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# IZAAK MAURITS KOLTHOFF
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*A Biographical Memoir by*

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# IZAAK MAURITS KOLTHOFF

*February 11, 1894–March 4, 1993*

BY JOHANNES F. COETZEE

IZAAK MAURITS KOLTHOFF is widely regarded as the father of modern analytical chemistry. His monumental research productivity (over 900 papers and numerous seminal textbooks and monographs) as well as his highly effective training of graduate students and postdoctoral associates were major factors in the elevation of analytical chemistry from a predominantly empirical art to a discipline based on sound fundamental principles.

It was September 1951. Professor Kolthoff leaned back in his chair and put a watch on his desk. "I am frightfully busy," he said, "but I want to talk to you two for half an hour." Bart van't Riet (from Holland) and I (from South Africa) had just arrived in Minneapolis as new graduate students planning on doing our doctoral research with Kolthoff as mentor. I was immediately struck by Kolthoff's unusually expressive face, especially his large, luminous, and intense eyes. For the next half-hour he mapped out our future activities and what he expected from us. At times he seemed to be lost in thought, looking up at the ceiling as he talked, except that now and then, at unexpected moments, he would fix us with a penetrating stare to determine, as we were to learn later in numerous research conferences,

whether we were paying full attention. "An analytical chemist," he said, "must have a sound grounding in physical chemistry. Therefore, even though you are analytical majors, you must take the majority of the core courses taken by physical majors. Do not take courses designed for people not majoring in physical chemistry. MacDougall (F. H. MacDougall, author of a rigorous text on chemical thermodynamics) is retiring and will offer his three-term course on thermodynamics for the last time. It is a good, rigorous course; take advantage of that. Also take physical courses in quantum mechanics and kinetics, as well as courses in radiochemistry in the inorganic division. You should already know about the analytical courses and that you must take all of those. Finally, be sure to attend all weekly seminars in the analytical division and to study critically the current literature. These things will prepare you for research. I see that our time is up," he said, and then added his final directive: "Be sure to pick up keys for the building from the office so that you may begin to work nights and weekends." It was clear to us from the beginning that Professor Kolthoff ran a no-nonsense operation. I was fortunate to get to know Kolthoff well, both professionally and socially, over the next forty years.

Izaak Maurits Kolthoff, son of Moses and Rosetta (née Wysenbeck) Kolthoff, was born in Almelo, Netherlands, on February 11, 1894, the youngest of three children. His father was highly orthodox, his mother much less so. His brother and sister, and later Kolthoff himself, gradually became more and more liberal. During his kindergarten days he acquired the nickname "Piet," apparently for no particular reason, and he was called by this nickname by almost everyone. During his first chemistry course in high school he developed a keen interest in the subject and appropriated part of the kitchen for his laboratory. Some of his experiments

involved hydrogen sulfide, to the dismay of his family. After graduating from high school in 1911 he entered the School of Pharmacy at the University of Utrecht. The reason he began his studies in pharmacy rather than chemistry was that he lacked Latin and Greek, which at that time were prerequisites for admission to the "pure" physical sciences. Nevertheless, he already was reasonably fluent in German, French, and English, in addition to his native Dutch. It is interesting to speculate about the direction Kolthoff's career would have taken if he had had the required competence in Latin and Greek. The pharmacy curriculum at Utrecht was thorough and involved a great deal of analytical chemistry. Furthermore, Kolthoff was greatly influenced by pharmacy professor Nicholas Schoorl, who emphasized a proper balance between descriptive chemistry and the fundamental principles of the field. At that time analytical chemistry tended to be largely empirical, and Schoorl's attention to the principles of chemistry was unusual. In his future career Kolthoff similarly emphasized fundamental principles, but he had an open mind about current hypotheses. He would often speculate about the probable outcome of experiments, but when unexpected results were obtained he would be entirely magnanimous in abandoning the assumptions on which his predictions had been based.

In 1915 Kolthoff received his "apotheker" diploma. He then took more courses at Utrecht, both in physical and colloid chemistry. He was impressed by the famous colloid chemist H. R. Kruyt and later did extensive research involving colloids. Also in 1915 Kolthoff published his first paper on the then-novel concept of pH introduced by S. P. L. Sørensen. In 1918 the requirement for Latin and Greek was abandoned by the University of Utrecht and Kolthoff received the Ph.D. degree in chemistry with a thesis titled "Fundamentals of Iodimetry." By then he had published 32 papers,

all on subjects different from his Ph.D. research. He remained at the University of Utrecht, first as "conservator" and then, from 1923 until 1927, as "privaat docent" (lecturer) in electrochemistry. The significance of the pH concept was not generally recognized at that time, and Kolthoff gave many lectures on it to academic and industrial chemists, biochemists (especially bacteriologists), and pharmacists. At the same time his research productivity was astronomical. During the ten-year period from 1917 until 1927 he published 270 papers and 3 books, but it was the originality, insight, and timeliness rather than the mere bulk of these publications that created an enviable international reputation for Kolthoff at an early age. The majority of his early publications were in Dutch, German, or French and, after 1924, increasingly in English.

In 1924 Kolthoff was invited on a lecture tour in Canada and the United States, and in 1927 he was offered a one-year appointment as professor and chief of the Analytical Division of the School of Chemistry of the University of Minnesota (annual salary $4,500). In his letter of acceptance he promised, "I may assure you that [on] my side I will try to do my duty as well as possible and I hope that your expectations will not be disappointed." His one-year appointment became permanent and he remained at Minnesota until his nominal retirement in 1962 despite attempts by other institutions (including his alma mater, the University of Utrecht) to attract him. That Kolthoff fully lived up to his promise can be illustrated, in part, by the following statistics. At the time of his retirement he had published 809 research papers. During the next approximately 30 years, mainly in collaboration with his senior postdoctoral associate Miran K. Chantooni, Jr., he published another 136 papers. Over the period 1924-55 he authored or coauthored 8 textbooks and monographs, several in multiple volumes and

editions, and from 1959 until 1980 he coedited 34 volumes of reference books. Finally, many of his 67 graduate students entered academia, with the result that by 1993 Kolthoff's academic descendants with Ph.D. degrees numbered almost 1,500.[1] All of this, however, is only part of the Kolthoff legacy, as will be elaborated below.

Kolthoff and analytical chemistry were fortunate, in a sense, that he appeared on the scene at an appropriate time for someone with the necessary ability to transform analytical chemistry. By 1915, when he began his research, analytical chemistry was essentially a highly developed art. However, key elements of the fundamentals of the field already existed in other disciplines, particularly physical chemistry, biochemistry, and pharmaceutical chemistry. One of Kolthoff's most significant accomplishments was that he recognized this fact and set out to further develop and apply these fundamentals to analytical processes. In doing this, he was always meticulous in crediting the work of pioneers in other fields. He particularly credited an early book by W. Ostwald (future Nobel laureate) on the principles of analytical chemistry,[2] even though the scope of the book was narrow with a number of puzzling omissions. It is amusing to note that Ostwald believed that analytical chemists should be the maidservants of other chemists, while Kolthoff (as he stated emphatically) did not want to be a maidservant of anyone. Nevertheless, Ostwald's little book proved to be an inspiration as Kolthoff systematically began to develop the fundamentals of analytical chemistry, an objective that he would pursue throughout his long scientific career. This fascinating process was described by Kolthoff in a number of publications and was summarized in a critical discussion in 1978.[3] Here he lists the fundamental contributions relevant to analytical chemistry of a number of luminaries from related fields, particularly J. W. Gibbs (thermodynamics,

phase rule), J. H. van't Hoff (stereochemistry, kinetics), S. Arrhenius (electrolytic dissociation), W. Nernst (electrochemistry), and N. J. Bjerrum (electrochemistry, principles of acid-base reactions). The significance of these contributions to analytical chemistry was not generally recognized when Kolthoff began his research, and one of his major accomplishments was that he amalgamated such diverse contributions and built on this background to create a vast edifice of the interpretation of analytical procedures. This, in turn, led to the improvement of existing procedures as well as the introduction of new methods.

Great diversity and insight characterized Kolthoff's research, whose main subjects were the following, listed more or less chronologically. It is to be noted, however, that he often returned to a favorite topic after a lapse of a few years, if new insights justified renewed attention.

1. **Proton transfer reactions in analytical chemistry: the pH concept, titrations, indicators, and buffers.** Kolthoff's first paper dealt with the titration of phosphoric acid as a mono- and diprotic acid and appeared in 1915. This was followed by a number of papers dealing with both fundamental and applied aspects of proton transfer reactions, subjects taken for granted today but very incompletely understood at the time. In 1922 he published his first monograph, *Der Gebrauch von Farbenindikatoren* (Julius Springer, Berlin). This book went through several German editions, was translated into English by N. H. Furman of Princeton University, and finally appeared in an expanded version in 1937 with C. Rosenblum as coauthor, titled *Acid-Base Indicators* (Macmillan, New York).

2. **Electron transfer and precipitation reactions.** Kolthoff's thesis work on the fundamentals of iodimetry led to 19 papers in 1919 and 1920. In this thorough work he addressed

the variety of reactions occurring in iodimetry, the mechanisms of these reactions, side reactions, and titration errors. During this period he began to use conductometry (1918) and potentiometry (1920) extensively, eventually leading to monographs *Konduktometrische Titrationen* (Dresden, 1924) and *Potentiometric Titrations*, coauthored with N. H. Furman in 1926 and revised in 1931 (John Wiley, New York). Particularly the latter monograph proved to be highly influential, not only in analytical chemistry but also in other fields. At the same time he continued his fundamental studies of classical methods, leading to the publication in 1927-28 of two volumes of *Massanalyse* (Berlin). This monograph was translated and coauthored by N. H. Furman, appearing in 1928 as *Volumetric Analysis* and finally, during the period 1942-58, in an expanded three-volume edition (Interscience, New York) coauthored by V. A. Stenger, G. Matsuyama, and R. Belcher. These reference books had a major impact on analytical chemistry. Parenthetically, Kolthoff served as an important adviser to Marcel Dekker and Eric Proskauer in creating Interscience Publishers, noted for scientific publications and later incorporated with John Wiley.

3. **Formation and properties of precipitates.** Kolthoff devoted much attention to the thorough study of the formation and properties of precipitates. In 1920-21 he published a set of 9 papers on the significance of adsorption in analytical chemistry. After a lapse of 11 years he returned to this field with a vengeance, then at the University of Minnesota. Fresh crystalline precipitates tend to be highly imperfect, but above ambient temperatures “aging” occurs, whereby purification by recrystallization takes place. This process was studied with radiotracers, thorium B for lead and bromine activated by neutrons from a radon-beryllium source. Surface areas were measured by dye adsorption. During the period 1932-48 he published 37 papers on aging

of precipitates and coprecipitation. He continued with these studies, but on a smaller scale, until 1960. These investigations were fundamental, rather than applied, and attracted much attention (e.g., by Otto Hahn).

4. **Voltammetry.** Kolthoff became interested in voltammetry in 1933 when J. Heyrovsky, the inventor of polarography (voltammetry at the dropping mercury electrode) and future Nobel laureate, visited Minneapolis. Two of Kolthoff's top students, J. J. Lingane (Ph.D., 1938) and H. A. Laitinen (Ph.D., 1940) began working on voltammetry, Lingane on the fundamentals of the dropping mercury electrode, Laitinen on solid microelectrodes. In 1939 Kolthoff and Lingane published a 94-page paper in *Chemical Reviews*. This was followed in 1941 by an influential monograph with Lingane as coauthor, *Polarography* (Interscience, New York), expanded in 1952 into two volumes. Kolthoff with several of his students continued to study voltammetry, both in aqueous and nonaqueous solutions, into the 1960s.

5. **Emulsion polymerization.** In 1942 the Office of Rubber Reserve was set up to promote the production of synthetic rubber as a crucial part of the war effort. Kolthoff was one of several prominent professors, including physical chemist P. Debye, organic chemists M. Karasch and C. S. Marvel, and colloid chemists W. D. Harkins and J. W. McBain, invited to work with the major rubber companies. Kolthoff was asked to develop analytical methods so that the rates at which reactants were consumed could be determined. A key constituent turned out to be n-dodecyl mercaptan, referred to as "OEI," for "one essential ingredient."[6] Kolthoff quickly developed an effective method for the determination of OEI based on amperometric titration at the rotated platinum microelectrode with silver nitrate. This method found worldwide use after the war, when it was published (1946). In typical fashion, immediately following this im-

portant applied research, Kolthoff launched a thorough fundamental investigation into factors influencing the rates of reaction of mercaptans, as well as the kinetics and mechanism of emulsion polymerization in general. These studies led to the development of novel initiating systems that worked at lower temperatures than usual and that produced so-called "cold rubber" with superior properties. In this field Kolthoff published, in addition to a number of significant papers, a monograph coauthored with F. A. Bovey, A. I. Medalia, and E. J. Meehan, *Emulsion Polymerization* (Interscience, New York, 1955).

6. **Induced reactions.** Kolthoff studied a number of these reactions; one example follows. Typical of numerous induced reactions is the iron(II)-hydrogen peroxide (Fenton) reaction. Kolthoff and Medalia (1949) showed that hydroxyl radicals produced in the first step can induce the oxidation of many organic compounds.

7. **Compounds containing sulfhydryl and disulfide groups.** Beginning in 1950 and continuing until 1980 Kolthoff carried out extensive studies of the reactivity of these groups in native and denatured albumin. These papers may be among the first in bioelectrochemistry, an active field at the present time.

8. **Chemistry of nonaqueous solutions.** Kolthoff did much to rectify the paradox that the chemistry of solutions as typically presented in textbooks and elsewhere had (and to some extent still has) what may be called a strong aquacentric bias, even though the majority of reactions in solution were carried out in nonaqueous media and, furthermore, water was (and is) the most atypical of solvents. His interest in the subject dated back to the early 1930s (1931, 1934), but it was not until the early 1950s that he began a long series of fundamental studies of how solvents influence the properties of solutes. Particularly noteworthy were five classical

papers in 1956-57 with Stanley Bruckenstein on acid-base equilibria in glacial acetic acid, in which the complex interactions occurring in this solvent were quantitatively interpreted. In particular, the contributions of proton transfer (ionization of Brønsted acids) followed by electrolytic dissociation were resolved. These studies were followed by a long series of investigations of a broad spectrum of solute-solvent interactions in various dipolar aprotic solvents, beginning with acetonitrile in 1957. This important solvent, which later became the workhorse of electrochemists, was studied in great detail well into the 1980s, particularly with M. K. Chantooni, Jr., as coworker. Parallel studies were carried out by a number of other research groups in several countries, but Kolthoff's contributions were among the most significant. During the course of this work Kolthoff became interested in the macrocyclic ligands (crown ethers and cryptates) introduced by J. Pedersen in 1967 and carried out extensive investigations of the reactions of these ligands in various solvents. In 1979 he wrote a critical and stimulating review of applications of these ligands in analytical chemistry, incorporating in his characteristic fashion many suggestions for future work. Kolthoff's fundamental studies in nonaqueous solvents occupied him until the end of his long and fruitful career in 1993 and produced a greater number of publications than any other topic studied by him.

Kolthoff generally produced a monograph on every subject on which he had done extensive research. These books had significant impact, and the majority was translated into several languages. His monographs on conductometric titrations, potentiometric titrations, indicators, classical volumetric analysis, polarography, and emulsion polymerization already have been mentioned.

In 1931 he published his first book intended primarily as

a text, *The Colorimetric and Potentiometric Determination of pH.* A second edition coauthored by H. A. Laitinen, *pH and Electrotitrations* (John Wiley, New York), appeared in 1941. Particularly noteworthy was the publication of a second text, *Textbook of Quantitative Inorganic Analysis* (Macmillan, New York, 1936) by Kolthoff and E. B. Sandell (Kolthoff's first graduate student [Ph.D., 1932] and professor at the University of Minnesota). This text was destined to become a seminal influence in the teaching of undergraduate analytical chemistry. It presented an admirable balance between the fundamentals and the experimental features of the field and repeated Kolthoff's motto, which had first appeared in *Massanalyse:* "Theory guides, experiment decides." This text was a quantum jump ahead of existing books and served as a model for future texts over many years. In my own case, it was the major cause of a change in career plans. For the first time, it was clear that someone actually understood the reasons for the experimental details in analytical procedures. Particularly noteworthy was the inclusion of numerous references to the original literature, many to research by Kolthoff himself. After reading a number of these, I decided to do my doctoral research with Kolthoff, and so I became an analytical chemist rather than a synthetic organic chemist as planned until then.

The most monumental of Kolthoff's productions is his *Treatise on Analytical Chemistry* (John Wiley, New York) in three parts coedited with P. J. Elving (University of Michigan) and others in later volumes. Part I deals with the general fundamentals of the field and was published over the period 1959-76 in 11 volumes. These reference books were so well received that an expanded second edition soon followed, appearing in 14 volumes until 1986. Part II deals with the analytical chemistry of organic and inorganic compounds in more specific terms and appeared over the period 1961-80

in 16 volumes. Finally, Part III concerns analytical chemistry in industry, with four volumes appearing until 1977. This treatise is the principal reference source of analytical chemistry and it has had a huge impact.

The significance of Kolthoff's prodigious output of research papers, textbooks and reference books can be summarized by quoting Lingane.[4] "Analytical chemistry has never been served by a more original mind, nor a more prolific pen, than Kolthoff's."

Kolthoff received numerous awards and other honors, including three awards from the American Chemical Society (Nichols Award [1949], Fisher Award in Analytical Chemistry [1950], and the Willard Gibbs Medal [1964]), the Electrochemical Society Olin-Palladium Medal (1981), and the Pittsburgh Analytical Chemistry Award (1981), as well as honorary doctor's degrees from the University of Chicago, Brandeis University, University of Arizona, University of Groningen (Netherlands), and the Hebrew University of Jerusalem. He was the recipient of numerous other honors from chemical societies and universities abroad. In 1938 he was knighted to the Order of Oranje-Nassau of the Netherlands, and in 1947 he was elevated to a commander of the same order by the Dutch queen. He was elected to the National Academy of Sciences in 1958.

One would expect that Kolthoff's prodigious output could be accomplished only by running a large, efficient, and hard-driven operation. This indeed was the case in the latter two respects, but Kolthoff's program was never particularly large. Nor were his interests of a routine nature that could lead to a large output with little effort. Instead they were strongly focused on the elucidation of significant and complex problems. The efficiency of his program derived from his talent for finding the most direct route toward solution of a problem. While current analytical chemistry is strongly

(arguably too strongly) instrumentation-oriented, Kolthoff's work was chemistry-oriented. Much of his research was done before the great influx of increasingly sophisticated instrumentation after World War II. For him, instrumentation was a means to an end, not an end in itself. Nevertheless, he used the complementary features of different types of instrumentation available to him to great advantage, e.g., conductometry, potentiometry, voltammetry, and ultraviolet-visible spectrophotometry in addressing the daunting problems of nonaqueous solution chemistry.

Kolthoff's personal work habits were unusual. He would begin his workday by spending a couple of hours reading abstracts, papers, and research reports in the seclusion of his apartment in the Faculty Club of the university. At the same time he would write directives to his coworkers for future work on notepaper printed at the top "From the desk of I. M. Kolthoff." All of us would find these notes on our desks later in the day. Kolthoff would not arrive in his office until 10:30 or 11:00. He would first dictate letters to his secretary, the highly competent Christa Elguther. He was a prolific correspondent and answered letters punctually. During the afternoons he would have individual research conferences with his graduate students and postdoctoral associates. The schedule in my own case was that I would turn in my weekly progress report on Wednesdays. This always would be returned to me on Thursdays, annotated in the margins and sometimes across the text with numerous comments, suggestions, and directives. During Friday afternoons, I would meet with Kolthoff for half an hour to discuss the report. He evaluated everything in a highly critical way, but the majority of us understood the need for that. Some of his suggestions were monumental in scope, requiring good fortune and several months of hard work, but they were presented with the clear expectation of a rapid

solution. We all lamented such unrealistic expectations. Towards the end of my four-year stay Stanley Bruckenstein (cozily finished with his research) gave me some sage advice: "When Kolthoff mentions a particularly daunting task, keep it in mind but do not necessarily work on it. If he mentions it a second time, begin working on it, and if he refers to it a third time you better have results to report." I only wish Stanley had divulged this to me earlier in my career. Perhaps we worried too much about some of Kolthoff's apparently unrealistic expectations. One Friday afternoon he mapped out a new and wide-ranging investigation. As he was talking, I was thinking, "I hope I will have something significant to report a month from now." Kolthoff, however, concluded by saying, "I travel to Iowa State tomorrow morning at 9 o'clock. Come to the airport and report what you have found." After some soul searching I decided to ignore this directive. He never mentioned it again.

Kolthoff could be harsh with his coworkers. I believe he did not fully realize just how intimidating he could be. Quite often after research conferences some of his graduate students and postdoctoral associates appeared to be in a state of shock. Kolthoff, in turn, would grumble afterwards about "a tale of woe" and "babe in the woods." Nevertheless, the great majority of his coworkers became his devoted friends after they left. Kolthoff, in turn, expended great effort in promoting their careers, at least for those people who had satisfied him that they were serious professionals. I was fortunate in getting to know him well over a period of 40 years. He was a longtime friend of my parents-in-law, the Luytens, who were also natives of Holland. He would often visit to talk (in Dutch, mostly about politics and administrators of all kinds), to drink "jenever" (Dutch gin), to eat such favorite dishes as "hutspot met boerenkool" (kale, potatoes and sausage), and to lament the slow progress of

his research. On one such occasion he confided in me: "I could have accomplished much more if I had worked harder." I was at a total loss how to reply.

After I became a faculty member at the University of Pittsburgh my contacts with Kolthoff continued. My wife and I visited her parents in Minneapolis every year, and often Kolthoff would be in town. He would always say, "I will set aside a day to talk about our research." I would then spend several hours of stimulating discussions with Kolthoff and sometimes with his dedicated coworker Miran Chantooni. The last time we had such a discussion was on the occasion of his ninetieth birthday. I met him in the Campus Club. He was scowling at a reprint. Many other reprints were scattered on tables and even on the floor. Immediately after greeting me he lamented, in typical fashion, "I do not understand a word of this—I think everything is wrong."

Kolthoff's monumental professional contributions were accomplished in spite of a number of physical limitations. In his younger days he was quite a sportsman, enjoying swimming, tennis, skiing, and horseback riding. Then, in 1942, when he was forty-eight years old, he was injured in a skiing accident. This was aggravated when he was later thrown from a horse. He had spinal surgery and ended up partially paralyzed, but intensive rehabilitation aided by his indomitable willpower improved his condition until he could manage with just a brace on his leg, although he then walked with a pronounced and permanent limp. He also suffered from essential hypertension and frequent bouts with pneumonia that landed him in the hospital. His confinements did not deter him, however, from having daily research conferences without much regard for visiting hours. After his accidents he had to abandon some of his physical activities, but he continued swimming and even horseback riding. When he was seventy years old he gave a talk in Houston

and then stopped for a week's respite at a ranch called "Whispering Winds." Here he made a big impression and became known as "Nature Boy" because of his strenuous program: 45 minutes of exercise before breakfast, followed by 4 to 5 hours in the saddle and finally a brisk swim. A newspaper reported: "Dr. Kolthopp (sic), Noted Chemist, Visits in Bandera Last Week." I have seen a clipping of this article on which Kolthoff had scribbled an addition to the headline: "Dr. Kolthopp, on a Horse."

Kolthoff never married but led an active social life. He had broad cultural and political interests. He particularly appreciated classical music and for many years regularly attended concerts of the Minneapolis Symphony Orchestra. He was a stimulating conversationalist and he was a friend of many prominent families in Minneapolis and St. Paul.

Kolthoff was concerned about social issues of all kinds, especially those that were of global significance. He was a freethinker, opposed to dogma of all kinds, and impressed this on his students. In his award address upon receiving the Gibbs Medal he discussed the duties of a mentor: "The teacher should impress upon his student the necessity to look on dogma as anathema and not to have unlimited faith in authority."

During the late 1930s Kolthoff and biochemist Ross Gortner were influential in relocating in the United States European scientists persecuted by the Nazis. Financial support came from the Rockefeller Foundation. Kolthoff abhorred all oppressive regimes. Immediately after World War II, on invitation of the respective academies of science, he traveled to the Soviet Union and Yugoslavia and wrote a long series of reports for the *Minneapolis Star*, in which he stressed the importance of reconstructing European universities and of cooperating with scientists in countries with which the United States had fundamental political disagreements. He

was an outspoken proponent of freedom of thought and expression, and his reports on social issues in these countries were as candid and perceptive as his scientific publications.

Kolthoff corresponded with many notable scientists, including Peter Debye, Otto Hahn, Jaroslav Heyrovsky, Joel Hildebrand, Frederic Joliot-Curie, and Linus Pauling. Some of these letters are in the University of Minnesota archives. His correspondence concerned not only professional matters but, after World War II, also such issues as control of nuclear weapons. In the early 1950s his contacts with Joliot-Curie landed him in hot water with the House Un-American Activities Committee (HUAAC). Joliot-Curie was organizing an international meeting on nuclear weapons and asked Kolthoff to be a sponsor. At first Kolthoff agreed but subsequently withdrew when he learned that the meeting was to be communist-dominated, writing that he wished to speak as a world citizen, not as a communist. In a letter to Pauling, who was in even worse trouble with the HUAAC, he referred to the HUAAC as "that nuisance committee in Washington." At one stage Kolthoff was accused of belonging to 31 subversive organizations (!) but nothing came of this and eventually these witch-hunts came to an overdue end.

Kolthoff promoted analytical chemistry in every way possible. In addition to his scientific publications and numerous lectures in many countries he was responsible for the creation in 1951 of the Analytical Division of the International Union of Pure and Applied Chemistry. He subsequently served as president of the Analytical Division and as vice-president of the union as a whole.

In summary, Izaak Maurits Kolthoff led an unusually long and influential life. His contributions to chemistry in general and analytical chemistry in particular were monumental. He was *the* major mover in elevating analytical chemistry to a fundamentally sound discipline. He accomplished this

through his extensive research papers and seminal text and reference books, as well as his decisive influence on graduate students, postdoctoral associates, and established scientists. At the same time he was an outspoken defender of social justice. He was a role model for all scientists.

THE AUTHOR ACKNOWLEDGES information obtained from several previous biographies and impressions written by Kolthoff's students and others, particularly by J. J. Lingane,[4] H. A. Laitinen,[5] Laitinen and E. J. Meehan,[6] and Laitinen, D. N. Hume, J. Jordan, and S. Bruckenstein.[7] In addition, P. W. Carr made available the extensive archives of the University of Minnesota and provided other useful information.

## NOTES

1. H. N. Blount III, P. W. Carr, and J. F. Parcher. Academic genealogy of Professor I. M. Kolthoff. Personal communication by Parcher, University of Mississippi, 1993.

2. W. Ostwald. *Die wissenschaftlichen Grundlagen der analytischen Chemie*. Leipzig: Verlag W. Engelman, 1894.

3. I. M. Kolthoff. Development of analytical chemistry as a scientific discipline. In *Treatise on Analytical Chemistry*, pp. 1-28, part I, 2nd ed., vol. I, eds. I. M. Kolthoff and P. J. Elving. New York: John Wiley, 1978.

4. J. J. Lingane. Izaak Maurits Kolthoff. *Talanta* 11(1964):67-73.

5. H. A. Laitinen. The scientific career of Izaak Maurits Kolthoff. *Trends Anal. Chem.* 1(1981):4-6.

6. H. A. Laitinen and E. J. Meehan. Happy birthday I. M. Kolthoff. *Anal. Chem.* 56(1984):248A-62A.

7. H. A. Laitinen, D. N. Hume, J. Jordan, and S. Bruckenstein. Happy 95th birthday, Piet Kolthoff. *Anal. Chem.* 61(1989):287A-91A.

## SELECTED BIBLIOGRAPHY

In view of Kolthoff's monumental output of 944 papers, selection of a mere 25 is difficult. The rationale for inclusion in this list is primarily to guide the interested reader through the diverse fields in which Kolthoff worked. For the two fields in which his research was most extensive, precipitates and nonaqueous chemistry, the list contains some of his earliest as well as some of his latest publications.

1915

Phosphoric acid as mono- and dibasic acid. *Chem. Weekbl.* 12:644-53.

1918

The importance of electrical conductivity in analytical chemistry. *Chem. Weekbl.* 15:889-96.

1920

Iodometric studies. XIX. *Pharm. Weekbl.* 57:53-65.

Oxidation potential of a ferri-ferrocyanide solution. *Z. anorg. Chem.* 110:143-52.

1921

The significance of adsorption in analytical chemistry. IX. *Pharm. Weekbl.* 58:463-71.

1925

The dissociation constants, solubility products and titration of alkaloids. *Biochem. Z.* 162:289-353.

1928

The salt error of indicators in the colorimetric determination of pH. *J. Phys. Chem.* 32:1820-33.

1931

The dissociation of acid-base indicators in ethyl alcohol with a discussion of the medium effect upon the indicator properties. *J. Phys. Chem.* 35:3732-48.

1932

The theory of coprecipitation-formation and properties of crystalline precipitates. *J. Phys. Chem.* 36:860-81.

1933

With E. B. Sandell. Coprecipitation. IV-VI. *J. Phys. Chem.* 37:443-58, 459-73, 723-33.

1934

With A. Willman. The dissociation of some inorganic acids, bases and salts in glacial acetic acid as solvent. *J. Am. Chem. Soc.* 56:1007-13.

1936

Perfection and agglomeration of crystalline precipitates on aging. *Science* 84:376-77.

1939

With J. J. Lingane. The fundamental principles and applications of electrolysis with the dropping mercury electrode and Heyrovsky's polarographic method of chemical analysis. *Chem. Rev.* 24:1-94.

With H. A. Laitinen. A study of the diffusion processes by electrolysis with microelectrodes. *J. Am. Chem. Soc.* 61:3344-49.

1946

With W. E. Harris. Amperometric titration of mercaptans with silver nitrate using the rotating platinum electrode. *Ind. Eng. Chem. Anal.*. 18:161-72.

1948

With I. Shapiro. Studies on aging of precipitates and coprecipitation. XLI. The bulkiness and porosity of silica powder. *J. Phys. Colloid Chem.* 52:1020-33.

1949

With A. I. Medalia. The reaction between ferrous iron and peroxides. *J. Am. Chem. Soc.* 71:3777-94.

1950

With W. Stricks. Argentometric amperometric titration of cysteine and cystine. *J. Am. Chem. Soc.* 72:1952-58.

1957

With S. Bruckenstein. Acid-base equilibria in glacial acetic acid. V. *J. Am. Chem. Soc.* 79:5915-21.

With J. F. Coetzee. Polarography in acetonitrile. III. *J. Am. Chem. Soc.* 79:6110-15.

1961

With S. Bruckenstein and M. K. Chantooni, Jr. Acid-base equilibria in acetonitrile. *J. Am. Chem. Soc.* 83:3927-35.

1975

With K. Yamashita and Tan Boen Hie. Brdicka currents observed with bovine serum albumin and completely reduced bovine serum albumin in the presence of urea. *Proc. Nat. Acad. Sci. U. S. A.* 72:2044-48.

1979

Applications of macrocyclic compounds in chemical analysis. *Anal. Chem.* 51:1R-22R.

1980

With S. Kihara. Effect of temperature on catalytic hydrogen currents of native and modified bovine serum albumin. *Collect. Czech. Chem. Commun.* 45:669-78.

1993

With M. K. Chantooni, Jr. Conductance of alkali metal and barium cryptates in dipolar aprotic solvents at 25°C. *J. Coord. Chem.* 29:371-77.