HEINRICH RUDOLPH HERTZ

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Hertz, the Discoverer of Electric Waves *

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FIFTY years have passed since those memorable researches of the young German physicist, Heinrich Rudolph Hertz, which have come to be regarded as the starting point of radio. For it was he who first detected, and measured, electromagnetic waves in space—waves which had been predicted, it is true, but which had never before been observed. It is not to be claimed, of course, that the radio art would have failed to be born were it not for his genius, for we know that almost simultaneously the experiments of Lodge in England were pointing with certainty to the same discoveries, and the speculations of others were revolving around the possibility of generating electric waves. Yet it was the remarkably clear vision of Hertz, combined with his consummate persistence and skill, that won for him the prize and justly enshrined his name among the immortal men of science.

So, upon this golden anniversary of the opening of a new epoch in the realm of communication, it is fitting that we pause to do honor to his memory and to consider anew the significance of his great accomplishment.

The formal facts of Hertz's biography can be set down very quickly. He was born at Hamburg on February 22, 1857, his father an attorney, belonging to a family of successful merchants, his mother the daughter of a doctor of medicine, and the descendant of a long line of Lutheran ministers—all of cultural tastes and attainments on both sides. At the age of twenty he went off to school at Munich, after a rather unorthodox preparatory training, supposedly to pursue an engineering career, but he was torn between this resolve and his natural inclination for the study of pure science. Soon after reaching Munich he felt compelled to put the matter before his parents, to whom he frequently and confidingly wrote concerning his plans and his work. In a long letter written in November, 1877, he said, "I really feel ashamed to say it, but I must: now at the last moment I want to change all my

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plans and return to the study of natural science. I feel that the time has come for me to decide either to devote myself to this entirely or else to say good-bye to it; for if I give up too much time to science in the future it will end in neglecting my professional studies and becoming a second-rate engineer. Only recently, in arranging my plan of studies, have I clearly seen this—so clearly that I can no longer feel any doubt about it. . . ." And then follows a lofty and appealing presentation of the reasons for his choice. Concluding, he wrote: "And so I ask you, dear father, for your decision rather than for your advice; for it isn't advice that I need, and there is scarcely time for it now. If you will allow me to study natural science I shall take it as a great kindness on your part, and whatever diligence and love can do in the matter, that they shall do. I believe this will be your decision, for you have never put a stone in my path, and I think you have often looked with pleasure on my scientific studies . . ."

Matters were arranged as he wished and he joyfully pursued his studies at the University and at the Technical Institute, working hard on mathematics and mechanics, and spending much time in the physical laboratory. In October, 1878, he went to Berlin and became there a student under the mighty giants, von Helmholtz and Kirchhoff; writing to his parents in November, "I am now thoroughly happy, and could not wish things better." In 1880 he gained his doctorate, and in October of that year was appointed assistant to Helmholtz, which delightful and stimulating association continued until Easter of 1883. He then went to the University of Kiel to become lecturer in theoretical physics, and here he first began to reflect seriously upon Maxwell's electromagnetic theory of light.

He was soon promoted again, and at Easter, 1885, he became professor of experimental physics at the Technical High School in Karlsruhe. Here, in 1886, at the age of twenty-nine, he married Elizabeth Doll, daughter of the professor of geodesy in the same institution, and their home became a congenial meeting place for their many cultured associates. It was at Karlsruhe also that he began his researches on electric waves. Before they were finished he was called in 1889 to succeed the celebrated Clausius at the University of Bonn, thus at the age of thirty-two having arrived at a position in the academic world not ordinarily to be achieved until much later in life.

He soon thereafter relinquished to others the further exploration of the great new territory of electric waves he had opened up and returned to some investigations on the discharge of electricity in rarefied gases, a subject which had interested him while at Berlin. He then devoted his attention entirely to what proved to be his last work, a treatise on mechanics. In the summer of 1892 he suffered a severe illness which eventually led to chronic blood poisoning, of which he died, after indescribable suffering, on January 1, 1894. He would have been just thirty-seven years old the following month.

Although the fame of Hertz rests primarily on his electric wave researches, these constitute by no means the whole of his work. His collected papers, edited by the German physicist, Dr. Philipp Lenard, and admirably translated into English by Professor D. E. Jones and associates, comprise three volumes. The first consists mainly of his miscellaneous earlier papers, some twenty-odd titles altogether. One of these, published in 1884, "On the Relations between Maxwell's Fundamental Electromagnetic Equations and the Fundamental Equations of the Opposing Electromagnetics," marked an important step in the development of Hertz's ideas, and has been called his greatest contribution to theoretical physics. In it he opposed the old orthodox theories of electric phenomena based on action at a distance, which were supported by most of the Continental physicists, and definitely aligned himself with the followers of Maxwell. This volume also contains his semipopular Heidelberg lecture of 1889, "On the Relations between Light and Electricity," giving a general account of his more recent work. It strikingly illustrates the charm and felicity of style he could employ in the presentation of a difficult subject, and cannot fail to be read, and reread, with pleasure and admiration. The volume ends with a eulogy of Helmholtz on the occasion of his seventieth birthday, wherein the pupil, in equally graceful language, paid homage to his beloved and inspiring preceptor. These two papers reveal so clearly between the lines the manner of man their author was.

The second volume contains the papers on electric waves, which had been collected by the author himself, as a result of numerous requests for reprints, and published under the German title, "Untersuchungen über die Ausbreitung der Elektrischen Kraft," and later in English as "Electric Waves," with a lucid introduction by Hertz explaining the motive and significance of each of the separate papers. One of the first of these describes an important by-product of the electric wave studies, the discovery of the effect of ultraviolet light upon an electrical discharge. This discovery itself uncovered a new wealth of physical problems and the subject became immediately of great interest to many experimenters, most of whom at the time little suspected that this subsidiary effect was not the main discovery, or imagined that electrical science was on the eve of much greater conquests. The paper attracted attention to Hertz and aroused a popular nterest in him, so that everything coming from him thereafter was eagerly read. Had it not been for this rather accidental circumstance the importance of his subsequent work might have gone temporarily unnoticed, as has happened with some of the greatest discoveries.

The third volume in the series is his book, "Die Prinzipien der Mechanik," completed with difficulty during his last illness and published a few months after his death. A lengthy preface by the venerable Helmholtz gives an appreciative sketch of the author's life and work—this time a sorrowful tribute from master to pupil.

In order to understand and appraise the work of Hertz on electric waves, it will be needful to review briefly the ideas about light and electricity that prevailed at his time and before. With regard to light, Newton's corpuscular theory had given way in the early 1800's to the wave theory of Young and Fresnel, and long before Hertz's day the idea of transverse vibrations in a hypothetical elastic-solid medium called the luminiferous ether had become firmly established. Length of wave and velocity had been measured many times. The wave theory accounted satisfactorily for all the known phenomena in optics and there was no doubt in anybody's mind about its essential correctness, regardless of any difficulties encountered in explaining the nature of the ether and its relation to matter.

As to electricity and magnetism, the older theories of instantaneous action at a distance were beginning to weaken with the discoveries, in the early part of the nineteenth century, of the reactions between electric currents and magnets, and the phenomenon of induction. Hitherto there had been no postulation of an intervening medium to explain the transmission of the force between two charged bodies, and it was supposed that electricity and magnetism, like gravitation, acted across empty space in straight lines and instantaneously. In somewhat different dress these ideas were given new life around the middle of the century, particularly by some of the German physicists. To Faraday, however, such views were unacceptable. He wished to get rid of the idea of action at a distance and in his mind pictured a medium, along the contiguous molecules or particles of which the force was propagated. In this medium he visualized "lines of force" emanating from or terminating upon the electric charges or magnetic poles, acting like stretched elastic threads, repelling each other sidewise as well as tending to contract. Thus, in his thinking, attention was focused upon the insulating medium surrounding a conductor, the "dielectric" as he called it, for here, he thought, was the real seat of the action. He believed also that there existed some direct relation between light and electricity or magnetism. He was ever seeking to find such a relation and in the course of his many experiments he discovered the rotation of the plane of polarization of light by a magnetic field. In his speculations there was one question which was continually presenting itself to him. Do electric and magnetic forces, like light, require time for their propagation? Are there waves? But to this question he was unable to find an answer.

And then came Maxwell, building upon the foundation that Faraday had laid, translating Faraday's ideas into the language of mathematics, and making the grand generalization that light and electric waves are one and the same phenomenon, propagated by the same medium, with the same velocity, and differing only in wave-length. Like Faraday, he considered the energy of the electromagnetic field to reside in the dielectric. He conceived the medium to have properties analogous to those of an elastic solid, which would spring back to its original state upon the removal of the straining force. The alteration of the displacement, or "polarization," in the medium was viewed by him as an electric current, which he called the "displacement current," as distinguished from the "conduction current" existing in conductors. From the general equations which he formulated it was shown that only transverse vibrations (like light) could be propagated in such a medium and that the velocity of propagation should be equal to the ratio of the two systems of electrical units, that is, to the number of electrostatic units of electricity contained in one electromagnetic unit. This ratio had been experimentally determined by Weber and Kohlrausch (it was later redetermined by Maxwell himself, by a different method), and the fact that it agreed so very closely with the measured velocity of light was one of the strongest points in favor of the view that light waves were identical with the hypothetical electromagnetic waves. Maxwell's comprehensive theory was first enunciated in his 1865 paper entitled "A Dynamical Theory of the Electromagnetic Field," and afterwards elaborated in his great "Treatise on Electricity and Magnetism," published in 1873, but for a number of years it was regarded by many as merely a speculation, by others as probably true, and by none as conclusively proved. It remained for Hertz to add the capstone to the theory by actually demonstrating for the first time the existence of electromagnetic waves in space; and furthermore, to show experimentally that they had all the physical properties of ordinary light waves.

In 1888, while he was teaching at the Technical High School in Karlsruhe, Hertz carried out the brilliant experiments which have made his name famous. These were actually a part of a long series of experiments which began in 1886, and which came about partly by accident, and yet were the result of his keen interest in everything connected with electric oscillations; an interest extending back to 1879, when, at the suggestion of Helmholtz, he had considered tackling a prize problem proposed by the Berlin Academy of Science aimed at the proof of a portion of Maxwell's theory, but which he had abandoned for the reason that oscillations of sufficiently high frequency were not then available. While using in his lectures at Karlsruhe a pair of flat ("pancake") coils, called Reiss or Knockenhauer spirals, mounted adjacent to each other, he was surprised to find how easy it was to obtain sparks between the terminals of the secondary coil when a small Leyden jar or even a small induction coil was discharged through the primary, provided the primary discharge took place across a spark gap. This, of course, was an indication of an exceptionally strong inductive effect. This observation led to his discovery of a method of exciting electric disturbances far more rapid than any hitherto known, such as those of Leyden jars or open induction coils as customarily used, and having wave-lengths, it turned out, capable of being measured within the confines of a laboratory. His oscillator was nothing more than a short metal rod with a spark gap in the middle (sometimes with metal spheres or plates attached to the ends, resembling a dumb-bell), the sparking terminals consisting of small knobs or spheres which were connected to the terminals of a Ruhmkorff induction coil; the small inductance and capacitance of this simple linear conductor, together with the proper functioning of the spark gap, accounting for its success. By such means Hertz obtained wave-lengths from a few meters down to 30 centimeters, and so began, it is seen, with the "ultra-short" waves that are again coming into vogue.

Hertz began his experiments with a study of the "induction" about this exciter. As he commented in his first paper in this series, "On Very Rapid Oscillations," published in May, 1887, theory had predicted the possibility of very rapid oscillations in open-wire circuits of small capacitance, but it could not be predicted from theory whether they could be produced on such a scale as to admit of their being observed. Hertz not only devised a method of producing such oscillations, but also discovered a method of detecting them, by their effects in the surrounding space. His detector consisted merely of a short length of wire bent in the form of a rectangle or a circle and containing a micrometer spark gap, across which minute sparks could be seen in a darkened room; especially if this secondary circuit was in electrical resonance with the exciter. This exceedingly simple detector was indeed a capital discovery. Some five years earlier Professor G. F. Fitzgerald, of Dublin, had suggested "the combination of a vibrating generating circuit with a resonant receiving circuit . . . as one by which this very question might be studied." But, as he said afterwards in speaking of Hertz's work, "I did not see any feasible way of detecting the induced resonance: I did not anticipate that it could produce sparks." Concerning this contrivance the following interesting remarks were made by its author in his Heidelberg lecture above referred to: "The method had to be found by experience, for no amount of thought could well have enabled one to predict that it would work satisfactorily. For the sparks are microscopically short, scarcely a hundredth of a millimeter long; they only last about a millionth of a second. It seems absurd and almost impossible that they should be visible; but in a perfectly darkened room they *are* visible to an eye which has been rested in the dark. Upon this thin thread hangs the success of our undertaking." *Multum in parvo*, truly!

After a series of preliminary experiments, in which he studied the various induction effects, including the phenomenon of resonance, and demonstrated waves on wires (an earlier, but overlooked, discovery of von Bezold, in 1870), and also solved the problem of the Berlin Academy—"to establish experimentally any relation between electromagnetic forces and the dielectric polarization of insulators"—he was fully convinced that the disturbance was propagated through space, independently of wires, with a finite velocity and in the form of waves, in accordance with Maxwell's prediction. His conclusion was then definitely and convincingly proved by making use of the well-known method of reflection and interference to produce standing waves, and noting the position of the nodes and antinodes. These epochal experiments were described in a paper entitled "Electromagnetic Waves in Air and Their Reflection," published in May, 1888. But he did not stop there, and in these and succeeding investigations he showed that electric waves are reflected from plane and curved metal surfaces in accordance with the same laws as light waves; that they are refracted in passing thorugh prisms of pitch, paraffin, and other dielectrics; and that they are polarized by a grating of parallel wires, and hence are transverse waves. From actual measurements of their wave-length and computations of their frequency (from the constants of his oscillator), he calculated their velocity and found that it was the same as the velocity of light. As summarized by Hertz himself, "The object of these experiments was to test the fundamental hypotheses of the Faraday-Maxwell theory, and the result of the experiments is to confirm the fundamental hypotheses of the theory." The old action-at-a-distance philosophy had come to an end.

The importance of Hertz's contributions to this great subject received instant and enthusiastic recognition, and his experiments were soon being repeated in all the important laboratories of the world. The English mathematical physicist, Oliver Heaviside, writing in 1891, said: "Three years ago electromagnetic waves were nowhere. Shortly after, they were everywhere." Here were researches of a most abstruse and complex character, with no apparent utility and having no elements of popular appeal, and yet bringing to their author such acclaim as had seldom been accorded to a man of science. Honors were showered upon him on every hand, at home and abroad. In England, where his work was especially appreciated, he was awarded the coveted Rumford medal by the Royal Society.

Hertz's characteristic modesty in referring to his own achievements was matched only by his generosity in giving credit to the accomplishments of others. In one of his lectures he said, "Such researches as I have made upon this subject form but a link in a long chain. . . . Lack of time compels me, against my will, to pass by the researches made by many other investigators; so that I am not able to show you in how many ways the path was prepared for my experiments, and how near several investigators came to performing these experiments themselves." Mention has been made of the investigations of Sir Oliver Lodge in the same field and the imminence of his discovery of the same phenomena. It is pleasant, indeed, in this instance to be able to record the absolute lack of any feeling of jealousy or envy on the part of either of these courteous gentlemen. In the introduction to his collected papers Hertz wrote, "I may here be permitted to record the good work done by two English colleagues who at the same time as myself were striving towards the same end. In the same year in which I carried out the above research, Professor Oliver Lodge, in Liverpool, investigated the theory of the lightning conductor, and in connection with this carried out a series of experiments on the discharge of small condensers which led him on to the observation of oscillations and waves in wires. Inasmuch as he entirely accepted Maxwell's views and eagerly strove to verify them, there can scarcely be any doubt that if I had not anticipated him he would have succeeded in observing waves in air, and thus also in proving the propagation with time of electric force. Professor Fitzgerald, in Dublin, had some years before endeavored to predict, with the aid of theory, the possibility of such waves, and to discover the conditions for producing them."

On his part Lodge just as generously wrote, only a few years afterwards, in an obituary of his rival: "Hertz stepped in before the English physicists, and brilliantly carried off the prize. He was naturally and unaffectedly pleased with the reception of his discovery in England, and his speech on the occasion of the bestowal of the Rumford medal by the Royal Society will long be remembered by those who heard it for its simplehearted enthusiasm and good-feeling. His letters are full of the same sentiment. . . ."

Noteworthy, indeed, was the extreme modesty of this scientific lion of the hour, and equally striking his consideration for the feelings of others. It is recorded that when the Royal Society presented him with the Rumford medal, "he silently disappeared from Bonn for a few days—none knew why—and he returned as silently." In refusing the request made by the editor of *The Electrician* (of London) in 1890 for his photograph, Hertz replied, "I feel as if presenting my portrait now in so prominent a place follows too quickly the little work I have done. I should like to wait a little, and see if the general approbation which my work meets with is of a lasting kind. Too much honor certainly does me harm in the eyes of reasonable men, as I have sometimes occasion to observe. If your kind intention is the same in two years, even one year, I shall readily consent and help you in every respect." Four years later the portrait was published, following upon Hertz's death.

Upon the untimely ending of his brief but brilliant career, occurring in the very prime of life, before he was yet thirty-seven, there was a feeling of shock and sadness in every scientific quarter. Many were the sincere tributes paid to his memory, honoring him for his rare personal qualities as well as his distinguished scientific attainments. Some expressions from Lodge have already been quoted. Said he in his obituary in *The Electrician*, "Not a student of physical science on the planet but will realize and lament the sad loss conveyed by the message, 'Hertz is dead.'" The editor of that journal wrote, "In the modesty and self-forgetfulness which blend so admirably in the spirit of true scientific research Hertz was singularly rich." In an editorial note in an American journal, *The Physical Review*, we find the following: "In addition to the recognition of those who were able to appreciate his work, Hertz received the acclamations of the entire world of thought. Fortunately he possessed a nature of such complete simple-mindedness that his sudden rise into a position akin to notoriety had no effect upon him. The unassuming bearing which had always characterized him remained with him to the end."

In a memorial address delivered by Professor Herman Ebert before the Physical Society of Erlangen on March 7, 1894, the following sentiments are expressed: "In him there passed away not only a man of great learning, but also a noble man, who had the singular good fortune to find many admirers, but none to hate or envy him; those who came into personal contact with him were struck by his modesty and charmed by his amiability. He was a true friend to his friends, a respected teacher to his students, who had begun to gather round him in somewhat large numbers, some of them coming from great distances; and to his family he was a loving husband and father."

It can be said in retrospect that the fundamental invention in radiotelegraphy was made by Hertz, and yet it is true that the discoverer of electric waves had no anticipations as to their utilitarian possibilities. There was no rush to the patent office; indeed, it was not until two years after Hertz's death that the first application for a radio patent was filed, by Marconi. The chief interest at the time was purely scientific, the results being hailed as the settlement of a great scientific controversy, the confirmation of Maxwell's theory, the annexation to electricity of the entire domain of light and radiant heat. In the current literature we find little of prophecy with respect to utility. Sir William Crookes has been credited with being one of the first to foresee distinctly the applicability of "Hertzian" waves to practical telegraphy. In an article in the *Fortnightly Review* for February, 1892, he made a remarkably accurate forecast of what was to come: "simpler and more certain means of generating electrical rays of any desired wave-length"; "more delicate receivers which will respond to wavelengths between certain defined limits and be silent to all others"; "means of darting the sheaf of rays in any desired direction. . . ." And for secrecy he foresaw that "the rays could be concentrated with more or less exactness on the receiver," if the sender and receiver were stationary; or, if moving about, "the correspondents must attune their instruments to a definite wave-length. . . ." "This is no mere dream of a visionary philosopher," he wrote. "All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact."

As we well know, all that he predicted, and more, has become reality, although progress was not to be as rapid as then seemed probable. One of those who at the time had the imagination to see, if only hazily perhaps, the great possibilities of Hertz's discovery was the youthful Marconi, who had also the initiative and the determination to put his ideas into execution, to make the new-found waves useful to mankind. Within a few years, around the turn of the new century, the world was to be thrilled by the detection of a wireless signal transmitted across the wide Atlantic. But there were insurmountable limitations to the means at hand, and it remained for still another wave in the onward roll of science, the advent of the magical era of electronics, to yield the tools necessary for the really great advance that was ahead. With the invention and development of the amplifying and oscillating vacuum tube progress was greatly accelerated, and in a comparatively short time there had been achieved, by a veritable army of experimenters, the marvels of world-wide intercommunication which are so familiar to us today.