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ERNEST GRUNWALD
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A Biographical Memoir by

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ERNEST GRUNWALD OCCUPIED an important and unique position in the development of physical-organic chemistry. To a field that has tended to be primarily identified with the elucidation of organic reactions through the kinetics of specially designed molecules, Grunwald was able to add an unusually broad perspective from the detailed physico-chemical analysis of solvent effects on the structures and energies of the principal types of reacting species. Friends and colleagues remember him as a friendly, generous man of great integrity and scientific insight.

From the mid-1940s to the mid-1990s he established a position of authority on the basic principles behind organic reactions in many ways similar to that of Louis Hammett, who originally coined the term “physical organic chemistry” as the title of his groundbreaking monograph of 1940. Unlike his illustrious predecessor, Grunwald arrived on the scene when most of the traditional barriers between physical and organic chemistry were breaking down and a postwar golden age of enthusiasm and financial support for chemistry was in full swing. Grunwald was fortuitously the right man in the right place to take full advantage of the new opportunities as they opened before him. It did not need to be so.

Born in Wuppertal, Germany, in 1923, Grunwald grew up in a middle-class Jewish family. His father had served in the German army and had received terrible wounds that required two years of hospitalization and finally amputation of his leg. During the chaotic post-World War I period of financial collapse, depression, hyperinflation, and the rise of the Nazi party the elder Grunwald established a successful business manufacturing high-quality shirts. As Ernest and his sister were growing up during the 1930s persecution of Jews became increasingly menacing, and the family made plans to emigrate to the United States. They escaped only by the skin of their teeth as is recorded in a small monograph "The Life and Graphic Arts Collection of Fred Grunwald" published by Ernest Grunwald after his father's death.

Immediately after the infamous Kristalnacht attack on the Jewish community by the Nazis, Grunwald's father was arrested and taken to Gestapo headquarters, where he seemed to be surely headed for a concentration camp with all the others who had been picked up; however, his leg wound probably saved his life, and that of the family. The Gestapo official who interviewed him was also a veteran and, out of sympathy for their shared experience, managed to save Grunwald and his family, an act of charity that may have cost the official his life later on the Russian front. After surmounting a series of gut-wrenching bureaucratic obstacles the Grunwald family managed to board a steamer to the United States and finally settled in Los Angeles in 1939. At the age of 15 young Ernie completed his high school education in the Los Angeles system and enrolled at the University of California, Los Angeles, where he earned a B.S. in chemistry and a B.A. in physics in 1944.

While still an undergraduate, he struck up a friendship that would last his lifetime with Saul Cohen, a National

Research Council fellow, who was sharing an office-laboratory with Saul Winstein, a young faculty member in the newly organized UCLA graduate program. Ernie spent many stimulating hours talking chemistry with Cohen, who had taken a number of young German-Jewish immigrants under his wing.

Winstein was exploring the details of organic displacement reactions through solvolysis (reactions where the solvent is the displacing agent). He gave particular attention to neighboring group effects, where a properly placed group within the reacting molecule participates in the displacement. Winstein was an enormously creative and demanding research director who insisted on the highest standards of rigor in the prosecution of his projects. Upon graduation from his undergraduate program Grunwald began his doctoral program with Winstein and was soon identified as a major addition to his group. A steady flow of publications came from their collaboration during and after Grunwald's doctoral research, summarized in his 1947 dissertation, "Solvolytic Substitution in the Presence of Neighboring Groups." Grunwald's introduction to the study of solvent interactions in Winstein's laboratory established a theme that would continue throughout the 50 years of his research career

After receiving his Ph.D. Grunwald continued for a brief period as an instructor at UCLA, where he had been elected to Phi Beta Kappa, but then spent the next year in an industrial position as a research chemist at the Portland Cement Company. Fortunately he was granted a Jewett Fellowship in 1949 to study at Columbia for a year. He had already been identified as a rising star, and in 1949 was recruited to join the chemistry department at Florida State University, which had embarked on a major program hoping to convert it from a prewar teachers college into "the Harvard of the South." In 1952 he married his wife, Esther.

During the years at Florida State from 1949 to 1961 Grunwald delivered on all the hopes offered by his promising early work at UCLA. Working with a relatively small group of students and doing considerable experimental work with his own hands, he began a series of imaginative physico-chemical studies on systems relevant to the understanding of organic reaction mechanisms.

Although the determination of activity coefficients is scarcely the type of research that normally stirs the blood of organic chemists, it is required if one is to make a quantitative accounting for solvent effects in free-energy terms. Thanks to his wide exposure in Winstein's group to the current problems of importance to organic chemists, Grunwald was strategically positioned to identify the most relevant systems to study by classical physico-chemical techniques. He developed a number of elegant methods of electrochemistry, solution thermodynamics, and acid-base chemistry to demonstrate quantitatively how the free energies of neutral molecules and ions respond to solvent change across a variety of water-organic binary mixtures and water-salt solutions.

In a series of carefully conceived and executed papers during the 1950s Grunwald demonstrated his understanding of the basic physical problems that needed clarification for the development of theoretical organic chemistry and also his mastery of the experimental techniques needed to quantify them. During the same period he established himself as a leading authority on the physical chemistry underlying organic reaction mechanisms through his lecture presentations at important conferences and his incisive comments during discussions.

The exciting progress being made in mechanistic organic chemistry during this period inevitably led to vigorous arguments at conferences that occasionally became quite acrimonious. I remember a number of meetings where the quiet and judicious contributions of Ernie Grunwald helped to lower the emotional temperature of a debate that was getting beyond the limits of objective, impersonal discussion. His talent for diplomacy, which served him later, began to be widely recognized.

Grunwald's interest in teaching led to a productive collaboration with a colleague, Russell H. Johnson, in writing a textbook for nonscience general-education students. *Atoms, Molecules and Chemical Change* was published in 1960, and almost at once became a runaway best seller. It was adopted swiftly by over 100 institutions of higher learning and was translated into several languages. Eventually over 100,000 copies were sold as second and third editions were published. The book led the way in trying to make chemistry interesting by discussing the development of chemical principles with a history-of-science perspective instead of the traditional approaches of stoichiometrical problems and balancing equations. Grunwald's concern for undergraduate teaching was manifested again when he published *Introduction to Quantitative Analysis* in 1972 with Louis Kirschenbaum, previously a student, who later became professor of chemistry at the University of Rhode Island.

During his tenure at Florida State Grunwald also began productive discussions with his colleague, John Leffler, on how the structures of organic molecules affected their thermodynamics in solution and those of associated ions and transition states. The results were published in 1963 as *Rates and Equilibria of Organic Reactions,* a volume whose lasting influence on the development of organic chemistry is probably second only to Hammett's original monograph. Grunwald and Leffler demonstrated by comparing a wide variety of kinetic and thermodynamic properties for organic chemical reactions that they were related through linear extrathermodynamic correlations of which Hammett's well-known linear free-energy correlations were a special case. Hammett showed that the logarithms of the rates of various reactions in the side chains of substituted benzoic acids were correlated linearly with the free energies of dissociation of the correspondingly substituted benzoic acids in water at 25°C. These relationships are called extrathermodynamic because there is no inherent reason why kinetic activation parameters should be rigorously correlated with thermodynamic ones as the structures of an organic series of compounds is varied.

By the early 1960s a much larger database of kinetic and thermodynamic properties for different series of organic compounds in reaction was available than Hammett had in the late 1930s. This made it possible for Grunwald and Leffler to probe not only the free energy relationships between rates and equilibria as a function of structure but also correlations of enthalpies of activation with heats of reaction and the corresponding free-energy terms. A solid theoretical understanding developed of how the effects of structure change were related to the energies of neutral reacting species, reactive intermediates (such as ions or radicals), and transition states. This provided a rationale for every stage of an organic mechanism in a continuous coherent way. The approach could be used qualitatively for planning syntheses and was teachable to sophomore college students. Furthermore, it could be expanded almost infinitely for quantitatively predicting rates and equilibria of an almost endless variety of engineering and biochemical systems, including pharmacology, environmental science, agriculture, and medicine. The interactions of the different thermodynamic and kinetic properties were explained clearly and rigorously and a suitable notation was given for discussing them.

Needless to say, the impact of Grunwald's many contributions was appreciated by the scientific community and recognized by important fellowships (Chaim Weizmann, 1955; Alfred P. Sloan, 1958-61). In 1959 he received the American Chemical Society Award in Pure Chemistry, the most prestigious award of the society at the time for a young chemist. Within the Florida State faculty he was recognized as a Distinguished Professor in 1960

This was also a happy time for the Grunwald family as the opportunity to enjoy the outdoors was available through the year-round comfortable Florida weather. Esther Grunwald, his wife of 50 years, remembers especially their pleasure in canoeing on the small, clear rivers and streams of the Florida panhandle.

Grunwald's interest in solvent effects increasingly fueled his curiosity about the nature and interconversion of solvent species, such as hydrogen-bonded polymers and their formation of solvated complexes with solutes. The favored physical chemical treatment at the time was the electrostatic one of Born, Debye, and Scatchard, which treated ion solvation in the general terms of a charged sphere in a continuous dielectric medium. This approach was a major theoretical advance for describing the behavior of "round" ions such as those of alkali halides, but could scarcely be expected to apply to oddly shaped organic ions with a variety of acidic and basic groups in hydrogen-bonding solvents, such as alcohols or water. Benefiting from his training in organic chemistry, Grunwald was one of the leaders in recognizing that site-specific solvent-solute interactions could also play an important role.

His careful studies of ion solvation in dioxane-water mixtures bear particular comment. The dioxane molecule is, like benzene, a six-membered ring, but is composed of two oxygen atoms symmetrically placed between two $–CH_2$-CH_2-

groups. Like benzene it has a low dielectric constant (2.21 at 25°C). However, it is not only readily miscible with many nonpolar organic solvents but also forms a continuous series of solvent mixtures with water. Grunwald and his students demonstrated, surprisingly, that alkali cations (and also some organic cations) are solvated selectively by dioxane in preference to water. This dramatically counter-intuitive discovery played an important role in developing the practical use of a variety of dipolar aprotic solvents and polyethers to selectively tie up organic cations and thereby activate organic anions that otherwise would be associated with their counter-cation, and thus opened up a whole new area of synthetic organic chemistry.

In one carefully crafted and analyzed study after another through the years Grunwald and his students added London dispersion forces and hydrogen bonding to the list of important interionic interactions. Although his research at Florida State provided powerful and illuminating new information about the interactions of solvents and solutes, it was mostly limited to the overall thermodynamic behavior of the systems studied with very little direct structural information about the various subspecies or kinetic measurements of their rates of interconversion. During the late 1950s a variety of new relaxation techniques were being developed to measure rates of reactions that were several orders of magnitude faster than any previously observed. Systems at equilibrium were suddenly subjected to a shock of some kind and the rate of return to equilibrium was followed by an appropriate method of observation.

Nuclear magnetic resonance was turning out to offer a cornucopia of opportunities for the study of an almost endless variety of previously inaccessible problems. At the Bell Telephone Laboratories Saul Meiboom was developing techniques for analyzing the broadening of nuclear magnetic resonance spectral lines as a means to investigate fast reactions. Grunwald saw this as the opportunity to study the structural and kinetic details for the interconversion of the kinds of hydrogen-bonded solvent-solute complexes whose presence he had inferred from his thermodynamic studies. In 1961 he resigned from Florida State and joined Saul Meiboom, who had the best equipment in the world for studying the systems of interest to Grunwald. The prospect of having hands-on access to this marvelous new tool was overpoweringly attractive.

At the time, Bell Labs enjoyed a prestige equal to or greater than any research institution in the world. An apocryphal tale of the times referred to a leading scientist at Bell who was being courted by the provost of one of the leading universities in his field. His rejection letter is quoted as saying, “ I know I could make more money as a Distinguished Professor at X university, but I wouldn’t have nearly as much freedom as I have here at Bell to work on problems of interest to me.”

In this high-powered environment the Grunwald-Meiboom collaboration was indeed highly productive and a steady series of papers appeared during Grunwald’s three-year stay at Bell illuminating the questions of greatest interest about the thermodynamics and kinetics of hydrogen bonding and proton transfer for a variety of classical Brönsted acid-base systems (e.g., methylamines in water, methanol, and acetic acid). These studies broke important ground by identifying the particular players and their interactions in some of the simplest and most fundamental systems in chemistry. One can only imagine the enthusiasm with which the great solution chemists of the past would have welcomed these revealing studies.

Idyllic as the sharply focused environment at Bell may sound Grunwald began to miss the more varied life of the university. In several chats with him during these years I began to hear wistful comments comparing the sometimes stressful life of total concentration on one or two problems at a research institute to teaching and working with students on a variety of problems and enjoying the interactions with colleagues in different areas of the sciences and other disciplines. Fortunately, he was able to contact Saul Cohen, his old friend from UCLA days, to see if he could arrange a professorship in the Brandeis Chemistry Department. Grunwald and his family were able to move in 1964 and spend the rest of his life in a friendly and stimulating environment.

In 1965 he was chosen to chair the Chemistry Department. The department was planning the construction of a new building and to the surprise of some of his colleagues Grunwald threw himself into the planning with great enthusiasm and saw several important opportunities for improving the design. His tenure as chairman is remembered very favorably by his colleagues; to quote one, "Ernie's old-world courtesy and gracious good humor were endearing. His unassuming bearing contrasted sharply with his critical thinking and vigorous, enterprising research style! In his editing and administrative duties, his judgments were firm, and shaped by the integrity of his values, humane outlook and common sense."

His style as chair is remembered as being totally consistent with his normal demeanor at home or in the laboratory. He was invariably friendly yet self-contained. He represented the department to the higher administration assertively yet politely. In approaching departmental problems, as with scientific problems, he is remembered for listening patiently to the various sides of a problem and then coming up with a totally new approach of his own. He was generally apolitical, although he had very strong feelings of concern for the welfare of individuals, especially students. Despite his strong bonds to the Jewish community his view was that of practical, cultural Judaism rather than that of religion. In the broader academic community of Brandeis Grunwald was chosen to chair the School of Sciences Council, a position that he held through four terms—a testimony to his diplomatic talent.

The Grunwalds moved into a house close to the campus so that he was only a short, pleasant walk from the laboratory and his NMR machine. His love of the outdoors and walking also were able to find expression in hiking trips in the White Mountains in New Hampshire, where he and Esther spent many a happy weekend. Later in his retirement Grunwald wrote several reminiscing essays, apparently for his own enjoyment as much as anything. One of them, entitled "My Hikes in the White Mountains," describes his enjoyment in taking five- to six-hour hikes with Esther and one of their dogs on trails that were carefully chosen to be invigorating. Later the Grunwalds built a vacation home on Cape Cod as a retreat from their active life at Brandeis.

Back in the department Grunwald's responsibilities expanded as he became an associate editor for physical organic chemistry for the *Journal of the American Chemical Society* in 1977, serving for four years under Cheves Walling and later Allen Bard. Earlier he had served on the editorial boards of *Accounts of Chemical Research* and *The Journal of Solution Chemistry.* Again he wrote an essay, "Peer Review," describing his perspective and experiences in performing this important job. His approach was typically careful in evaluating the number of minutes that would be required for each stage of reviewing and editing each paper and finally budgeting two and a half days a week for his work. The problems that he faced in finding suitable reviewers and negotiating between authors, reviewers, and editors would be familiar to most members of the National Academy of Sciences, but I do not recall having seen them organized and described step by step in one place before. His essay would be of value to any young faculty member entering the complicated and often misunderstood culture of peer review on which so much of the credibility of the scientific effort depends. As both Walling and Bard make clear in their letters responding to the essay, many of the problems of handling manuscripts that Grunwald found to be most frustrating have been dealt with through computer systems and improved policies.

The illness and death of Fred Grunwald, Ernest's father, in 1964 meant that Ernest and his sister, Lottie Talpis of Beverley Hills, found themselves responsible for handling the Los Angeles shirt factory that their father had established soon after their arrival in the United States. Furthermore, Fred Grunwald had gathered an outstanding collection of over 3,500 prints, including numerous pieces by Renoir, Picasso, Toulouse-Lautrec, and Kollwitz. Ernest Grunwald and his sister donated these and a number of other prints, drawings, photographs, and notebooks to UCLA, where they are housed as the Grunwald Center for the Graphic Arts in the Armand Hammer Museum of Arts and Cultural Center in Westwood Village.

By 1971 Grunwald's stature in the scientific community had led to election to membership in the American Academy of Arts and Sciences (in 1969) and to the National Academy of Sciences (in 1971). His search for new methods to study the rapid interconversion of solvated subspecies now led him into a series of investigations using electric dipole moment measurements with particular interest in solvation of ion pairs and relaxation of the ionic atmosphere. Inevitably these studies combined with his ongoing use of NMR line broadening focused his interests on the making and breaking of hydrogen bonds between ions and the solvent and eventually on the perennial problem of the microscopic structure of liquid water.

In the mid-1970s his research moved in the direction of attempts to use megawatt infrared lasers to selectively stimulate and cleave specific bonds in organic molecules. Early announcements of this approach by Russian chemists had excited both great interest and skepticism. Clearly, control of chemical reactions could be moved to a new level of sophistication if a blast of infrared light at a sharply tuned frequency could be used to break a specific bond and initiate reaction at a chosen locus in a molecule. However, the majority of experts in the relevant fields of spectroscopy believed that even if the energy burst could be absorbed preferentially by the desired bond, it would be redistributed throughout the molecular framework before the bond could be selectively pumped up to the point of cleavage.

In a series of 10 papers Grunwald described his carefully designed studies to test the basic requirements for selective bond cleavage by infrared lasers. The work culminated in a book, *Megawatt Infrared Laser Chemistry* (1978), with D. F. Dever and P. M. Keehn as coauthors. In the ensuing years it has turned out that selective bond cleavage is not impossible, but that so far the early hopes for a powerful tool of broad usefulness were too optimistic.

In 1989 Grunwald retired from Brandeis as Henry F. Fischback Professor of Science Emeritus. Following his retirement he completed several research papers and then turned to writing a book, *Thermodynamics of Molecular Species* (1997), which attempted to pull together and organize his life's work in a coherent theoretical overview. This task was accomplished well before his death on March 28, 2002, at the age of 78. He also took pleasure in writing an essay on his volunteer work helping elderly low-income people prepare their income taxes.

Grunwald's principal lifework was dedicated to understanding the ways that solvents affect the behavior of organic chemical reactions. To pursue this goal he took advantage of every advance that was offered by new instrumentation during the 50 years of his research career. At the beginning, in the 1940s, he relied on classical physicochemical methods to determine important thermodynamic properties, such as activity coefficients, in order to analyze solvent effects on reaction rates. Later, as new relaxation methods for studying fast reactions developed he was able to identify many of the short-lived, interconverting solvent-solute species whose presence could only be inferred or speculated upon from the gross thermodynamic or kinetic measurements. His studies are notable for their theoretical rigor as well as experimental ingenuity and elegance. Ernest Grunwald occupied a unique niche in the turbulent interface between physical and organic chemistry. He is survived by his wife, Esther; daughter, Judith; and two granddaughters. He is remembered with much affection by his many friends in the Brandeis and scientific communities,

I APPRECIATE THE HELP in preparing this memoir that I received from Esther Grunwald, his wife, and his colleagues in the Brandeis Chemistry Department, especially professors Saul Cohen, Emily Dudek, Myron Rosenblum, Colin Steel, Phillip Keehn, Henry Linschitz, and Robert Stevenson.

SELECTED BIBLIOGRAPHY

1948

With S. Winstein. General theory of neighboring groups and reactivity. *J. Am. Chem. Soc* 70:828.

With S. Winstein. The correlation of solvolysis rates. *J. Am. Chem. Soc.* 70:845. (This article was chosen as a citation classic for October 22, 1984.)

1953

With B. Gutbezahl. The acidity scale in the system ethanol-water, the evaluation of degenerate activity coefficients for single ions. *J. Am. Chem. Soc.* 75:565.

1954

Interpretation of data obtained in nonaqueous media. *Anal. Chem.* 26:1696.

1957

With A. Lowenstein and S. Meiboom. Rates and mechanisms of protolysis of methylammonium ion in aqueous solution, studied by proton magnetic resonance. *J. Chem. Phys.* 27:630.

1959

With E. F. J. Duynstee. Organic reactions occurring in or on micelles. II. Kinetics and thermodynamic analysis of the alkaline fading of triphenylmethane dyes in the presence of detergent salts. *J. Am. Chem. Soc.* 81:4542.

1960

With G. Baughman and G. Kohnstam. The solvation of electrolytes in dioxane-water mixtures. *J. Am. Chem. Soc.* 82:5801.

With R. H. Johnsen. *Atoms, Molecules and Chemical Change.* Englewood Cliffs, N.J.: Prentice-Hall.

1962

With C. F. Jumper and S. Meiboom. Kinetics of proton transfer in methanol and mechanism of the abnormal conductance of hydrogen ion. *J. Am. Chem. Soc.* 84:4664.

1963

With J. E. Leffler. *Rates and Equilibria of Organic Reactions.* New York: John Wiley.

1964

With E. Price. Relative strengths of picric, acetic, and trichloroacetic acids in various environments. Dispersion effects in acid-base equilibria. *J. Am. Chem. Soc.* 86:4517.

1965

Ultra-fast proton transfer reactions. *Prog. Phys. Org. Chem.* 3:317.

1969

With R. L. Lipnick and E. K. Ralph III. Lifetimes of amine-alcohol hydrogen-bonded complexes in hydroxylic solvents. Role of London dispersion forces in solvation. *J. Am. Chem. Soc.* 91:4333.

With C. S. Leung. Substituent effects in the ion-pair dissociation of anilinium acetate and anilinium p-toluenesulfonate in acetic acid. *J. Phys. Chem.* 73:1822.

1970

With M. R. Crampton. Kinetics of ion-pair exchange in acetic acid. *Chem. Commun.* (16):983.

1971

With E. K. Ralph. Kinetic studies of hydrogen-bonded solvation complexes of amines in water and hydroxylic solvents. *Acc. Chem. Res.* 4:107.

1972

With L. J. Kirschenbaum. *Introduction to Quantitative Chemical Analysis.* Englewood Cliffs, N.J.: Prentice-Hall.

1975

With D. Eustace. Participation of hydroxylic solvent molecules. In

Proton Transfer Reactions, eds. T. Caldin and V. Gold, pp. 103-19. London: Chapman and Hall.

1976

With K. C. Pan. Hydrogen bonding in polar liquid solutions. 5. Theory of dipole correlation for chain-associated solvents containing hydrogen-bonding solutes. Application to 1-octanol. *J. Phys. Chem.* 80:2941.

1978

With D. F. Dever and P. M. Keehn. *Megawatt Infrared Laser Chemistry*. New York: Wiley-Interscience.

1983

With M. T. Duignan and S. Speiser. Infrared multiphoton photochemistry of hexafluorobenzene studied by time-resolved visible luminescence spectroscopy. *J. Phys. Chem.* 87:4387.

1984

Thermodynamic properties, propensity laws, and solvent models in solutions of self-associating solvents. Application to aqueous alcohol solutions. *J. Am. Chem. Soc.* 106:5414.

1985

Reaction mechanism from structure-energy relations. 1. Base-catalyzed addition of alcohols to formaldehyde. *J. Am. Chem. Soc.* 107:4710.

1995

With Colin Steel. Solvent reorganization and thermodynamic enthapy-entropy compensation. *J. Am. Chem. Soc.* 117:5687.

1997

Thermodynamics of Molecular Species. New York: John Wiley.