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# WERNER EMMANUEL BACHMANN 1901—1951

A Biographical Memoir by ROBERT C. ELDERFIELD

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Biographical Memoir

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W. E. Bachmann

# WERNER EMMANUEL BACHMANN

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BY ROBERT C. ELDERFIELD

WERNER EMMANUEL BACHMANN was a classical organic chemist in the finest sense of the word. An exceptionally gifted experimentalist and an incisive and constructive thinker, he brought his talents to bear on a wide variety of problems in studies ranging from those on free radicals and molecular rearrangements to synthetic approaches in the fields of polynuclear carcinogens and steroid hormones. Such was the fundamental nature of his work that the results far transcended the immediate goal in mind. A wealth of dependable procedures originating with him have furnished reliable bases for further investigations by other workers throughout the world. But perhaps of greater importance was the inspiration Bachmann provided to generations of undergraduates as a teacher and to his many graduate students as preceptor and counselor.

W. E. Bachmann was born in Detroit, Michigan, on November 13, 1901. His father came to the United States from Switzerland at the age of nine and, after studying for the ministry, built up his own church in Detroit. His mother was a kindly woman of strong principles and character. From this happy combination Werner Bachmann inherited many of the traits which were to distinguish him in later life.

After progressing through the grammar schools of Detroit, Bachmann entered Western Technical High School in that city. During these years his interest in chemistry began to take form, and in his later years in high school he held an assistantship in chemistry.

# BIOGRAPHICAL MEMOIRS

These were the troublesome times of the First World War and it is typical of the later Bachmann that when a call to serve his country came he responded characteristically. In the spring of 1917 a request was received at the high school for a person with sufficient knowledge of chemistry to formulate the mixtures being used in preparing certain alloys in a Detroit foundry. Bachmann volunteered for this position and was allowed to omit the last two months of his high school course on the basis of his excellent record. Thus, at the age of seventeen, he found himself the boss of a gang of laborers in the foundry. This work lasted for about a year.

With the cessation of hostilities, he continued his education at Detroit Junior College, and, after completing the two-year course there, he entered the University of Michigan as a student in Chemical Engineering. Although he completed the engineering course and received the Bachelor of Science degree in engineering in 1923, it was during these years that he decided to forsake applied science for pure science. Throughout his undergraduate, as well as his graduate, career, Bachmann never received a grade lower than A, and, if it were the practice of the University of Michigan to award degrees *cum laude*, his would certainly have been *summa cum laude*.

During the course of his engineering studies he attended Moses Gomberg's lectures in organic chemistry and the inspiration he derived from Professor Gomberg was largely responsible for his decision to pursue a career in that field. As an undergraduate he was an assistant to Gomberg, who soon recognized the unusual ability possessed by the young man. Toward the close of Bachmann's undergraduate career Gomberg presented him with a set of the third edition of Beilstein's *Handbuch* as a tribute to his performance and by way of encouragement to continue with organic chemistry. Thus began a long and fruitful period of collaboration between the two.

Following receipt of the degree of Master of Science in 1924, Bachmann acquired industrial experience through a summer position in the research laboratories of the National Aniline Division of the Allied Chemical and Dye Corporation in Buffalo, New York. After

resuming his graduate work, he was awarded the degree of Doctor of Philosophy in 1926. His dissertation was concerned with the reducing action of magnesium and magnesium iodide on diaryl ketones. While he was a graduate student his sterling qualities as a teacher became apparent and he was appointed Instructor in Chemistry in 1925. In the summers of 1926 and 1927 his experience in synthetic organic chemistry was broadened by work in the newly established organic preparation laboratories of the Eastman Kodak Company in collaboration with Hans Thatcher Clarke.

During his student days, Bachmann took almost no part in extracurricular activities. However, he did attend every lecture and musical event on the Ann Arbor campus in addition to carrying on his academic work. In view of the number and frequency of such affairs this was no mean feat.

In 1927 he married Marie Knaphurst of Chicago. They had known each other since grammar school days and the two families frequently exchanged visits. Gomberg, who never married, held the firm conviction that graduate students should not assume the responsibilities of marriage. It was his sincere belief that the cares attendant upon support of a wife during graduate studies represent a serious handicap, and moreover that since a graduate student could only do his best in research by neglecting his wife, such a state of affairs would be quite unfair to her. However, once the Ph.D. had been attained, he would advise his students, "Now don't wait too long." In the case of the young Bachmann, Gomberg's convictions apparently carried somewhat further. His comment at the time of Bachmann's marriage was "What a pity." He could not have been more in error. Marie Bachmann was a great help to Werner in many ways, always ready to assist in the preparation of manuscripts and particularly in helping to provide a home and counsel for his students away from home. Two children were born: Joan Marie (Mrs. Robert F. Johnston) and Roger Werner, who graduated with distinction from the School of Natural Resources at Michigan.

The year 1928 was spent in Europe on a Rockefeller Foundation

Fellowship. In Paul Karrer's laboratory in Zurich, Bachmann's interest in natural products was awakened as a result of a study of the chemistry of lycopene. In this work the handicap of scarcity of starting material, under which so many investigators in this field labor, was conspicuously absent. The source of lycopene was a wellknown brand of canned tomato paste available in unlimited quantities from neighboring Italy. During the year in Zurich the famous little black book made its appearance. Henceforth this was his constant companion and in it he jotted down a cascade of research ideas. His untimely death prevented exploitation of many of them.

During the course of his work on lycopene an incident occurred which clearly illustrates the meticulous care with which Bachmann approached an experimental problem. In the determination of the structure of the end group of lycopene, acetone was isolated as a derivative from an ozonization experiment. Subsequently, after the paper describing the work had been accepted for publication, he remembered that he had cleaned his flasks with acetone and wondered whether the small amount of acetone derivative isolated might not have had the wash acetone as its source. Repetition of the ozonization experiment showed that the original observation was correct. Bachmann never forgot this incident and repeatedly used it as an example in cautioning his students on the dangers of artifacts.

He returned to Michigan in 1929 as Assistant Professor of Chemistry. In the summer of 1931 he served as Assistant Professor at the University of Illinois. In 1933 he received the Henry Russel Award from Michigan for outstanding ability in teaching and research the highest honor which the University confers on a member of its faculty. This was followed by promotion to Associate Professor in 1935.

Award of a Guggenheim Fellowship in 1935 enabled Bachmann to spend another year in study in Europe. This was divided between work with J. W. Cook at the Royal Cancer Hospital in London and with Heinrich Wieland in Munich. From his association with Cook arose his interest in the cancer problem. During his sojourn in Cook's laboratory, he made a lasting impression on his British friends by the earnestness and intenseness with which he approached his work. His habit was contagious and it is rumored that conventional working hours were changed as a result of his visit. He arrived in Munich with the manuscript of a paper representing the results of three months' work in Cook's laboratory. When Wieland saw the manuscript he found it hard to believe that so much had been accomplished in so short a time. A year was more realistic according to his view.

Promotion to Professor of Chemistry at Michigan came in 1939 and in the same year the outbreak of the Second World War set in motion the train of events which were ultimately to lead to his premature death.

In the summer of 1940 the National Defense Research Committee was established and in the fall of that year a group of organic chemists, most of whom were ignorant of the chemistry of explosives, met in Roger Adams's residence in Urbana, Illinois, to discuss how they could best contribute to the budding war effort. Among the neophytes was Werner Bachmann and among the topics discussed was how best to manufacture and use a high explosive known in this country as Cyclonite and in England as RDX. The potential military value of RDX as the most powerful of the nonatomic high explosives had already been appreciated. However, in this country there was no knowledge at the time as to how it could be used safely and no practical process for its manufacture. It subsequently developed that the British had largely solved the problem of the use of the explosive and had developed a fairly satisfactory batch process for its manufacture. To Bachmann was assigned the problem of devising a more efficient and economical manufacturing process.

In some respects Bachmann's achievement in discovering an efficient new method for preparing RDX testifies most eloquently to the amazing versatility and experimental technique of this extraordinary chemist. He had no previous experience in the chemistry of explosives, and was best known for his elegant syntheses of complicated molecules such as the sex hormones. When Bachmann first learned that his assignment under the NDRC program was to be the development of a practical method for the large-scale manufacture of the highly sensitive RDX, he records that his "heart sank."

In January of 1941, J. C. Sheehan, who had just completed his doctoral thesis with Bachmann, began work on a novel approach to the synthesis of RDX. In the conventional British process for making RDX, hexamethylenetetramine is treated with 98–100 percent nitric acid, as is shown in equation (1).

$$C_6H_{12}N_4 + 3HNO_3 \rightarrow C_3H_6O_6N_6 + 3HCHO + NH_3$$
(1)

This direct nitration method suffers from at least two serious disadvantages: large excesses of nitric acid must be employed for optimum yield, and one half of the equivalent of formaldehyde is lost, principally through oxidation by the nitric acid. Thus, the maximum amount of RDX possible is one mole from one mole of hexamethylenetetramine, and the actual yield is considerably less. In 1940 Bachmann learned that Ross and Schiessler at McGill University had obtained RDX from formaldehyde, ammonium nitrate, and acetic anhydride in the absence of nitric acid, but no details of their experiments were available. Although equation (2) is undoubtedly an oversimplification of the reaction, it occurred to Bachmann and Sheehan to attempt utilization of the by-products of the nitrolysis to obtain a second mole of RDX. In this way, if two moles of ammonium nitrate and six moles of acetic anhydride were present during the nitrolysis of hexamethylenetetramine, then two moles of RDX might be obtainable from one mole of hexamethylenetetramine.

Although exploratory experiments were discouraging and frequently led to spectacular "fume-offs," from a few reactions a small amount of RDX was obtained. After each experiment, Bachmann, who personally spent long hours in the laboratory, would carefully and ingeniously design a variation in the experimental conditions until finally, after literally dozens of experiments, the reaction condi-



tions which permitted control of the process were worked out and a consistent yield of RDX was obtained. A memorable occasion was the day on which Bachmann and Sheehan isolated more than 100 percent yield of RDX based upon one mole of hexamethylenetetramine to demonstrate conclusively that a "combination" process was prevailing. The enthusiastic encouragement given by Roger Adams and J. B. Conant was most heartening in the early phase of the work. It now became important to adapt the process for relatively large-scale use. A number of scaled-up reactions were carried out involving quantities as large as several kilograms. Owing to the hazardous nature of the reaction these experiments were conducted on Sunday mornings and at other times when the University buildings were sparsely occupied.

The RDX prepared by the new process was at first considerably more sensitive to impact than was RDX from the direct nitrolysis reaction. At one point an urgent telegram was received from the U.S. Bureau of Mines Laboratory in Bruceton, Pennsylvania, reporting that an RDX sample submitted to them for evaluation was highly sensitive and should be handled with extreme care. This sensitivity was later traced to the presence of impurities, in particular to a small amount of a high-melting substance termed HMX (HM—high melting), and to a lesser extent to an impurity termed BSX (BS—Bachmann and Sheehan).

In the early phase of this work the armed services showed little interest in RDX as a military explosive, but during the summer of 1941 Admiral Blandy, then Chief of the Bureau of Ordnance, after consultation with top scientists of the Office of Scientific Research and Development, recognized the potentialities of RDX for use in rockets, torpedoes, and aerial bombs. The greater explosive power as compared to TNT (RDX has 150 percent of the power of TNT on a weight basis; on a volume basis, which is important for certain applications, RDX is approximately twice as powerful by virtue of its greater density) offered tremendous potential advantages. In addition, its markedly greater brisance, or shattering power, made RDX the ideal explosive for use in shaped charges, the principle behind the bazooka.

In the fall of 1941 Bachmann's RDX group at the University of Michigan was strengthened by the addition of E. L. Jenner, William MacNaughton, Lawrence B. Scott, and Norman Deno. The process was further improved, and many features of the chemistry of RDX formation were elucidated.

After the work had progressed to a point where the new process obviously had real possibilities for the large-scale manufacture of RDX, other laboratories were asked to cooperate in order to expedite a detailed study and development of the reaction. Participating continuously or for a short time in the project were groups at the University of Toronto, McGill University, Cornell University, Pennsylvania State College, Harvard University, the University of Pennsylvania, Tennessee Eastman Company, E. I. du Pont de Nemours and Company, Western Cartridge Company, Indiana University, Vanderbilt University, and in Great Britain. Several companies undertook the development of the new combination process, but the efforts of Tennessee Eastman were the most successful. At Kingsport, Tennessee, the largest munitions plant in the world was constructed to produce RDX by the new process on ten continuous production lines. It has been reported (*Scientists against Time* by James Phinney Baxter, 3d) that RDX was produced in this way at the rate of 360 tons per day. The production of RDX by the direct nitration process would not only have been considerably more expensive but would have involved much larger quantities of critically short corrosion-resistant materials for handling the nitric acid. It has been estimated that the saving to the government in plant cost alone was over two hundred million dollars.

The contribution of RDX to Allied success in the Second World War can scarcely be overestimated. Although RDX was considered too sensitive to fire from conventional artillery, it found wide application in rocket heads, in the 12,000-pound "Tallboys," in blockbusters, and in the torpedoes which sank the "unsinkable" German battleship *Tirpitz*. Thus Bachmann, the very prototype of the unassuming scientist, was able to make an outstanding contribution to his country's and to the free world's victory by bringing to bear his extraordinary scientific prowess, his imagination, and his perfection in laboratory technique.

Simultaneously with and subsequent to his work on RDX he also carried on important investigations on the oxynitration of benzene as a route to picric acid and on various aspects of the penicillin problem. The strain created by these wartime researches and the effort devoted to them undoubtedly contributed to the serious undermining of his health.

In recognition of his services Bachmann was the recipient of the Naval Ordnance Award in 1945, and in 1948 he was granted the Presidential Certificate of Merit by the United States government and the King's Medal by the British government. During the war years he became an ardent victory gardener, and from his experience in augmenting the food supply arose his devotion to horticulture as a hobby. He became a skilled and enthusiastic grower of roses and iris and, more particularly, orchids.

In 1947 the University of Michigan honored Bachmann by appointment to the newly created Moses Gomberg University Professorship of Chemistry. He was elected to membership in the National Academy of Sciences in 1940. In the spring of 1947 he gave a series of lectures in Basel, Zurich, and Geneva under the auspices of the Swiss-American Foundation for Scientific Exchange. He served as Associate Editor of the *Journal of the American Chemical Society* from 1941 to 1945 and was on the Board of Editors of the *Journal* of Organic Chemistry from the inception of this journal in 1936 until his death. He was also an editor of Organic Reactions until his death and edited Volume 25 of Organic Syntheses.

Werner Bachmann was truly an artist and a perfectionist. All who knew him were impressed with his intense interest in careful experimental work. His successes were due not only to meticulous, thoughtful planning but also to exceptional manipulative skill. He never gave up active participation in bench chemistry and consistently refrained from publishing speculations unsupported by sound experimental evidence.

Bachmann published over one hundred and fifty contributions to the literature of organic chemistry. His first publication, in 1924, resulted from research as a first-year graduate student with Moses Gomberg and described a safe and reliable method for coupling unstable diazonium compounds with derivatives of hydrocarbons to form derivatives of biphenyl—a reaction which came to be known as the Gomberg-Bachmann reaction.

In later years, after the equilenin synthesis, Bachmann told his collaborators, Wilds and Cole, that in spite of all his efforts to gain recognition for them, undoubtedly many would refer to this as the Bachmann equilenin synthesis. He said his own work with Gomberg was, after all, usually referred to as the "Gomberg synthesis." Then with a twinkle he continued, "Don't be upset; your turn *will come* later."

His doctor's thesis involved a study of the reducing action of a mixture of magnesium and magnesium iodide on aromatic ketones to form pinacols. The results of this work stimulated a long series of papers with Gomberg on the action of this unusual and powerful reducing reagent on acids, esters, aldehydes, and a variety of nitrogenous organic compounds. Undoubtedly his admiration for and close association with Gomberg tended to influence Bachmann to pursue this line of research longer than would otherwise have been the case.

His views on the course of these reductions led Bachmann into a controversy on the nature of sodium ketyls and the mechanism of reduction of aromatic ketones to secondary carbinols by sodium. His arguments, characteristically buttressed with clear, convincing experimental evidence, showed conclusively that dimeric sodium pinacolates rather than the monomeric sodium ketyl radicals were the species involved. It is ironic that the Michigan school played such an active role in disproving many cases of alleged free-radical structures when, in his early work, Gomberg himself met with such vigorous opposition to the concept of stable free radicals.

From this experience with polemicals on the ketyl question, Bachmann drew several lessons which he tried to pass on to his students. He felt that speculation unsupported by experimental evidence, although extremely useful as a working hypothesis, had no place in publications. Rather it represented needless cluttering up of the literature which more often than not could be avoided by performing a critical experiment to verify or disprove a point. He also concluded that polemicals were futile and refused to become involved in them later, even when urged to do so by his co-workers. His creed was that sound scientists would reach the correct conclusion if only the facts were published. It was but natural that his work on pinacol formation should have led him into a study of the pinacolone rearrangement and thence to the closely related Beckmann rearrangement. During this period Bachmann developed an appreciation of the need for a more rigid experimental approach to theoretical organic chemistry. This interest remained a prime concern throughout his career. The migration aptitudes of various aryl groups in rearrangements of symmetrical aromatic pinacols were determined. In general, these paralleled the relative electronegativities of the groups and were valid for predictions. However, with unsymmetrical pinacols the generalizations which governed migratory aptitudes with the symmetrical pinacols were not followed. Subsequent to Bachmann's death the important steric effects controlling such rearrangements were recognized, a circumstance which in no way detracts from his pioneering work in this field.

As a result of his long association with Gomberg, Bachmann maintained a lively interest in the chemistry of free radicals, in particular the dissociation of aryl-substituted ethanes. With Wiselogle and others he reported careful kinetic studies to determine the effect of structure on energy of activation in many examples of this class of compounds.

The rapid developments in the late 1920s and early 1930s in the chemistry of the steroids on the one hand and the isolation of carcinogenic hydrocarbons on the other quickened Bachmann's interest in polycyclic compounds. By the middle 1930s his earlier experience with polycyclic compounds studied in connection with the pinacol rearrangements was put to use in the preparation of pure carcinogens and of synthetic analogs of the estrogenic steroid hormones. The period spent with Cook and Wieland intensified his interest in both fields.

In attacking the carcinogen problem two goals were set, namely, to find more potent and faster-acting compounds than those heretofore available and to prepare biologically useful water-soluble car-

cinogens. In 9,10-dimethyl-1,2-benzanthracene and the related 5,9,10trimethyl-1,2-benzanthracene two compounds were found which produced tumors much more rapidly than methylcholanthrene and 3,4-benzpyrene. During the course of this work important contributions were made to the synthesis of many other derivatives of these hydrocarbons as well as to members of the chrysene, phenanthrene, and tetrahydrophenanthrene series.

By 1934-1935 the total synthesis of the estrogenic steroid hormones had become a major objective. In the fall of 1938 prospects for the synthesis of 3-desoxyequilenin looked so promising that the synthesis of equilenin itself appeared to be feasible. With A. L. Wilds efforts were concentrated on completing the synthesis of 3-desoxyequilenin and with Wayne Cole attentions were devoted to improving the preparation of 7-methoxy-1-keto-1,2,3,4-tetrahydrophenanthrene, the key intermediate in the synthesis of equilenin. As a result of this teamwork and close collaboration the actual synthesis of equilenin was accomplished in less than a month from 7-methoxy-1-ketotetrahydrophenanthrene. Bachmann has stated in regard to the equilenin synthesis: "The reactions which were used are fairly obvious ones and the successful preparation of the hormone depended principally on developing the proper conditions for making the reactions proceed." As a matter of fact, each reaction was studied so critically and the synthetic procedures were developed to such a degree that they have found extensive use in many other laboratories for a wide variety of syntheses. The contributions which came from this work included the novel discovery of the use of powdered soft glass as a catalyst for the elimination of carbon monoxide from a glyoxylic ester, favorable conditions for accomplishing the Reformatsky reaction with sluggish polyfunctional compounds, development of satisfactory conditions for the Arndt and Eistert reaction with aliphatic acid chlorides, and the need for a nitrogen atmosphere in sodium alkoxide catalyzed condensation reactions.

Inasmuch as the essential feature of the equilenin synthesis had

been the development of satisfactory methods for attaching the fivemembered ring D to the tricyclic ketone, 7-methoxy-1-keto-1,2,3,4tetrahydrophenanthrene, it was immediately apparent that the general method should be applicable to the synthesis of the related hormones, estrone and androsterone, from the appropriate tricyclic ketones. Although the tricyclic ketone required for the synthesis of estrone had been described by Robinson and his associates, a method of preparation suitable for obtaining larger amounts of the compound was urgently needed. After exploration of some ten possible approaches, an improved procedure leading to the tricyclic keto ester, 7-methoxy-1-keto-2-carbomethoxy-2-methyl-1,2,3,4,4a,9,10,10aoctahydrophenanthrene, was developed. Work was well advanced on elaboration of Ring D of estrone as Bachmann reported at the American Chemical Society Organic Symposium in Ann Arbor in December, 1941. However, by that time he had taken on responsibility for developing a practical synthesis for RDX as discussed above, and, in the realization that the wartime effort would demand his undivided attention, the hormone work was put aside.

Tragically, he gave of himself so unsparingly during the war years that the conclusion of hostilities found his strength and health so sapped that, despite further significant advances in the hormone field, Bachmann was never able to bring his old vigor and enthusiasm to the work.

By the time the major part of the RDX work had been completed the outstanding value of benzyl-penicillin as a chemotherapeutic agent had become apparent and a large number of laboratories both in England and the United States embarked on a cooperative effort directed toward proof of structure and synthesis of the antibiotic. In 1943 Bachmann was asked to initiate a program of synthesis. Although the structure was not completely understood, the major fragments, penicillamine and benzylpenaldic acid, and the penicilloic esters were recognized, and spectrographic evidence suggested an oxazolone-thiazolidine structure. With these observations in mind, Bachmann and his co-workers studied methods of preparation of the benzylpenaldic acids and their esters and the related azlactones. A number of improvements in existing methods were made and new methods were developed.

In 1945, when the  $\beta$ -lactamthiazolidine structure was just emerging, a coupling reaction between benzylpenaldic acid azlactone and penicillamine was attempted by the Bachmann group. Unmistakable microbiological evidence for the presence of penicillin in the crude reaction mixture was obtained. However, the yield was extremely low, and no further work along this approach was done. Bachmann felt that common sense dictated that further investigation of a procedure designed for synthesis of an erroneous structure which accidentally produced a trace of the correct material was wasted effort. It remained for others to take advantage of Bachmann's characteristic spirit of team cooperation and natural modesty in reporting the first "total synthesis" of penicillin.

Subsequent to the federally sponsored penicillin program, a group of drug houses asked Bachmann and others to continue efforts toward a total synthesis of penicillin. Working with a small group, Bachmann achieved at least one additional penicillin synthesis. However, the yield, although much better than that obtained previously, was not sufficiently high to warrant isolation of the antibiotic, and again Bachmann felt that publication was not warranted unless improvements could be made.

Further contributions to the chemistry of the penicillins were cut short by Bachmann's failing health. Nevertheless, it is impossible to read the monumental monograph, "The Chemistry of the Penicillins," without realizing the extent of his contributions in a relatively short period of time.

Werner Bachmann learned early that the essence of science is the reproducible experiment and applied this maxim continually to his own work. He strove not only to make his experimental procedures reproducible in his own laboratory but to eliminate such uncertainties both in method and description as to make them dependable for others. His papers, therefore, have provided a fountain of reliable methods of wide use in many areas of organic chemistry.

In talking with a student, he frequently expressed the opinion that any organic reaction, if properly understood and carried out with good technique, should give a yield of at least 90 percent of the theoretical. He spoke fondly of those reactions which furnished yields of 99 percent or higher. Although he admitted that this state of affairs had not been reached for some reactions, he nevertheless provided a spectacular goal toward which the student could strive. The pedagogical value of such an approach was great. Acquisition of accurate and quantitative methods of manipulation followed almost automatically.

Of equal, or perhaps of even more, importance was the development in the student of a critical attitude toward experimental procedures: the purpose and effectiveness of each step, where material went that was not accounted for in the main product, and the isolation and identification of side products. He stressed the significance of these side products as well as of all direct observations such as the formation of a precipitate, a color, or some more subtle change in pointing the way to improving a reaction or a yield.

One example of the results of this meticulous attention to detail may be given. At one stage of the equilenin synthesis, the fivemembered Ring D was closed by Dieckmann cyclization of a diester to a  $\beta$ -keto ester. Although the yield of 40–50 percent from the use of sodium as the reagent was comparable to many reported in the literature, Bachmann was bothered by the formation of about 10 percent of a colored acidic oil as a by-product even under his rigorously anhydrous conditions. He then recalled his earlier work with the sodium enolate of benzoin which was oxidized by air to sodium benzoate as well as to colored products. This led him to run the cyclization reaction in an inert nitrogen atmosphere which, with substitution of sodium methoxide for sodium, raised the yield to a respectable 98 percent. Today it has become standard practice to carry out most base-catalyzed condensations under nitrogen with beneficial results.

Bachmann seldom discouraged a student from trying a reaction, particularly if it were described in the literature as being unsuccessful. Often enough the experiment was successful if properly carried out. However, he also succeeded in directing the student to the major problem rather than to side issues, mainly by keeping enthusiasm high and balancing discouraging results with encouragement. When a student suggested an interesting deviation from the main objective, his usual comment was that it was a good "holiday reaction."

Toward the stranger or casual visitor, Bachmann displayed a reserve that occasionally was thought to be aloofness or pride. In part this was a result of a natural shyness and in part it was a natural barrier erected to enable him to carry out his laboratory work free from unnecessary interruption. As Conant wrote of Kohler: "He suffered—the fate of more than one shy person whose aloofness is attributed to pride." To his research students and close friends, however, Bachmann revealed a warm, friendly personality of great charm and keen wit.

In addition to his brilliant research accomplishments, Werner Bachmann was an inspiring teacher. His beautifully delivered lectures were well-planned models of clarity. The influence of his personality as a teacher is well reflected in those of his students who have gone on to successful careers in teaching. His efforts were devoted both to graduate and to undergraduate students and his patient understanding of the undergraduate and his problems undoubtedly was responsible for attracting many young men to the study of organic chemistry, just as the young Bachmann was himself inspired by the great teacher Gomberg, whose tradition he so effectively carried on.

The strain and effort of the war years finally took their toll and,

with his health undermined, Werner Bachmann died of heart failure at the age of forty-nine on March 22, 1951. While the work he was doing will be taken up by others, no one can fill the place he occupied in the hearts of his family and friends. As expressed by a former associate: "That he was a brilliant scientist everyone knows, but only those who knew him well recognized his modesty and humility, which are the true test of greatness." And again: "He won us all by his outstanding mastery, by his charm and modesty. Few have accomplished so much and fewer still in so short a life."

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# **KEY TO ABBREVIATIONS**

Helv. Chim. Acta=Helvetica Chimica Acta

J. Am. Chem. Soc.=Journal of the American Chemical Society

J. Chem. Soc.=Journal of the Chemical Society (London)

J. Org. Chem.=Journal of Organic Chemistry

Org. Reactions=Organic Reactions

Org. Syntheses = Organic Syntheses

Proc. Royal Soc. London=Proceedings of the Royal Society (London) Yale I. Biol. and Med.=Yale Journal of Biology and Medicine

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