NATIONAL ACADEMY OF SCIENCES

EDGAR COLLINS BAIN

1891—1971

A Biographical Memoir by
JAMES B. AUSTIN

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September 14, 1891–November 27, 1971

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THE DECADE between 1925 and 1935 was one of the most intensely creative periods in the history of physical metallurgy. A number of first-rate men were active then, but one of the most outstanding was Edgar Collins Bain, whose often inspired contributions added much to the excitement of the time.

He was born on September 14, 1891, near La Rue, Marion County, Ohio, the second child of Milton Henry and Alice Anne Collins Bain. On his father's side he was of Scottish descent, his great-grandparents, John Bean and Anne Horne Bean, having emigrated from Dundee to America in 1832. They apparently went directly to the Marion area in Ohio, where John's older brother had settled some years before. Once in this country, they changed their name to Bain. Edgar's grandfather, John II, was at one time a senator in the Ohio legislature; his father, Milton, was a farmer who also, with several of his brothers, owned and operated a general store in Marion.

Edgar's mother's family had likewise been in this country for several generations, living in Logan County, Ohio, where her father was a farmer. She taught in a one-room schoolhouse with mathematics as her specialty.

At an early age, Edgar acquired a strong interest in an unusual number of activities that would mean a great deal to him in his later life. He was, for example, much interested in music and in craftsmanship. But there were two of these activities that indicated a developing scientific bent. He became deeply absorbed in photography, which he pursued ardently for the rest of his life, both as a metallographic tool and as a hobby. He was also fascinated by the development of the compound microscope and yearned to work with one, though this desire had to wait some years for fulfillment.

As had many of his contemporaries, Bain came to metallurgy through chemistry. After attending the public schools in Marion, he entered Ohio State University to study chemical engineering. There, in the early winter of 1910, as he recalls in *Pioneering in Steel Research: A Personal Record* (1975, p. 2), he had one of the most exciting experiences of his college years. It came in Professor Nathaniel Wright Lord's class on the metallurgy of iron and steel, when Professor Lord projected some slides that he had just received from abroad, one of which was a photomicrograph of pearlite in a eutectoid carbon steel. This was a revelation to Bain, since he had not, up to that time, been acquainted either with the use of reflected light or with the special illumination required for an opaque sample. This experience made a lasting impression on him and strengthened his urge to work in the field of microscopy.

On receiving his B.Sc. degree from Ohio State in 1912, he entered government service, first with the U.S. Geological Survey, then, a little later, at the National Bureau of Standards, where he was assigned to the routine chemical analysis of Portland cement for the Panama Canal. It was not long before his contacts with the scientists on the staff of the bureau convinced him that he should return to Ohio State for graduate study. So, in August 1915 he approached his friend Dr. James R. Withrow, then head of chemical engineering. To his delight, Withrow offered him an assistantship, which he promptly accepted. Professor Withrow also suggested that a suitable subject for his master's thesis would be a check on the correctness of a schematic drawing in Abegg's *Handbook* showing an electrolytic apparatus for preparing solid crystals of alkali amalgam. The point in question was that this diagram showed the crystals accumulating at the bottom of the container, whereas there was some reason to believe that the density of the crystals should be lower than that of liquid mercury. This investigation was carried out with results demonstrating that the density of the solid crystals was indeed lower.

Although Bain's chief work at this time was in chemical engineering, he became intrigued by a new lecture and laboratory course in metallography then being offered by Earle C. Smith, an interest doubtless stimulated by his continuing desire to enter the field of microscopy. So he enrolled in the class and learned to prepare metallographic specimens and to observe their microstructure.

By the spring of 1916, it was clear, however, that he would not have enough credit hours to obtain his master's degree during that school year, so Professor Withrow arranged for an assistantship for the following year. Shortly thereafter Professor O. L. Kowalke, head of the Department of Chemical Engineering at the University of Wisconsin, asked Withrow to recommend a young man for an instructorship in the teaching of metallurgy and the measurement of high temperatures. Withrow recommended Bain, who was much interested but hesitant because he feared that his one course in metallography did not qualify him for this opening. Withrow suggested that he could prepare for this new assignment by attending a suitable summer school, such as that at Columbia University, where he could intensively study these two specific areas.

He therefore arranged to attend summer classes under Professor William Campbell of the Columbia School of Mines. To his great delight he found that Earle Smith was also attending these sessions. It proved to be an exciting summer. On the completion of these courses, Bain was much more confident about the instructorship at Wisconsin and was pleased that Ohio State gave him credit for the summer's study and awarded him an M.Sc. degree.

His year of teaching proved interesting and rewarding but left him with a deep dissatisfaction with the prevailing definitions of such microconstituents as troostite and sorbite. At the end of the school term, he was engaged for the following year, during which time he hoped to complete work toward a doctor's degree.

Meanwhile, he wanted summer employment, which he found with the B. F. Goodrich Company, examining the numerous large steam boilers in one of their plants. At the conclusion of this task, he was offered an attractive permanent position in the research laboratory with the prospect of some interesting assignments under the direction of the vice-president in charge of research. So he decided to postpone his work toward a Ph.D. and accepted the offer, after obtaining a release from his instructorship at the University of Wisconsin. One of the projects on which he worked was the development of improved gas masks.

A year and a half later, when World War I broke out, he tried, unsuccessfully, to join first the Army Ordnance and then the Army Air Corps. He was, however, given a commission as first lieutenant in the Chemical Warfare Service.

After the armistice, he could have returned to the rubber industry but decided to look for something in metallurgy. This he found at the Cleveland Wire Division, National Electric Lamp Works of the General Electric Company, where he worked in the wire plant, mainly in research, under the supervision of Zay Jeffries, who was then a consultant to General Electric. One of his first investigations was a close observation of the mechanism of the burning out of tungsten wire filaments. For this purpose he employed high-speed photographs (720 exposures per second) taken with a rotating sector. The report of this study was accepted in fulfillment of the requirement for a professional degree in chemical engineering, which was awarded by Ohio State University. As Jeffries was much interested in the growth of grains in metals, especially in the high-speed steels used in making tools for the drawing of ductile tungsten wire, he suggested that Bain explore this field.

About 1920, Jeffries became interested in the X-ray diffraction studies being carried out by A. W. Hull at the General Electric Company Research Laboratory in Schenectady, New York. So Bain visited Hull to explore the possible usefulness of X-rays in solving metallographic problems. The result was that Bain designed and constructed X-ray diffraction equipment that was based on Hull's apparatus and began a series of pioneering investigations that was to extend over many years. He also found X-rays a useful adjunct to the more conventional techniques of metallography.

There was at this time a great deal of ignorance and confusion regarding the nature of metallic solid solutions. The general tendency was to accept the prevailing view of the chemists that all matter is built up of molecules rather than atoms. Even the view that all metals are crystalline was by no means universally accepted. Bain recognized the value of X-rays in investigation in this field, even though he did not at this early stage fully understand all the theoretical ramifications of the results. He was, however, well aware of the potential hazards of this new technique and of the precautions he should take in using it.

In his first two published articles (1921), he presented the first experimental evidence that metallic solid solutions are essentially a simple replacement of atoms of solvent by those of solute. He also obtained the first indications of order–disorder reactions and of superlattices, though their significance was not fully recognized until much later. His penchant for broad systematic investigations was evident in a 1923 paper, "The Nature of Solid Solutions," in which he reported data on fourteen binary alloy systems. He pursued his investigations to broaden the usefulness of X-ray crystal analysis for some years, and, even when he turned to other fields, it remained a favorite tool in studying solid solutions and in the identification of various structures, especially carbides in steel.

One notable investigation with Zay Jeffries in 1923, in which X-ray data played a significant role, was a study of the cause of red hardness in tool steel. The ideas they presented are, with slight additions or modifications, those still basically used to explain this phenomenon. It also is noteworthy that their paper was written in language that the modern metallurgist does not find strange or antiquated. Indeed, this was one of the first papers in which the art and science of metallurgy were successfully bridged.

With his growing interest in ferrous metallurgy and particularly special-alloy steels, Bain was receptive to an offer from the Atlas Steel Corporation in Dunkirk, New York, so he left the General Electric Company early in 1923 to join the staff of his friend, Marcus Grossmann, then Chief Metallurgist at Atlas.

There shortly began to appear a series of papers with Grossmann that extended the study of tool steel. There was a general paper on the nature of high-speed steel; others on the function of chromium and on low-tungsten tool steels; and a broader study on oil-hardening, nondeforming tool steel. All these were summed up a few years later with the publication of the book *High Speed Steel* by Bain and Grossmann.

In 1923, the Atlas Steel Corporation experienced some financial difficulties, and early in 1924 it was under the direction of an ancillary receivership. Bain, perceiving that the company might come under new corporate ownership, whereby many positions would be filled by persons selected by the new management, decided to look elsewhere. Among other possibilities, he applied to Dr. F. M. Becket, President of Union Carbide and Carbon Research Laboratories in Long Island City, New York. He was promptly employed and in July 1924 joined the staff.

There he began a characteristically systematic study of iron–chromium alloys, which are somewhat difficult to work with because of their sensitivity to impurities and, even more, because of their sluggishness in responding to heat treatment. Nevertheless, Bain, by an ingenious combination of metallography, X-ray diffraction, and magnetic measurements, made the significant discovery of the existence of the so-called gamma loop. Moreover, he showed that the maximum solubility of chromium in gamma iron is about 13 percent and that an increase in carbon content enlarges the field of stable austenite. More recent investigations have changed only marginally the boundaries reported by Bain.

In 1927, Bain published a paper with W. E. Griffiths entitled "An Introduction to Iron–Chromium–Nickel Alloys." The word *introduction* was well chosen, as the authors, recognizing the complexities of the system and the difficulties of studying it, had no illusions that their results were definitive. Among other significant results, however, they discovered the existence of an important intermetallic compound.

By this time Bain was widely regarded as one of the outstanding metallurgists in the country. So, in 1928 Dr. John Johnston, who was organizing a new research laboratory for the United States Steel Corporation, asked Bain to head the research in physical metallurgy. This gave Bain the opportunity he had long sought to get more deeply into the steel industry, particularly into the new chromium stainless steels, so he accepted and set about building a small but very competent staff.

As might be expected, he continued his investigations begun at Union Carbide into alloys of the iron–chromium–nickel system, particularly the 18–8-type alloy that was coming into wide use. Two years later, with R. H. Aborn, he published a paper, "The Nature of the Nickel–Chromium Rustless Steels," that was a major contribution to an understanding of this system. When intergranular corrosion of stainless steels became a serious problem, Bain and his colleagues set out to find the cause and to seek a cure. This they were able to do with the suggestion that addition of titanium in suitable amounts might be a remedy. Bain also investigated the structure of austenite and the shape of the unit cell of martensite, and he showed that the amount of retained austenite in quenched steel increases as the severity of the quench decreases.

About this time he began to recognize that in addition to the usual factors affecting metallurgical reactions, the influence of time had not been given due consideration. This led him to undertake his greatest work, an investigation with E. S. Davenport of the rate of transformation of austenite at a series of constant, subcritical temperatures. The result was a classic paper ("Transformation of Austenite at Constant Subcritical Temperatures") presenting the famous diagrams originally called S-Curves but now more generally known as time–temperature–transformation diagrams. This work at one stroke clarified metallurgical thinking about the process of, and the products of, the transformation of austenite. In particular, it made possible a more logical set of names for the decomposition products of austenite and of martensite, which had become thoroughly confused because of their similarity in appearance under the microscope.

One of the results of this investigation was the discovery of a hitherto unknown microstructure, which, in 1934, Bain's colleagues christened "bainite," a name that has become a very familiar term in metallography.

It is interesting that, although one can hardly overestimate the importance of this work in virtually completing a working understanding of the heat treatment of steels, the isothermal method is used in only a limited number of applications. It was, first and foremost, an excellent example of "basic" research, undertaken with a specific purpose in mind.

In this early work, the role of austenite grain size in the position of the isothermal transformation curve was not appreciated, but this subject soon was investigated. This led to the conclusion that effective grain size seems to be the most potent single factor influencing the hardenability of steel.

In January 1935, Bain was appointed assistant to R. E. Zimmerman, Vice-President of Research and Technology for the U.S. Steel Corporation, and moved from the research laboratory in Kearny, New Jersey, to the company's headquarters in New York City. This was practically the end of his career as a laboratory investigator, but during his eight years at the laboratory he had accomplished an amazing amount of significant research.

In his new post he was called on for a variety of administrative duties. He assisted Zimmerman in reviewing appropriations for new facilites and equipment, helped the patent department in many ways, and interviewed the many inventors who hoped to interest U.S. Steel in their ideas. He also assisted in the review of all publications, including advertising. This last brought him an interesting and instructive experience. In 1936, the company decided to have a motion picture produced showing the principal operations of steel making and shaping—from ore to finished products—all in thirty-seven minutes of running time! Bain was assigned the task of being an ad hoc technical adviser to the producers to insure that each scene was photographed clearly and accurately. From this he gained a comprehensive and detailed knowledge of the company's varied operations and also of the complex methods and equipment used with the newly developed Technicolor film.

In late 1937, the U.S. Steel Corporation formed a new company, the U.S. Steel Corporation of Delaware, which was to exercise a coordinating function for the principal manufacturing subsidiaries and had its headquarters in Pittsburgh, Pennsylvania. Dr. Zimmerman and his staff were included in this new organization, so, in May 1938, Bain moved to Pittsburgh. His duties were about the same except for a more specific mandate to coordinate the research and development activities within various components of the corporation.

About this time, with the threat of war developing, Bain began to spend more and more time in conferences with government technologists, both in and out of the armed services. In 1941, at the request of James B. Conant, then Chairman of the National Defense Research Committee, Bain headed an ad hoc group to recommend an immediate and feasible research program to improve the materials, chiefly steels, used in essential military equipment. He was rather amused that he was again serving under the man who, as Major Conant, had been his superior in the Chemical Warfare Service during World War I. This task led to his becoming a member of the National Research Council's War Metallurgy Committee, of which his former colleague Zay Jeffries was Chairman. He was also appointed to the Science Advisory Board to the Office of the Chief of Ordnance, U.S. Army.

In addition to these duties in Washington, Bain was assigned by Zimmerman to monitor problem areas in the production of steel. One of these was the search for ways to meet the shortage of alloying elements and in some cases to find satisfactory substitutes for grades of steel that were in very short supply. This program resulted in the NE (National Emergency) steels, which proved to be a valuable contribution to the war effort. Another area of concern was the serious failure of welded ships. Work on this problem led Bain to set up a welding laboratory that made some notable contributions to this field.

In March 1943, Bain was appointed Vice-President—Research and Technology of the Carnegie–Illinois Steel Corporation, the largest subsidiary of the U.S. Steel Corporation. In this new post he had two major responsibilities: the first was to coordinate and improve the programs of the several laboratories then existing within the Carnegie–Illinois Steel Corporation; the second was to establish means of improving and monitoring the quality of the company's products. He carried out both assignments with great success.

In addition to these duties, he continued to be active on the national scene. He was instrumental in organizing the General Research Committee of the American Iron and Steel Institute and became its first Chairman, serving from 1946 until his retirement from U.S. Steel. In 1954, he was elected to the National Academy of Sciences. Two years later, he was named Chairman-designate of the Division of Engineering and Industrial Research of the National Research Council and then served as its Chairman during 1957 and 1958.

In 1950, when Carnegie–Illinois was merged into U.S. Steel, Bain became Vice-President—Research and Technology for the entire corporation. Again, he was called on to coordinate all the research programs then under way in the former divisions and subsidiaries, which were widely scattered. Plans to consolidate a number of these laboratories culminated in the construction of a large research center in Monroeville, Pennsylvania dedicated in May 1956. The group at Kearny, New Jersey, of which he had been a member many years before, was housed there in a building that was named, appropriately, "The Edgar C. Bain Laboratory for Fundamental Research."

About a year later, Bain retired from U.S. Steel, but continued his writing and engaged in some consulting. In February 1959, he suffered a stroke which left him partially paralyzed. He recovered sufficiently, however, to continue some of his consulting, using his home as his office. Moreover, despite his handicap, he prepared, with H. W. Paxton, a revised edition of *Alloying Elements in Steel;* edited for the American Society for Metals a fifth edition of Grossmann's book *Principles of Heat Treatment;* and published an interesting and instructive paper on Japanese swords, which was based largely on his own collection. Of even greater importance, and again at the request of the American Society for Metals, he began to write his personal memoirs of the great period of development of alloy steels, in which he had played so prominent a role. Indeed, his place in the history of metallurgical progress is well attested to by the numerous honors and awards that came to him. In several cases, he was the first American ever to receive them.

In October 1971, to celebrate his eightieth birthday, the Materials Science Division of the American Society for Metals held, in Detroit, an "Edgar C. Bain Seminar on Phase Transformations and Related Phenomena in Steels." The first paper was written by Bain himself. At the time of his death, the following month, the manuscript of his memoirs was not quite complete but was far enough along that, after some editing, it could be published by the American Society for Metals early in 1975.

But a recital of the bare facts of his scientific career does not do Bain justice. He was a man of boundless energy and great enthusiasms. He was a voracious reader and had an amazing fund of knowledge that covered a wide variety of subjects. He had an unusual feeling for words, which he used as precision tools, and insisted on searching out just the right word or phrase to express his meaning. In spite of this, or perhaps because of it, his highly developed sense of humor led him to enjoy a good pun or a play on words. He could, and often did, make jokes in several languages.

He enjoyed social contacts, conversation, and exchanges of views on all manner of subjects. He was a fine talker, a sound thinker, and even an expert "doer"—a rare combination of talents. As an experimenter he was ingenious and was often able to obtain significant results with the simplest of equipment. He had an uncanny ability to get at the heart of a problem, and he was expert in suggesting solutions or explanations that could be tested by a "critical experiment," an approach of which he was a strong advocate.

He was not afraid of controversy and was skillful in the defense of his views. Nor did he hesitate to challenge traditional metallurgical thinking if he had good reason to do so. He was, in fact, something of a champion of "nontraditional metallurgy." And he seemed to be able to say the right thing at the right time and to back up his statement with pertinent data.

He also had great skill with his hands. He loved to work with wood and did beautiful things with it. In his younger days he wanted a violin so badly that when his family was unwilling to invest in one he proceeded to make a fairly workable instrument. He made bookcases for his home, and at the time he suffered his stroke he had almost completed a copy of an antique French chair that had been a wedding present, duplicating even the original carving and pegged construction. Such work was a great relaxation for him, and he used to remark, characteristically, that one couldn't stay angry about anything while planing a board.

Another favorite form of relaxation was music, which interested him all his life. His father, who had a fine tenor voice, had sung in a church choir and with a quartet that was highly regarded and in demand in their area of Ohio. Edgar likewise was a good tenor and loved to sing. In some personal memoirs intended only for his children, he wrote: "My earliest recollections of recurring experiences are of singing fortissimo while standing under the dining room table. The tunes were, I believe, 'Bringing in the Sheaves,' and 'Marching Through Georgia.' " Later, he was to derive great pleasure from singing in choruses, and he was well acquainted with most of the standard choral works. During his graduate study at Ohio State University, he earned enough to sustain himself by singing in the choir of the Broad Street Congregational Church in Columbus. He also ushered at symphony concerts and took extra parts in opera productions for sheer love of the music. While he was with General Electric in Cleveland, he played the French horn in a band. Though he could not read piano music, he could play almost anything by ear and was skillful at improvising. He was one of the early hi-fi addicts and seemed to enjoy making his own equipment almost as much as he did the music.

To complete the record: in 1927, he married Helen Louise Cram of Cleveland. They had two children: a daughter, Alice Anne, and a son, David. He died at his home in Edgeworth, Pennsylvania, on November 27, 1971, after a long illness.

HONORS AND DISTINCTIONS

HONORARY DEGREES

Doctor of Engineering, Lehigh University, 1936
Doctor of Science, Ohio State University, 1947

HONORARY MEMBERSHIPS

American Institute of Mining, Metallurgical and Petroleum Engineers, 1963
American Society for Metals, 1961 (President, 1937)
Japan Iron and Steel Institute, 1958
Japan Institute of Metals, 1964
Iron and Steel Institute, London, 1963
Charter Fellow of the Metallurgical Society of the American Institute of Mining, Metallurgical and Petroleum Engineers, 1963; Fellow: American Physical Society, the American Association for the Advancement of Science

HONORARY LECTURES

Edward DeMille Campbell Memorial Lecture, American Society for Metals, 1932
Henry Marion Howe Memorial Lecture, American Institute of Mining, Metallurgical and Petroleum Engineers, 1932
Charles M. Schwab Memorial Lecture, American Iron and Steel Institute, 1952
Hatfield Memorial Lecture, Iron and Steel Institute, London, 1955

MEDALS AND AWARDS

With W. E. Griffiths, the Robert W. Hunt Medal of the American Institute of Mining and Metallurgical Engineers, 1929
With K. Heindlhofer, the Henry Marion Howe Medal of the American Institute of Mining and Metallurgical Engineers, 1931
Institute Medal of the American Iron and Steel Institute, 1934
Benjamin Lamme Gold Medal of Ohio State University, 1937
Sauveur Achievement Award of the American Society for Metals, 1946
Distinguished Service Award of the American Society for Metals, 1948
Gold Medal of the American Society for Metals, 1949
John Price Wetherill Medal of the Franklin Institute, 1949

Grande Medaille of the Société Française de Métallurgie (first presentation to an American), 1952

Ambrose Monell Medal of Columbia University, 1958

Gold Medal of the Japan Institute of Metals (first presentation to an American), 1964

Meiji Centennial Award of the Order of the Sacred Treasure by the Government of Japan, 1968

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KEY TO ABBREVIATIONS

Chem. Metall. Eng. = Chemical and Metallurgical Engineering
J. Iron Steel Inst. = Journal of the Iron and Steel Institute, London
Met. Prog. = Metal Progress
Met. Handb. Am. Soc. Met. = Metals Handbook, American Society for Metals
Rev. Metall. = Revue de Metallurgie (Paris)
Trans. Am. Inst. Min. Metall. Eng. = Transactions of the American Institute of Mining and Metallurgical Engineers
Trans. Am. Soc. Met. = Transactions of the American Society for Metals (Before 1934, Trans. Am. Soc. Steel Treat.)
Trans. Am. Soc. Steel Treat. = Transactions of the American Society for Steel Treating (After 1934, Trans. Am. Soc. Met.)
Yearb. Am. Iron Steel Inst. = Yearbook of the American Iron and Steel Institute

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1925

The persistence of austenite at elevated temperatures. Trans. Am. Soc. Steel Treat., 8:14–22.

1926

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