NATIONAL ACADEMY OF SCIENCES

WILLIAM WEBSTER HANSEN

1909—1949

A Biographical Memoir by

FELIX BLOCH

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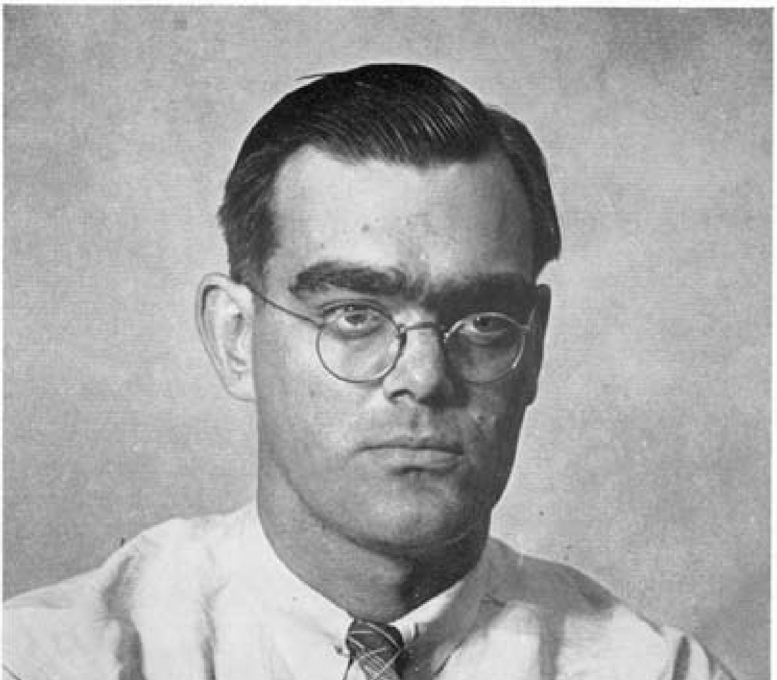

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A few weeks after his election to a membership in the National Academy of Sciences, William Webster Hansen died, on May 23, 1949, just before his fortieth birthday. A life wholly devoted to the pursuit of science had come to its premature end at the height of brilliant achievements.

Hansen was born in Fresno, California, on May 27, 1909. His paternal grandfather came from Denmark to America after fighting in the war in which Germany took Schleswig-Holstein from his country. His father had to go to work at the age of 12 and augmented his education by attending night schools, his interests tending towards mathematics and mechanics. He went into the hardware business in 1895.

As the first-born of two surviving sons, Hansen very early showed signs pointing in the direction in which his life's work was to develop. At the age of three he preferred to play with dry cells and various electrical toys, some of which he made himself; encouraged by his mother, it was the delight of his early boyhood to fill an ever-increasing part of the house with parts of electrical equipment and to test their functions. Soon his mathematical talents became apparent. The solution of arithmetical problems posed by his father was one of his favorite games; once having discovered it as a source of deep satisfaction, mathematics became an absorbing passion of his young mind.

By the time he entered high school he had acquired by himself a sufficient scientific knowledge to allow his graduation after two years, at the age of fourteen. Having decided to become an electrical engineer, but being too young to enter a university, he spent another year at the Fresno Technical High School before starting his college training.

Attracted by its famous school of electrical engineering, he entered Stanford University at the age of sixteen. It was to become the main scene of his life's activity with ever stronger bonds, personal as well as professional, attaching him to the institution. The atmosphere of informality, combined with high scholastic standards, which he found here, was eminently suited to his temperament, and it is difficult to imagine a more ideal place for the further development of his particular genius than the one which he found at the very start of his higher education. With the exception of one subsequent year at the Fresno State College, all of his training was completed at Stanford. Here also he later accomplished the major part of his scientific work.

It is characteristic of our age of technology that Hansen, like many other physicists of his generation, received his first stimulus from the practical side of science and that he felt himself at first destined to become an engineer. While most others found this stage merely transitory and soon lost almost all interest in its applications, the applied aspect of science was always of vital importance in Hansen's life and strongly determined his course of action. At the same time, however, he was profoundly attracted towards problems of a more basic character than those offered to the engineering student. Shortly after his return to Stanford in 1928 he had the opportunity to work in the department of physics as a laboratory assistant; it was this first contact which decided him to devote his further work to physics and to leave the school of engineering.

The research in which he became immediately interested was an extensive study of the mechanism of x-ray excitation, carried out under the guidance of D. L. Webster; the fact that his participation was not long restricted to mere assistance but advanced to active collaboration is evidenced by the first appearance of his name in a paper published in the same year with Webster and two other collaborators, Clark and Yeatman.

Starting in 1929, Hansen did his graduate work at Stanford University during the subsequent three years; after the first year, his training had reached a level which allowed him to hold an instructorship at the department of physics for the remainder of this period. At the same time he actively continued research on x-ray excitation. With quantum mechanics in its initial stage, there existed no reliable theory to predict the absolute primary yield of excitation and its dependence upon the energy of the exciting cathode rays and careful measurements were necessary to gain an insight into the underlying mechanism. The problem was complicated due to inevitable secondary processes, such as fluorescence and cathode-ray diffusion, which became particularly pronounced with thick targets and required a separate study. It took several more years before the problem could be satisfactorily solved and qualitatively understood and Hansen contributed substantially to the eventual attainment of this goal, deploying both his mathematical skill and his sound judgment in the construction of apparatus. During this period he had the good fortune to receive expert aid and encouragement from D. L. Webster, P. A. Ross and P. H. Kirkpatrick, who were staff members working in the same laboratory. His work in the field of x-rays, as well as his graduate work, came to its conclusion with his thesis on "Probabilities of K-electron ionization of silver by cathode rays" published in 1933 with Webster and Duveneck as co-authors.

After obtaining his Ph.D. in 1933, Hansen received a National Research Fellowship which enabled him to continue his studies for 1½ years, most of this time being spent at the Massachusetts Institute of Technology and some of it at the University of Michigan. It is evident that he started his fellowship in a stage of transition, approaching complete scientific maturity and trying to find a field to which his talents would be particularly suited. Still under the influence of his previous work with x-rays he felt attracted towards more general problems of electromagnetic radiation; in his application for the fellowship he planned to work on complex spectra and on a relation between the intensities of line and continuous x-radiation.

Except for a few attempts in this direction, the specific program was, however, not followed. While at M.I.T., he became greatly interested in boundary value problems, stimulated particularly by P. M. Morse and his work in this field. In close relation to this new interest, the opening chords of the theme which he was to follow with the greatest success in later years are found in a memo entitled "Emission and Absorption of Radiation," and written at M.I.T. in 1933; although it deals manifestly with the radiation of atoms, no new results are claimed beyond those obtained earlier by Dirac. However, following a suggestion by E. U. Condon, the problem is treated in spherical coordinates instead of using the customary plane waves of radiation, with the advantage that this procedure leads to a natural separation between the various types of radiation, such as electric dipole, electric quadrupole, and magnetic dipole radiation. It is this very consideration of vector functions in more general coordinates which led Hansen later to the rhumbatron, his first and significant achievement in the field of microwaves.

Enriched by fresh stimuli and by numerous friendships established among his eastern colleagues, Hansen returned to Stanford in the autumn of 1934 as an Assistant Professor in the department of physics. He found here a somewhat changed attitude, reflecting the profound changes which physics had undergone in the previous years and meeting his own desire for new types of activity. While there were still many challenging problems to be solved in the investigation of x-rays and while these investigations were actively continued, particularly by Ross and Kirkpatrick, they had outgrown the stage of pioneering. Quantum mechanics had been firmly established and there was little doubt that it held the key for the proper interpretation of atomic phenomena. This, however, was not the case with regard to processes concerning the nucleus. Nuclear physics had just received a powerful impulse from Chadwick's discovery of the neutron and the successful experiments of Cockcroft and Walton in producing nuclear transmutations by artificially accelerated particles.

Plans were maturing at Stanford, as in many other places, to undertake research on nuclei by bombardment with particles accelerated to energies of the order of a million volts, and

Hansen, soon after his return, was deeply involved in these plans. In view of the experience with x-rays already existent in the department, it seemed natural to accelerate electrons, rather than protons and other heavy particles used in other laboratories, and particularly, to work with the artificial gamma rays thus produced, in close analogy to x-rays. It would lead too far to discuss the various stages reached and abandoned in the discussions of this program, with their occasionally rather ambitious scope. Nuclear and specifically neutron research was actually initiated shortly afterward, avoiding any major instrumental developments; the existing voltage of 200 kv was first used to obtain a weak neutron source through the d-d reaction, and a few years later a small cyclotron was constructed in close imitation of a prototype functioning at the University of California in Berkeley. While Hansen was always interested in the work and the results gradually developing from these modest beginnings, he was far more fascinated by the instrumental problems and the long-range possibilities which their solution promised to offer. Knowing his strength, he chose at that time the path which led him to become the applied physicist "par excellence." To the end of his life, however, pure and actually rather abstract research was held by him in almost exaggerated admiration; with typical modesty and humor he sometimes referred to his "platonic love for pure research."

In considering various schemes to accelerate electrons to high energy, Hansen preferred methods based upon the characteristics of rapidly varying fields to those using static or quasistatic voltages. With the latter he justly foresaw grave problems of insulation, and he would symbolize his preference by stating that it would be better to work with the vector potential than with the scalar potential. The idea which he decided to develop was suggested by experiments carried out by D. H. Sloane in Berkeley, where the voltage necessary for the acceleration of electrons was derived from a resonating coil. Adhering to the principle of electromagnetic resonance, it was evident that with a given input power, the stronger accelerating fields would build up, the smaller the losses.

The problem of finding a resonating arrangement with low losses was solved by Hansen in an ingeniously simple fashion. Departing from the conventional circuit elements, he realized that the normal modes of vibration of the electromagnetic field in the interior of a closed conducting surface represent the ideal resonators. His above-mentioned earlier treatment of the radiation field in spherical coordinates allowed him immediately to discuss this idea quantitatively for the case of a sphere with the result that the losses in this case could indeed be expected to be considerably smaller than those of a coil and condenser arrangement, oscillating at the same frequency. With Webster taking a lively interest in this new possibility for electron acceleration, it was soon found, however, that the spherical shape would not be suitable for this purpose. On the other hand, it was clear that this particular shape of the "hohlraum" was not essential; one remembers that the normal modes of vibration in a cavity with reflecting walls were familiar to the physicist from the classical treatment of the black-body radiation by Rayleigh and Jeans who assumed it, for convenience's sake, to be rectangular. As a simple shape for which the acceleration of electrons should be possible, Hansen chose that of a flat cylinder. In the normal mode of lowest frequency the electric field is here parallel to the cylinder axis so that an electron with sufficient initial velocity, entering at a proper phase, would gain energy in traveling along this axis. Hansen's main efforts during the year 1936 and the early part of 1937 went into the construction of an electron accelerator, based upon the principles outlined above. While it served to test the theoretically predicted electrical characteristics, it never came to be used for the purpose for which it was designed.

In 1937 the brothers, Russell H. and Sigurd F. Varian, came to Stanford, deeply aware of the inevitably impending war and the urgent need for developing air defenses. As an old friend from his earlier years at Stanford, Russell Varian re-established close contact with Hansen, having realized that the resonating cavities could be used in conjunction with a new source for short electromagnetic waves. It is sufficient to mention here the enormous later development of radar in order to emphasize the importance of this realization and the stimulus which it derived from forebodings of the coming war.

Hansen's original relatively large cavity was excited by vacuum tubes; it required a new principle to excite the considerably smaller cavities necessary as resonators for waves of 10-cm length. This was found by R. H. Varian in an ingenious arrangement, called the "klystron" where a first resonant cavity (the "buncher") produces modulation of velocity in an axial electron beam which excites a second cavity (the "catcher") reacting by feedback upon the first one. While it found its immediate use in the klystron, Hansen's resonant cavity, the "rhumbatron," rates as an independent invention of very great importance in the field of microwaves.

Hansen was promoted to Associate Professor of Physics in 1937. He devoted the following years until the end of 1940 principally to the development of the klystron in close collaboration with the brothers Varian as well as with D. L. Webster, J. R. Woodyard, and E. L. Ginzton. It was a period of intensive activity whose pace was set by the ever-darkening political horizon, and which required the simultaneous approach of widely different problems. A considerable part of Hansen's efforts was devoted to developing techniques of microwave measurements; besides, different forms of klystrons were developed and tested, and began to be used in a new system, later known as the Doppler radar, where the velocity of the object was observed by the frequency shift of the reflected radiation. As a sideline to these activities, Hansen found the time to publish several papers which exhibit his masterly skill in the mathematical treatment of radiation problems; in one of them (with J. R. Woodyard) a new principle of antenna design was formulated by showing that the total gain of an array is increased if the elements do not radiate exactly in phase in the direction of maximum transmission.

During this period, filled with intensive and successful work, Hansen's life was also enriched from the personal side; in October 1938 he married Betsy Ross, the younger daughter of the late Professor P. A. Ross, thus establishing another firm bond with Stanford in general and with its department of physics in particular.

Hansen's work at Stanford came to a temporary end when, in the beginning of 1941, he and practically the whole group of his collaborators transferred their activities to the Research Laboratories of the Sperry Gyroscope Company in Garden City, Long Island. With patent interests in the klystron, this company had already supported the research at Stanford which was now to continue on a larger scale on its own sites. The development of the klystron was approaching the production stage, and with the war in Europe in its second year, the political developments clearly called for acceleration and expansion.

By the time of Pearl Harbor, Hansen was already a veteran of war research which he continued, with multiplied intensity and under various aspects, until the end of the war. With the concentration of microwave and radar research on the east coast and particularly in Cambridge, Hansen was soon a prominent figure among the many physicists and engineers who became engaged in the work and were mostly newcomers in the field. Equally versed in the methods and terminology of both, he was one of the first and most important links in the close connection between engineering and physics, which was responsible for the rapid development of radar. With his previous experience and clear insight in the principles of microwave techniques he was asked to deliver a series of lectures at M.I.T. and for a considerable period of time he willingly submitted to the strain of commuting between Garden City and Cambridge. In these lectures he touched upon almost all of the central problems, restricting himself to those topics which he knew to be of basic significance. Many of the leading scientists, engaged or about to engage in radar research, were among the audience and gratefully acknowledge the important stimulus received from his masterly exposition.

The development of the klystron and its use for microwave techniques was continued in the Sperry laboratories, largely under the guidance of the men who formed the originating group at Stanford. Because of its high frequency stability and the fact that it could serve as an amplifier for microwave power, the significance of the klystron became ever more widely established. One of the important practical applications was its use as local oscillator in radar systems, and it has also become an invaluable tool for later microwave research.

While maintaining his active interest in these developments, Hansen's research also contributed to the nation's war effort in quite different directions. Much of his interest was centering on the possibilities of a Doppler radar system; in addition he worked on the problems of blind landing by microwaves and of electronic anti-aircraft directors. On one occasion the Sperry Gyroscope Company was asked to undertake work on super-chargers, and without being able to go further, the directors resorted to submitting papers on the subject to Hansen's examination; it is typical of his versatility and quick grasp of essentials that Hansen immediately took up the problem and by going back to the basic principles was able, by his suggestions, to contribute substantially to the improvement of super-chargers. Another important phase of his war research took place in the summer of 1943 when he worked for three months as consultant at the University of California on some of the problems which had arisen in the great project of atomic energy, carried out there under the Manhattan District.

Hansen unsparingly exerted himself under the great mental strain of all these activities; the truly heroic devotion to his tasks is highlighted by the fact that during these hectic war years he suffered several severe attacks of the illness of his lungs which, too soon, was to become fatal; even in the intervals of relative well being, it seriously reduced his physical strength. Due to the fact that he was of powerful build and that he never complained in his merciless self-discipline, it was hard, even for his close associates, to realize that he was working to the limit of his endurance.

Towards the end of the war, Hansen turned his interests to problems of less immediate urgency. He ingeniously observed the mathematical analogy between the general problem of amplifiers and electrostatics through their common use of complex functions; the method allows the use of the electrolytic tank in the design of amplifiers and has become of practical value. Early in 1945, however, another interest arose in his mind which continued to absorb him almost completely for the remaining four years of his life.

It would seem that Hansen's work had carried him far from the ideas which he pursued ten years earlier, for accelerating electrons by means of microwave power, but he proved the truth of the French saying that one always returns to one's first loves. With an amount of power available from the multicavity magnetron, which would have seemed beyond the realm of possibilities before the war, the problem reappeared under an entirely different aspect. Hansen realized that high energies should be gained by electrons traveling through a wave guide which was driven by great power and which was designed to maintain the proper phase of the electric field along the path of the electron.

With many essential features of this linear electron accelerator already clear in his mind, Hansen returned in August 1945 to Stanford; during his leave of absence he had been promoted to a full professorship in 1942. Upon his return the formal steps towards the foundation of the Stanford Microwave Laboratory were taken with the aim of giving Hansen, as director, full facilities for the realization of his plans.

In the first few quiet months after the end of the war and before turning his energy completely to the development of the accelerator, Hansen worked on another program which had been brought to Stanford at that time. The author had become acquainted with some radio techniques through his war work, and planned to investigate the magnetic moment of atomic nuclei by a new method in which the moments were to induce radio signals capable of detection in a suitable receiving system. Asked for his expert help and advice, Hansen immediately became interested and his skill and sound judgment, together with his many valuable suggestions, largely contributed to the fact that the method of "nuclear induction" was successfully demonstrated in the first days of 1946. At the same time Purcell and his collaborators at Harvard had independently discovered the same phenomenon and later improvements of the method by both groups have since made it an important new tool for the study of nuclear moments; but even in the elaborate present modifications there are still features which were originated by Hansen.

By adding to its staff and attracting visiting scientists, the Microwave Laboratory soon after its foundation started to grow rapidly and to populate densely the department of physics. Under Hansen's guidance the foremost aim became the actual construction of a linear electron accelerator and many problems, both of principle and of detail, had to be solved in its pursuit. The first pilot model was built primarily to test the type of disk-loaded wave guide which seemed most suitable for the purpose. It consists of a long cylindrical tube in which metallic disks with circular apertures are inserted. Each segment between two disks represents in principle a cavity resonator similar to the original rhumbatron, and the apertures provide a coupling between two successive segments. They are designed in such a way that the accelerating electric field acts always with the proper phase upon an electron traveling along the axis of the guide with its speed gradually approaching that of light. Starting with the mathematical theory of this structure and carrying it to high perfection, Hansen was concerned at the same time with the practical problem of finding simple methods for the production of a large number of segments with the necessary small tolerances. The other essential feature of the accelerator, a source of high microwave power, was incorporated in the first model in the form of a conventional magnetron. The first section was tested in the spring of 1947 and it proved beyond doubt the soundness of the underlying principles. In his report to the Office of Naval Research, under whose generous support the work was carried out, Hansen laconically announced: "We have accelerated electrons."

Through improvements during the subsequent years both the output current and the final electron energies were substantially augmented; delivering a peak current of several hundred microamperes at an energy up to 6 million volts, the first linear electron accelerator, 14 feet in length, is now operating in the department of physics and it is beginning to be used as a valuable research tool.

The final goal which Hansen set himself went, however, far beyond this first step. With the successes of the circular accelerating devices, the betatron and the synchrotron, in yielding electron energies of several hundred million volts, a linear accelerator was planned whose performance should equal and surpass them. This plan was not conceived in a mere ambition to reach the record of high energies; the fact that it avoids the high radiative losses of circular motion and that the electron beam shoots out at its end is a definite and characteristic advantage of the linear arrangement. To attain the desired energies of the order of a billion volts, an extremely large amount of pulsed synchronized microwave power had to be available and the expert collaborators of Hansen developed the bold scheme of developing the klystron to a point far beyond its previous power output, so that it could serve as the driving source. Encouraged by Hansen's faith in the seemingly extravagant proposal, the work was vigorously pursued and the operation of the first high-power klystron, shortly before his death, removed the last major doubt about the ultimate success of the large accelerator. This fervent wish of Hansen is now nearing its fulfillment in the new separate building of the Microwave Laboratory where the group of able men whom he had drawn to Stanford carries on the work, inspired by his genius.

It is befitting that the foregoing description of his scientific work should constitute the major portion of this biographical memoir, considering that Hansen subordinated all other aspects of his life to his devotion to science. Yet, this devotion became never more manifest than during the personal tragedy of his last years. The symptoms of an extensive bronchiectasis and fibrosis of the lung, dating back to his teens and causing periods of severe illness during the war, became ever more menacing. Moreover, a deep shadow was cast over his life and that of his wife when their long-desired and only child died six weeks after his birth in the fall of 1947. Profoundly grieved, his physical abilities more and more reduced through fatigue and shortness of breath and in the full knowledge of his impending death, Hansen did not relax in the passionate devotion to his work to the last day. His condition was seriously aggravated through a trip to England in the fall of 1948, to which he forced himself in order to attend an international conference on accelerators. Barely able to move, he still visited the Microwave Laboratory in its new building during the spring of 1949, and at his bedside he gladly received visitors to discuss with them scientific matters, exhibiting the full clarity of his mind. Although it did not come without warning, his death came as a deep shock; his wife followed him a few months later.

With all its highly developed intellectual traits, Hansen's personality will be remembered by his friends as that of a warm human being. In unbounded generosity he gave advice and material aid to his fellow man whenever they were needed, making the acceptance of his gifts easy through his understanding and his natural tact. Rather shy and embarrassed in great social gatherings, he nevertheless was fond of good companionship and always ready for a joke. As an ardent individualist, there were few issues closer to his heart than those of human liberty; his feelings were particularly aroused over the attempts, witnessed in our time, to restrict the freedom of science.

Hansen's scientific work is characterized by its high degree of originality but through the brittle medium of physics one can also discern a strong artistic inclination. Although he did not allow himself the luxury to cultivate it in a more general sense, this inclination was otherwise apparent in his sensitivity to music; it found its strongest expression in his approach to scientific problems where he sought and found not only truth but a deep esthetic satisfaction.

Among the external signs of recognition for his outstanding achievements, Hansen received the Morris N. Liebmann Prize of the Institute of Radio Engineers in January 1945 and the Presidential Certificate of Merit in March 1948. As the crowning honor of his career, he considered, however, his election to the National Academy in 1949, the announcement of which filled him with the last great joy of his short and rich life.

Acknowledgment

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KEY TO ABBREVIATIONS USED IN BIBLIOGRAPHY

Amer. Phys. Teacher = American Physics Teacher
J. Appl. Phys. = Journal of Applied Physics
Phys. = Physics
Phys. Rev. = Physical Review
Proc. I. R. E. = Proceedings, Institute of Radio Engineers
Proc. Nat. Acad. Sci. = Proceedings, National Academy of Sciences
Rev. Sci. Instr. = Review of Scientific Instruments
Terr. Mag. Atmos. Elec. = Terrestrial Magnetism and Atmospheric Electricity

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