacturing photographic papers in the 1890's that Baekeland became a pioneer in air conditioning as an aid to chemical processing. He found that atmospheric conditions, particularly the moisture content of the air, were responsible for large variations in the photographic printing papers produced. Up to that time, only refrigeration had been used for hardening coatings on papers by a chilling process. But, as such chilling had the bad effect of making the coating brittle, Baekeland worked out and installed a system for removing moisture from the air by putting the air through a refrigeration unit and subsequently warming it to the proper temperature by passing it over steam coils before it entered the coating room. This gave rapid drying of the emulsion without the development of brittleness. Being troubled, however, in the winter time with the development of static electricity on the paper, Baekeland installed also a system in which silver chains were trailed over the paper on the coating machines to carry off the charge through the frame. And, in a paper presented in 1903, he said, "In photographic paper factories hygrometers and electroscopes should be consulted as often as the thermometer."

After the sale of his photographic paper interests to Eastman, Baekeland purchased as a home for his family and a place where he could continue his experiments the estate in North Yonkers known as "Snug Rock." Situated high above the Hudson, it looked across to the Palisades on the west bank. Of his situation at that time Baekeland said the following:

> Thus at thirty-five I found myself in comfortable financial circumstances, a free man, ready to devote myself again to my favorite studies. Then truly began the very happiest period of my life. I improvised one of the buildings at my residence in Yonkers into a modest but conveniently equipped laboratory. Henceforth I was able to work at various problems of my own free choice. In this way I enjoyed for several years that great blessing, the luxury of not being interrupted in one's favorite work.

From time to time Baekeland employed a number of assistants in his work there, but the greatest of his helpers was his wife, who assumed the responsibility of keeping his records, and whom he consulted on many of his problems and transactions.

At this time Baekeland became interested in electrochemistry. This was because he saw that electrochemistry, which in his student days had been limited to the electro-deposition of a few metals from aqueous solution, had since that time become an important branch of chemical industry. It was then being put to such uses as separating aluminum from bauxite, producing carborundum and graphite, making calcium carbide, manufacturing sodium, and simplifying the preparation of important compounds of that metal, such as sodium cyanide. Because of his interest in these developments, Baekeland decided in 1900 to visit Germany for what he called a "refresher" in the science of electrochemistry. He spent a winter there in the electrochemical laboratory of the Technological Institute of Charlottenburg brushing up on his knowledge of the subject. And when he returned to Yonkers he fitted his laboratory with electrochemical equipment for further study.

It was about that time that Clinton P. Townsend invented his electrolytic cell for producing caustic soda and chlorine from salt. And Baekeland was asked by Elon H. Hooker to undertake an investigation of the Townsend electrolytic cell, preliminary to its application on an industrial scale. This Baekeland did in company with the inventor and several other persons skilled in electrolysis. An important one of Baekeland's contributions to the Townsend cell at that time was an improved diaphragm of much greater durability than had been available before. That work led to two of the earliest of the many patents which Baekeland took out, and to the formation in 1903 of the Hooker Electrochemical Company and the erection at Niagara Falls of one of the largest electrochemical plants in the world. For several years afterwards Baekeland continued to be connected with that company in a consulting capacity.

In his work on the Townsend cell which preceded the building of the Hooker plant at Niagara Falls, Baekeland constructed two full-size electrolytic cells embodying the improvements made by his group; and these he operated under varying conditions, day and night, for months. With the further knowledge thus gained, the specifications for the full-sized plant were drawn. But even that plant was not built in full at first, only the smallest section that could be operated. Thus, by this careful step-wise procedure, involving an expenditure of only $300,000, as Baekeland said later, blunders that might have cost millions were prevented. And that experience gave rise to a maxim of Baekeland's which has been widely quoted: "Commit your blunders on a small scale and make your profits on a large scale."

Baekeland then turned his attention to the subject upon which his greatest fame rests—the research which pioneered the important plastics industry. By finding how to direct the action of formaldehyde upon phenols in proper channels, he gave to the world an important new material which was named and trade-marked "Bakelite." The condensation of aldehydes with the phenols was not a new reaction at all. It had been known for twenty years, or ever since the work of Adolph Bayer in 1872. But the condensation of formaldehyde with phenol does not of itself give bakelite. Even when the reaction yielded a resin, it was one that had no special utility. Only under the very special conditions established by the long researches of Baekeland is a product of the amber-like and highly resistant properties of bakelite produced. Nor was Baekeland the first investigator who had tried to obtain that result. Years afterwards Baekeland said of those earlier workers, "They *should* have succeeded, but they wouldn't." What he did not say was that it was only after five years of the most intensive effort, and after many failures and disappointments, that he himself succeeded.

But, as a result of a long and systematic investigation, in which he tried to study all factors of the reaction between formaldehyde and phenol, Baekeland found that he could dissect the reaction or separate it into different steps. He found that pressure was valuable in controlling the reaction, and that by the presence of ammonia or other base he could spread the reaction out over a longer period and so could stop it at any stage he wished by cooling. He found that he could thus control the reaction in steps, and use was made of that fortunate circumstance in furnishing the new product, bakelite, to those who had use for it.

In respect to making the new material available commercially to those who had need of it, Baekeland said this:

> I firmly intended to escape the recurrence of business occupations, as in my Velox days. So I planned, instead of manufacturing myself, to grant licenses to established manufacturing concerns, especially experienced in plastics. But I soon was confronted with a repetition of my former experience with Velox: that it was very difficult to teach new methods to men who had acquired routine in older processes. The preparation of the new resinoid and its molding compositions, which to me seemed very simple, appeared either very difficult or needlessly complicated to others. Reluctantly I had to start manufacturing the raw materials in a sufficiently advanced stage so that the users had only to complete the operation of molding and polymerization.

The bakelite resin, as thus produced for distribution to the trade, would soften on heating and it could be dissolved; but, on further heating, it set into a permanently hard and insoluble substance, which was strong, which had excellent electrical insulating properties, and which was resistant to heat and to many chemicals. The material thus found many important uses, chiefly at first in replacing hard rubber and amber in electricity and industrial arts at places where those materials were not satisfactory. In my own case, for instance, as a maker of ignition systems for automobiles at that time, bakelite served a very useful purpose indeed in respect to such vital parts as distributor heads. The hard rubber, which, before bakelite became available, had had to be used for molding distributor heads, gave trouble whenever conditions were such that it got hot. But distributor heads molded out of bakelite were strong and altogether free from troubles due to temperature.

The early manufacture in connection with the commercialization of bakelite was done in Yonkers. But in 1910 a company called the General Bakelite Company (later the Bakelite Corporation) was organized to manufacture and distribute the raw materials for making bakelite parts, and a factory was then established at Perth Amboy, N. J. Baekeland served as president and moving spirit of that company from the time of its organization until in 1939 it was merged with the Union Carbide and Carbon Corporation. Nevertheless, by intelligent organization and by careful selection of associates, Baekeland was able to keep free enough from routine and business entanglements so that he could maintain his interest in research, and could still devote some time to it, as well as to the numerous scientific, patriotic, and educational calls which were made upon him.

Baekeland published the results of his experiments in full in the many scientific papers of which he was author. In all, he published about 75 papers, letters, and addresses. It has been suggested—by Wallace P. Cohoe—that, in considering the magnitude of the work reported in Baekeland's scientific papers, they should be weighed rather than counted. And it surely is true that, by the customary standards in publishing the results of scientific research, some of Baekeland's papers could well have been divided to give more titles; but that was a thing to which he was indifferent.

Except in the case of Velox, Baekeland also took out patents to protect his discoveries—more than a hundred patents in all, including domestic and foreign. He was a believer in the worth of the patent system and much interested in proper patent procedure. He was a member, and for one year chairman, of the Committee on Patents of the National Research Council, and a number of his published papers relate to what he believed were needed modifications of the United States Patent System. On his own experience with patents, Baekeland said this:

One of the evidences of a successful patent is infringement. So I had to go through the experience of almost every successful inventor of defending my rights before the courts. Fortunately, I won every case. Furthermore, I was lucky enough to find among my former rivals many of the excellent men whom I count today as my dearest friends and most distinguished collaborators in our corporation.

Having begun his career as a teacher of chemistry, Baekeland had a lifelong interest in education. He had a gift of talking on the many subjects which interested him in a manner that held the attention of all who heard him. He was always ready to give others, and young people in particular, the benefit of his knowledge and experience. Respecting his own education, Baekeland said this in his Perkin Medal Address in 1916:

I feel very grateful for the excellent opportunities of education I had at the University of Ghent. I should state, however, that my real intense education only began after I had left the university, as soon as I became confronted with the big problems and responsibilities of practical life; this education I received mainly in the United States, where for twenty-seven years I was thrown in contact with so many varied subjects. I hope to remain until I die a post graduate student at that greater school of practical life, which has no fixed curriculum and where no academic degrees are conferred, but where wrong petty theories are best cured by hard knocks.

In 1917 Baekeland accepted an honorary professorship of chemical engineering at Columbia University. The value of

Baekeland's service to that university, where in early life he had received vital inspiration from Professor Chandler, was once expressed by his colleagues there in these words:

> For more than a quarter of a century, his wise counsel and brilliant lectures, which were enrichened by a vast scientific knowledge and an almost limitless industrial experience, brought to the university a high quality of inspiring instruction and sound research enthusiasm that had much to do with giving Columbia the high reputation it has in chemical and chemical engineering education and research throughout the world.

Baekeland was a member of the important scientific societies in his field, both in the United States and abroad, and he was elected to the National Academy of Sciences. No matter how busy he might be, he found time to attend scientific meetings, and also to take part in them. He was most active in the societies devoted to chemistry, of course, and he served as an officer of a number of them. He was president of the Electrochemical Society in 1909; of the American Institute of Chemical Engineers in 1912; and of the American Chemical Society in 1924; as well as of the Chemists' Club in New York (of which he was one of the founders) in 1904. In 1906, only seventeen years after coming to the United States, Baekeland was chosen to represent the chemists of America at the Jubilee of the Foundation of the Coal-Tar Color Industry by Sir William Perkin. Also, in 1909 he was U. S. delegate to the International Congress of Chemistry, and he was president of the Section on Plastics when in 1912 the Congress met in the United States. How much his association with his fellow chemists meant to Baekeland was expressed in the conclusion of his Perkin Medal Address, as follows:

> My friends, chemists of America, how can I let pass an occasion like this without reminding you of what *you* did for me?
>
> Twenty-seven years ago I came here as a stranger among you and now I feel so much as one of you that sometimes I wonder that there was ever a time when we did not work and play together.
>
> When I was young and poor and unknown you never hesi-

tated to extend to me the cordial hand of welcome, you never missed an opportunity to show me your friendliness, to help me by advice or otherwise. Much of what I have used in my work I learned from you at the meetings of our chemical societies, or in the brotherly surroundings of our Chemists' Club.

You—your friendship, your generosity, your good-natured modesty, your example, inspired me in my work.

What Baekeland did not say in the above was that, by the very active part he took in chemical affairs and by the full presentations of the results of his scientific and industrial researches, he contributed to the profession as much as he himself received, or even more.

In his personal life Baekeland liked simplicity. He rose early and retired early. He worked hard and made heavy demands on his physical and mental energy. He was usually at work before other members of his staff. He was an excellent conversationalist and greatly enjoyed associating with congenial people. Possibly out of his life-long interest in photography, he had a great interest in motion pictures, and he often took time out in afternoons to see the new motion pictures being shown in New York.

One of Baekeland's chief hobbies was motoring. He began driving a car in the late 1890's when motoring was little more than a sport. He was one of the first to take long motor trips, having in 1906 gone with his wife and two children on an automobile tour through Europe. He afterwards wrote a long account of that extensive trip, giving the results of his experiences over there as a pioneer motor tourist, as well as interesting and humorous accounts of what happened to the family and what they saw. That story, illustrated with many of the beautiful photographs which Baekeland took on the tour, was published serially in 1907 in the pioneer motor magazine, *Horseless Age*. Later the several chapters were assembled by the publishers of *Horseless Age* and issued as a book, "A Family Tour Through Europe" by Dr. L. H. Baekeland.

Baekeland was also an enthusiastic yachtsman. His first boat, purchased in 1899, was a gasoline launch in which gasoline served both as the expansive fluid in the boiler to drive a reciprocating engine, and as the means of firing the boiler! In that launch Baekeland, accompanied by Maximilian Toch, went on a cruise from Yonkers up the Hudson and connecting waters to the St. Lawrence and back. And, in spite of the seemingly hazardous nature of the outfit, they returned home safely. In 1915 Baekeland purchased a 70-foot yacht, which he christened the "Ion." It was in some respects of unusual design, constructed after Baekeland's own ideas, and was equipped with a diesel engine as auxiliary power. In the "Ion" Baekeland sometimes sailed in late summer from his home on the Hudson down to Florida and spent part of the winter months in that area, cruising among the islands there, fishing and exploring. Later he purchased an estate at Coconut Grove, Florida, where he lived most of the winter.

Life on his Florida estate gave Baekeland the opportunity of pursuing another of his hobbies, cultivating such rare tropical fruits and flowers as would grow in southern Florida. In this endeavor he was greatly assisted by a neighbor of his at Coconut Grove, the noted botanist David Fairchild. Baekeland used to delight to send to his friends at the North rare tropical fruits from his garden.

In his family Baekeland was particularly fortunate and happy. Mention has already been made of Mrs. Baekeland, a woman who was skilled in music, gifted as a painter, a charming hostess, as well as one who assisted her husband mightily in all his endeavors. So highly did Baekeland value the assistance and inspiration of his wife that he once told Mrs. Wallace P. Cohoe that he never would have amounted to anything but for her help. The Baekelands had two children: a son, George W., now vice president of the Bakelite Corporation; and a daughter, Mrs. Nina Baekeland Wyman.

Baekeland was a long-time member of the U. S. Naval Consulting Board; member of the U. S. Nitrate Supply Commission, 1917; chairman of the Committee on Patents, National Research Council, 1917; a trustee of the Institute of International Education for many years; and a member of the advisory board, Chemistry Division, U. S. Department of Commerce, for some years beginning in 1925. Of honors and distinctions he received such a large number that a special list of them is appended to this memoir.

During World War I, when my laboratory was collaborating with the U. S. Bureau of Mines in an effort to secure a better (more nearly knock-free) aviation gasoline, Baekeland was in touch with the endeavor in his capacity as a member of the Naval Consulting Board. When, after an extensive program of engine tests of hydrocarbons of various types, our men proposed to manufacture cyclohexane as the basis of a better airplane fuel, Baekeland advised against the attempt, as he thought it impractical. To emphasize his belief, he offered to give the group a wooden medal if they could make a pint of cyclohexane.

The effort to produce cyclohexane by the catalytic hydrogenation of benzene was undertaken nevertheless. And, after an intensive research, the effort turned out to be much more feasible and successful than Baekeland, or we ourselves, had thought. And so, knowing that Baekeland's sportsmanship resided on a high plane, we ceremoniously presented to him from the first batch of cyclohexane produced a liter bottle of it in a plush-lined mahogany box. Along with the sample of cyclohexane, we gave him a suggested design, implying CATalysis, for the wooden medal he had promised to present the group. The outcome was so pleasing to Baekeland that that bottle of cyclohexane became one of his prized possessions, and he kept it on his desk for a long time afterwards. That he should have been so pleased when a prediction of his turned out to be wrong was because his long experience in industrial chemistry and consultation work had taught him, as he once expressed it, "to bow humbly before the facts, even if they did not seem to agree with my favorite theories." All his own successes in research, Baekeland said also, had had their origin in divergences between facts observed in experiment and currently accepted theory.

Leo Hendrik Baekeland came to the end of his long, eventful, and highly useful life on February 23, 1944, at the age of eighty-one. As a boy he had wanted to follow the sea. But, when he chanced to hear a lecture in chemistry, the subject fascinated him so greatly that his search for adventure was shifted into that field instead. And, fortunately, the field of chemistry turned out to be one full of high adventure for him. It was fortunate also that, by virtue of Baekeland's distinctive genius and his hard work, his explorations there yielded discoveries of the highest importance to the world.

HONORS CONFERRED ON LEO HENDRIK BAEKELAND

Doctor of Chemistry, University of Pittsburgh (1916)
Doctor of Science, Columbia University (1929)
Doctor of Applied Science, University of Brussels (1934)
Doctor of Laws, University of Edinburgh (1937)
Member, National Academy of Sciences
Honorary Member, Royal Society of Edinburgh
Life Member, American Philosophical Society
Life Member, American Association for the Advancement of Science
Life Member, Franklin Institute
Life Member, Royal Society of Arts (London)
Life Member, Société Chimique de France
Honorary professor, Columbia University
Honorary Member, American Institute of Chemists
Honorary Member, Electrochemical Society (president, 1909)
Honorary Member, Société Belge des Électriciens
Honorary Member, Société de Chimie Industrielle (Paris)
Vice president, Society of Chemical Industry, London (1905)
President, American Institute of Chemical Engineers (1912)
President, American Chemical Society (1924)
Nichols Medal, New York Section American Chemical Society (1909)
John Scott Medal, Franklin Institute (1910)
Willard Gibbs Medal, Chicago Section American Chemical Society (1913)
Chandler Medal (first award), Columbia University (1914)
Perkin Medal, Society Chemical Industry (1916)
Messel Medal, Society Chemical Industry, London (1938)
Franklin Medal, Franklin Institute (1940)
Grand Prize, Panama-Pacific Exposition (1915)
Pioneer Trophy, Chemical Foundation (1936)
Scroll of Honor, National Institute of Immigrant Welfare (1937)
Sigma Xi
Phi Lambda Upsilon
Tau Beta Pi
Officer of the Legion of Honor (France)
Officer of the Order of the Crown (Belgium)
Commander of the Order of Leopold (Belgium)

KEY TO ABBREVIATIONS USED IN THE BIBLIOGRAPHY FOLLOWING

Congr. intern. quim. pura aplicada = Report of the 9th International Congress of Pure and Applied Chemistry
Electrochem. Met. Ind. = Electrochemical and Metallurgical Industry
Ind. Eng. Chem. = Industrial and Engineering Chemistry. (Formerly Journal of Industrial and Engineering Chemistry.)
J. Am. Chem. Soc. = Journal of the American Chemical Society
J. Chem. Education = Journal of Chemical Education
J. Franklin Inst. = Journal of the Franklin Institute
J. Soc. Chem. Ind. = Journal of the Society of Chemical Industry
Trans. Am. Electrochem. Soc. = Transactions of the American Electrochemical Society
Zeit. angew. Chem. = Zeitschrift fur angewandte Chemie

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