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ALBERT WALLACE HULL

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A Biographical Memoir by

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THE DEATH OF Albert W. Hull on January 22, 1966, at the age of eighty-five ended the career of the world's most prolific inventor of electron tubes. Hull was one of the group of five people (the others being Whitney, Coolidge, Langmuir, and Dushman) whose lifelong contributions provided firm foundations for the growth and expansion of scientific research in the General Electric Company.

Hull's start in science was unusual. As an undergraduate at Yale he majored in Greek, and it was his acquaintanceship with this language that was to impart Greek roots to the names of early electron tube types. Thus Pliotron, Dynatron, Pliodynatron, Thyratron, and Magnetron are functionally correct adaptations of Greek roots to the terminology of the early electron tube art.

Some years ago Hull recalled how he, a farm boy, became first a Greek scholar and then a physicist. His remarks reflect the modesty and directness that were characteristic of him:

"I was brought up on a Connecticut farm. I remember on one occasion, when my father was ill, I milked twenty cows before breakfast. That was when I was twelve years old. However, that was an interesting experience rather than a hardship. I remember those years only as a happy and carefree life.

"I had no idea of going to college until a friend of mine went to Yale, and was able to pay his own expenses. That was a new idea, so I decided I would try it. I arrived in New Haven with a hundred dollars in my pocket, and enrolled in Yale College.

"A fortunate experience in high school led to the solution of the financial problem at Yale. During the next to last year, I had completed all but two of the subjects that were needed for entrance. So I had some extra time during the last year and did some extra reading in Greek. I think we read at sight nearly all of the *Odyssey*. Our teacher was a very unusual young man who was a graduate student at Yale, taking time off in order to earn some money. He was a real Greek scholar, and I caught by contagion his love for Greek, Greek poetry especially, and developed some facility in Greek.

"About four months after entering college, I came unprepared to a Greek class and being called on—as *always* happens—proceeded to try to read the assignment at sight. The professor didn't tell me to stop until I had read about a page beyond the end of our proper assignment. He then told me to sit down and said he would like to see me after class. I had visions of some discipline, but what he wanted to tell me was that he would like to have me do some tutoring in Greek.

"From that time on, my financial worries, if I ever had any, were ended. I tutored in Greek for the first two years, and in mathematics and physics and a little English during the last two. I majored in Greek, with a minor in social science, under William ("Billy") Sumner. Up to this time, I had not been interested in science or at least had not realized it. I took only one course in physics and one in chemistry during my whole college career.

"After graduation I taught French and German at the Albany Academy in Albany, New York, for one year. Dr. Warren, the headmaster, had come down to New Haven to get a teacher, and wanted someone who could manage the class in German. For the previous two years, he had had native German teachers and the students had forced them to resign before the end of the year. He picked me out, as someone who looked husky enough to manage the situation. I was twenty-five, having stayed out of school four years before entering college.

"In the Albany Academy I had no difficulty in managing the students, and I found that I could teach. But I certainly didn't want to teach anything in which I wasn't really an expert. I didn't wish to make modern languages my career, so I stopped for the first time in my life to think about what I was most interested in.

"I decided that, of all the things I had come in contact with in college, the subject I really liked best was physics—in spite of the fact that I had had only one course in it. I had had a very unusual teacher, Dr. Albert Kreider, and my course in physics stood out in my memory as something that I had liked and found very easy. I went back to Yale for graduate work in physics. It was the first correct decision I had ever made, and I have never regretted it.

"After finishing my postgraduate work, I taught for five years in the Worcester Polytechnic Institute. During those years I spent all the spare time I could snatch from sleep in research work. Dr. A. Wilmer Duff, the head of the department, was very generous in giving me encouragement and equipment. My wife often accompanied me to the laboratory in the evening, and sat and read while I made glassware apparatus. Generally we went home when the apparatus broke.

"I have always felt that I owed my introduction to the General Electric Company to my wife's intuition. After five years I was getting a bit discouraged about the future prospect of teaching. I couldn't see the way ahead. There was to be a meeting of the American Physical Society in New Haven, and my wife decided it was time for me to give another paper. I had been working for a long time on a photoelectric problem and had an immense amount of material, but my ideals were too high and I felt that I wasn't ready to present it. At her insistence, however, I did give the paper. At that meeting I met Langmuir and Coolidge of the General Electric Research Laboratory. They asked me to have lunch with them, and a couple of weeks later I received an invitation to talk at the colloquium of the General Electric Research Laboratory in Schenectady.

"The result of this introduction was an invitation to spend the summer of 1913 in the Research Laboratory at Schenectady. In the fall of that year, Dr. Willis R. Whitney, the director of the Laboratory, invited me to join the Laboratory staff. I was a little hesitant about accepting the offer, and told him that I didn't think I could do anything practical. His answer was wonderful: 'Don't worry about the practical part, that's my business. Just go ahead and do anything you want to.' He was as good as his word. His typical greeting, as he made his daily rounds of the Laboratory, was not 'Have you solved that problem?' but 'Are you having any fun?' Before the year was over I was so happy in this new work that there wasn't any question about the decision. This was the place where I wanted to be. It still is."

At the age of thirty-four, Hull had begun a research career in physics and electronics that was to continue for over half a century.

In 1914, during Hull's first year at the Research Laboratory, he invented the Dynatron, a vacuum tube having true negative resistance. While this tube never came into widespread use, it demonstrated the negative resistance concept, and his study of the dynatron action contributed to the development of other uses for secondary emission.

"I called this tube a *pliodynatron,*" Hull wrote of a later invention, "because it combined with the dynatron the grid-control principle of Langmuir's newly invented *pliotron.* With the pliodynatron, I was able to radio-telephone to Ballston Spa, a distance of about 16 miles, using a crystal detector at the other end as a receiver. This was quite good at that time, for radio-telephony was new."

Early in his career, Hull developed a new powder method of X-ray crystal analysis, the details of which were published in December 1917. After the end of World War I, it was learned that this technique had been discovered independently by Peter Debye and P. Scherrer and published in Germany a few months earlier. Since the publications took place almost simultaneously, the method has been known subsequently as the Debye-Scherrer-Hull technique. Hull told of his decision to begin this work as follows:

"My work in electronics was interrupted for several years by a lecture by Sir William Bragg. Sir William was in this country early in 1915, and we invited him to speak at our colloquium. He told us about his new work on the study of crystal structure by means of X-rays. At the close of the lecture, I asked him if he had been able to find the structure of iron. He had told us about some structures, sodium chloride and copper and a few other materials that he had successfully analyzed. His answer to my question was typical of him. He might have said, 'No, but we think we'll have it very soon.'

"Instead of that he answered very simply, 'No, we've tried, but we haven't succeeded.'

"Well, that was a challenge—such a challenge as a young man needs—and I decided that I'd like to try to find the crystal structure of iron, reasoning that it might throw some light on the fact that iron is magnetic material. I made this decision in spite of the fact that I was almost totally unfamiliar with either X-rays or crystallography."

The technique Hull developed is probably the most powerful tool that has ever been discovered for crystal analysis, and it has had widespread use ever since. Hull determined the crystal structure of a number of metals and was awarded the Potts Medal from the Franklin Institute in 1923 for his crystal analysis work. To obtain a steady source of high D-C voltage for his X-ray work, he placed two capacitors across the high voltage output of a Kenotron rectifier with an inductive choke between them. This filter circuit was patented and later used in practically all radio receiver power supplied throughout the United States.

During World War I, Hull originated the use of Rochelle salt crystals to pick up noise from submarines. Rochelle salt had not previously been used as a piezoelectric element, and he developed a method of growing and cutting these crystals to obtain maximum sensitivity.

Hull is perhaps best known for his work in the field of electronic phenomena and devices. His contributions to basic electron tube types probably exceed those of any other scientist.

In 1920, Hull first conceived the idea of the smooth-bore Magnetron—a tube comprising a coaxial cylindrical anode and filament operated in an axial magnetic field. With F. R. Elder, he developed high-power magnetron oscillators and multistage, high-gain magnetron amplifiers. The multianode magnetron concept was developed by others, primarily by the British, for generating microwave power for radar. As a result of this, Hull's World War II work consisted largely in directing the development of these magnetrons for radar and radar countermeasures. In 1929, the Axitron, a magnetron controlled by the magnetic field resulting from current through the filament, was also invented by Hull.

"At the end of World War I," Hull wrote, "small electronic tubes were in considerable production, although still there were no high-power tubes, such as were needed for broadcasting. However, the chief obstacle to broadcasting was not the tubes but the patent situation. The radio patents were about equally divided between three different companies and there seemed to be no way in which any one of the three could proceed with a development. I conceived the idea of breaking this stalemate by the development of a magnetically controlled tube which would be free from these patents.

"Essentially the *magnetron* is a simple diode in which the electron current from a cylindrical cathode or filament to a coaxial cylindrical anode is controlled by a magnetic field parallel to the filament. Electrons leaving the wire when there is no magnetic field travel straight across to the cylinder in radial paths, but under the influence of the magnetic field the paths are bent. The amount of bending increases with the strength of the magnetic field until at a certain critical field they are bent all the way around and fail to strike the anode at all. The current then falls abruptly to zero. The magnetic field, therefore, affords the means of controlling the current from the cathode filament to the anode.

"After the fundamental studies of the magnetron were completed, I spent considerable time developing it as an audio-amplifier and as a generator of radio-frequency waves. While these efforts were successful, they did not prove to be the solution of the patent impasse. That problem was solved in a much better way by the formation of the Radio Corporation, and the magnetron wasn't necessary.

"It was in 1940 that Randall in England developed the first multi-cavity, pulsed magnetron, which was destined to play such an important part in radar, the uncanny 'seeing eye' that made it possible for the RAF to save England from the furious onslaught of Hitler's bombs and rockets, and which profoundly influenced the final outcome of the war. The Germans used conventional tubes in their radio-ranging or radar equipment, and hence were limited to relatively long wave lengths. Almost at the start, the British conceived the idea of using magnetrons, thereby obtaining much shorter waves and greater power. The very first model of Randall's magnetron exceeded the most optimistic expectations. It was immediately flown to New York and duplicated at the Bell Telephone Laboratories. Then followed a race against time and one of the finest examples in history of cooperative effort between countries, England and the United States, and between widely separated scientific groups in each country, working in a common cause. The American effort was coordinated under NDRC with the cooperation of several industrial laboratories, notably the Bell Telephone Laboratories and the Raytheon Company.

"The Radiation Laboratory, which was operated by Division 14 of NDRC at M.I.T., was devoted almost exclusively to the development of microwave radar, and undertook an extensive magnetron program. There the development of the ten-centimeter pulsed magnetron was carried to the astounding output of two million watts peak power."

The problem of noise in superheterodyne receivers prompted Hull to measure the shot-effect in temperature-limited diodes and space-charge limited triodes. This work was done in 1923 in collaboration with N. H. Williams, on leave from the University of Michigan, and laid the basis for the understanding and cure of the heterodyne noise problem. His invention of the screen-grid tube was a by-product of this work on the shot-effect. The necessity for obtaining an amplification of 100,000 at a megacycle prompted him to make a special tube in which there was no feedback; namely, a tube in which the grid and plate were completely screened from each other.

In studying the disintegrating effects on thermionic cathodes by gas ion bombardment Hull discovered in 1927 that the ions did no harm if their velocities were kept below a critical value, which he called the "disintegration voltage." For mercury, it is 22 ev. This discovery led directly to his invention of the Phanotron and the Thyratron, which he considered to be his most important inventions. In connection with these devices, he later developed several efficient cathodes with a very long life expectancy that were also applicable to gas discharge lamps. The Thyratron opened up the whole field of industrial electronics and power control.

At one period in Hull's work, he became immersed in the problems of high-power transmission lines. One of the great General Electric engineers in this field was C. W. Stone, and through a personal acquaintanceship he interested Hull in some of the basic problems of future high-power transmission lines. Hull and Stone spent long hours plotting and replotting various strategies in this field. The stability problems of alternating current transmission lines of great length were well known, and the alternative of D-C transmission links was under discussion.

Somewhat prior to this time, D. C. Prince and associates, who were then in the Company's General Engineering Laboratory, had demonstrated that it was possible to make a D-C to A-C inverter, employing high-power, high-vacuum triode tubes, of the type then used in radio broadcasting. This inverter, plus the mercury arc rectifier, provided the basic terminal components required for a D-C transmission line. However, the rectifier had fundamental problems of arc-back, and the efficiency of the high-power vacuum tubes, even at very high voltage, was not satisfactory. Hull developed the Thyratron inverter, employing circuitry similar to that used by Prince, and Hull and Stone then set up a D-C transmission line between Schenectady and Mechanicville, New York (about fifteen miles), which operated for a long period of years on a demonstration basis. This development was somewhat ahead of its time, and did not attain useful application during that period.

Hull also invented the vacuum lightning arrester. While this device worked initially, it became gassy on repeated operation. It was not until the recent development of gas-free electrode materials for vacuum switches that this difficulty was avoided. His pioneering work on this device, however, laid the foundation for the triggered vacuum gap.

Large glass-to-metal seals were in a very rudimentary state in the early 1930s, and presented a serious handicap in making large, high-power electron tubes. It was at this point that Hull's industrial research work took a wide detour into metallurgy and glass. He was prompted, with the help of E. E. Burger, to make an intensive investigation of the general problem of sealing glass to metal. Prior to his work, the only available solutions to this problem were the Dumet seal, suitable for low currents, and the Housekeeper seal. The latter could be used for high-power tubes, with, however, serious limitations owing to fragility. Hull first identified the alloy and glass requirements for glass-to-metal seals, and studied their expansion coefficients over the range of temperatures employed in making seals. This work resulted in a number of matched combinations of glass and metal capable of producing strain-free seals. The most notable of these was Fernico, an alloy that would permit a true match of expansion coefficients between metal and glass. In collaboration with Louis Navias, Hull developed sealing glasses for 42 percent nickel-iron and pure iron. This led to low-cost, cast-glass bushings with sealed metal inserts, the development of metal receiving tubes, and later the lighthouse tube.

During Hull's early work on mercury-arc tubes, he had visions of replacing the mercury with cesium vapor, an idea conceived by J. M. G. Mackay and E. E. Charlton. The low ionization potential of cesium would ensure a low arc drop, and by continuous condensation on the cathode surface the cesium would provide an efficient electron emitter with infinite life.

His early attempts to make a practical tube failed because all known sealing glasses were attacked by the chemically active cesium. Some twenty-five years later, with the availability of ceramic-metal seals, he succeeded in making a practical cesium-vapor rectifier, but this development came too late and could not compete with the semiconductor rectifier. While many ardent electron tube men were resentful of the inroads made in their field by semiconductor devices, Hull welcomed them and encouraged his young colleagues to pursue the new field, for he felt that it offered them the same opportunity that he had experienced in the early days of the electron tube.

Hull's industrial scientific work with General Electric has had tremendous scientific and practical consequences. Together with Dr. Coolidge's work on tungsten, and Dr. Langmuir's work on high vacuum electronic phenomena, his developments provided the foundation for the electronics business of General Electric.

It is difficult to summarize a great career like Albert Hull's, but in all of his many accomplishments, two outstanding characteristics seem to have provided the essence of his success. First and foremost was his great courage. In a group of people around a conference table, discussing research proposals and projects, one could depend upon him to point out the reasons why the idea had merit, might work, might even be better than anticipated, and by all means should be pushed forward. He was sometimes wrong, but his batting average was exceptionally high, and his courage and optimism opened doors that were closed to many people.

The second outstanding feature of Albert Hull's career was his willingness to enter a brand new field. He started in Greek, then entered the field of physics, first in X-ray diffraction, then later became fascinated by Langmuir's high vacuum electronics, which led to power electron devices, because of which he took a broader detour into metallurgy and glass science. At many points in his career he might have relaxed to become the continuing authority in his field. Instead, he was constantly challenged by new problems, and he had the courage to become a neophyte in a new field where, after a few years, the same native research abilities again brought him to the top as an expert and an authority.

"In my experience," Hull once remarked, "the initiation of projects or inventions comes from two different directions. One is a chance observation, such as that which led to the gas-filled tube. This is the most prolific source of invention. It should be noted that such observations in general are fruitful of results only when one is sufficiently familiar with the field and its problems to be aware of the significance of the observation.

"The other type of stimulus which may lead to invention is need of some kind, most often a need that is only incidental to the main problem under investigation. For example, the screen grid tube was the result of such a need for an amplifier free from feedback in order to measure the shot-effect. In general, when the need occurs in this form, the solution appears quite naturally."

Although Albert W. Hull officially retired in 1949, he continued as a consultant and could be found in the Laboratory almost every day—usually with the younger men—observing, advising, and inspiring. His fifty-seven-year span of technical publications is an accomplishment seldom witnessed.

In recognition of his work contained in 74 papers and 94 patents, Hull received honorary degrees from four colleges. He was president of the American Physical Society in 1942 and was a member of the National Academy of Sciences (to which he was elected in 1929) and an honorary member of the Brazilian Academy of Sciences. He received the Morris Liebmann prize from the Institute of Radio Engineers in 1930 for his research on electron tubes and the Institute's Medal of Honor in 1958. Less than two months before his death he was awarded the U.S. Army's Decoration for Distinguished Civilian Service for his contributions as a member of the Scientific Advisory Committee at the Ballistics Research Laboratories from 1940 to 1964.

While Hull was mostly widely known for his individual research contributions, as assistant director of the Research Laboratory from 1928 until his retirement in 1949 he did much to maintain the spirit of enthusiasm and friendly cooperation implanted by the Laboratory founder, Willis R. Whitney. Hull was not one to spend time on writing books, calling meetings, or participating in organized classroom study. He much preferred to forge ahead on research problems and encouraged others to do the same. He was not embarrassed by mistakes and thought there was much to be learned from experience, provided the same mistake did not reoccur. He always insisted that real research needed very little direction and that one of the greatest assets of the Laboratory was the freedom of individuals to do research without interference or guidance. It is of interest that those who enjoyed this freedom most were the ones who made the most valuable contributions to the electrical industry. Albert Hull's inspiring leadership and encouragement of the men who worked under him have resulted in an unusually high number of rugged individualists who have gone on to make prominent names for themselves.

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KEY TO ABBREVIATIONS

Am. J. Phys. = American Journal of Physics
Elec. Eng. = Electrical Engineering
Gen. Elec. Rev. = General Electric Review
J. Am. Inst. Elec. Engrs. = Journal of the American Institute of Electrical Engineers
J. Appl. Phys. = Journal of Applied Physics
Phys. Rev. = Physical Review
Proc. Inst. Radio Engrs. = Proceedings of the Institute of Radio Engineers
Proc. Nat. Acad. Sci. = Proceedings of the National Academy of Sciences
Rev. Sci. Instr. = Review of Scientific Instruments
Trans. Am. Inst. Elec. Engrs. = Transactions of the American Institute of Electrical Engineers

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