ELECTRIC WAVES

BEING

RESEARCHES ON THE PROPAGATION OF ELECTRIC ACTION WITH FINITE VELOCITY THROUGH SPACE

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TRANSLATOR'S NOTE

THE publishers of *Wiedemann's Annalen*, being unable to comply with the numerous applications made for copies of Professor Hertz's researches, invited him to prepare his papers for publication in a collected form. To recast or thoroughly revise them would have been a serious undertaking; and researches are most easily understood when described from the standpoint from which they are undertaken. It was therefore felt best to reprint the separate papers in the form in which they were originally published; but Professor Hertz fortunately decided to supplement the papers by explanatory notes, and to write an Introduction, in which he describes the manner in which the investigations were undertaken, and also discusses their bearing upon electrical theory and the criticisms to which they have been subjected. The collected researches were published early last year under the title, *Untersuchungen über die Ausbreitung der Elektrischen Kraft.*

The book now presented to the English reader is a translation of the German original, with only one or two slight alterations in the notes, and a change, suggested by Lord Kelvin, in the title. I would scarcely have undertaken the translation if I had not been able to rely upon the supervision and kind assistance which Professor Hertz has most freely given, and for which my heartiest thanks are due. I have had the advantage of revising the proofs with him in Bonn, and now trust that no serious error will have escaped notice.

For advice and help in seeing the book through the press, I am indebted to several friends; but most especially to Dr. Philipp Lenard, *Privat-docent* in the University of Bonn. Dr. Lenard has not only read and revised the translation from start to finish, but has shown as keen an interest in it as if it were his own work. I am very glad to have this opportunity of acknowledging his valuable assistance, and of thanking him most warmly for his kindness.

D. E. JONES.

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PREFACE TO THE ENGLISH EDITION

To fully appreciate the work now offered to the English reading public, we must carry our minds back two hundred years to the time when Newton made known to the world the law of universal gravitation. The idea that the sun pulls Jupiter, and Jupiter pulls back against the sun with equal force, and that the sun, earth, moon, and planets all act on one another with mutual attractions seemed to violate the supposed philosophic principle that matter cannot act where it is not. The explanation of the motions of the planets by a mechanism of crystal cycles and epicycles seemed natural and intelligible, and the improvement on this mechanism invented by Descartes in his *vortices* was no doubt quite satisfactory to some of the greatest of Newton's scientific contemporaries. Descartes's doctrine died hard among the mathematicians and philosophers of continental Europe; and for the first quarter of last century belief in universal gravitation was an insularity of our countrymen.

Voltaire, referring to a visit which he made to England in 1727, wrote: "A Frenchman who arrives in London finds a great alteration in philosophy, as in other things. He left the world full; he finds it empty. At Paris you see the universe composed of vortices of subtile matter; at London we see nothing of the kind. With you it is the pressure of the moon which causes the tides of the sea; in England it is the sea which gravitates towards the moon. . . . You will observe also that the sun, which in France has nothing to do with the business, here comes in for a quarter of it. Among you Cartesians all is done by impulsion; with the Newtonians it is done by an attraction of which we know the cause no better."[1]

[1] Whewell's *History of the Inductive Sciences*, vol. ii. pp. 202, 203.

Indeed, the Newtonian opinions had scarcely any disciples in France till Voltaire asserted their claims on his return from England in 1728. Till then, as he himself says, there were not twenty Newtonians out of England.[1]

In the second quarter of the century sentiment and opinion in France, Germany, Switzerland, and Italy experienced a great change. 'The mathematical prize questions proposed by the French Academy naturally brought the two sets of opinions into conflict.' A Cartesian memoir of John Bernoulli was the one which gained the prize in 1730. It not infrequently happened that the Academy, as if desirous to show its impartiality, divided the prize between Cartesians and Newtonians. Thus, in 1734, the question being the cause of the inclination of the orbits of the planets, the prize was shared between John Bernoulli, whose memoir was founded on the system of vortices, and his son Daniel, who was a Newtonian. The last act of homage of this kind to the Cartesian system was performed in 1740, when the prize on the question of the tides was distributed between Daniel Bernoulli, Euler, Maclaurin, and Cavallieri; the last of whom had tried to amend and patch up the Cartesian hypothesis on this subject.[2]

On the 4th February 1744 Daniel Bernoulli wrote as follows to Euler: 'Uebrigens glaube ich, dass der Aether sowohl *gravis versus solem*, als die Luft versus terram sey, und kann Ihnen nicht bergen, dass ich über diese Puncte ein völliger Newtonianer bin, und verwundere ich mich, dass sie den Principiis Cartesianis so lang adhäriren; es möchte wohl einige Passion vielleicht mit unterlaufen. Hat Gott können eine *animam*, deren Natur uns unbegreiflich ist, erschaffen, so hat er auch können eine attractionem universalem materiae imprimiren, wenn gleich solche attractio *supra captum* ist, da hingegen die Principia Cartesiana allzeit *contra captum* etwas involviren."

Here the writer, expressing wonder that Euler had so long adhered to the Cartesian principles, declares himself a thoroughgoing Newtonian, not merely in respect to gravitation *versus* vortices, but in believing that matter may have been created simply with the law of universal attraction without the aid of any gravific medium or mechanism. But in this he was more Newtonian than Newton himself.

[1] Whewell's *History of the Inductive Sciences*, vol. ii. p. 201. [2] *Ibid.* pp. 198,199.

Indeed Newton was not a Newtonian, according to Daniel Bernoulli's idea of Newtonianism, for in his letter to Bentley of date 25th February 1692,[1] he wrote: "That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a vacuum without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking, can ever fall into it." Thus Newton, in giving out his great law, did not abandon the idea that matter cannot act where it is not. In respect, however, merely of philosophic thought, we must feel that Daniel Bernoulli was right; we can conceive the sun attracting Jupiter, and Jupiter attracting the sun, without any intermediate medium, if they are ordered to do so. But the question remains—Are they so ordered? Nevertheless, I believe all, or nearly all, his scientific contemporaries agreed with Daniel Bernoulli in answering this question affirmatively. Very soon after the middle of the eighteenth century Father Boscovich[2] gave his brilliant doctrine (if infinitely improbable theory) that elastic rigidity of solids, the elasticity of compressible liquids and gases, the attractions of chemical affinity and cohesion, the forces of electricity and magnetism; in short, all the properties of matter except heat, which he attributed to a sulphureous essence, are to be explained by mutual attractions and repulsions, varying solely with distances, between mathematical points endowed also, each of them, with inertia. Before the end of the eighteenth century the idea of action-at-a-distance through absolute vacuum had become so firmly established, and Boscovich's theory so unqualifiedly accepted as a reality, that the idea of gravitational force or electric force or magnetic force being propagated through and by a medium, seemed as wild to the naturalists and mathematicians of one hundred years ago as action-at-a-distance had seemed to Newton and his contemporaries one hundred years earlier. But a retrogression from the eighteenth century school of science set in early in the nineteenth century.

[1] *The Correspondence of Richard Bentley*, D.D., vol. i. p. 70.

[2] *Theoria Philosophiæ Naturalis redacta ad unicam legem virium in natura existentium auctore P. Rogerio Josepho Boscovich, Societatis Jesu,* first edition, Vienna, 1758. Second edition, amended and extended by the Author, Venice, 1763.

Faraday, with his curved lines of electric force, and his dielectric efficiency of air and of liquid and solid insulators, resuscitated the idea of a medium through which, and not only through which but *by* which, forces of attraction or repulsion, seemingly acting at a distance, are transmitted. The long struggle of the first half of the eighteenth century was not merely on the question of a medium to serve for gravific mechanism, but on the correctness of the Newtonian law of gravitation as a matter of fact however explained. The corresponding controversy in the nineteenth century was very short, and it soon became obvious that Faraday's idea of the transmission of electric force by a medium not only did not violate Coulomb's law of relation between force and distance, but that, if real, it must give a thorough explanation of that law.[1] Nevertheless, after Faraday's discovery[2] of the different specific inductive capacities of different insulators, twenty years passed before it was generally accepted in continental Europe. But before his death, in 1867, he had succeeded in inspiring the rising generation of the scientific world with something approaching to faith that electric force is transmitted by a medium called ether, of which, as had been believed by the whole scientific world for forty years, light and radiant heat are transverse vibrations. Faraday himself did not rest with this theory for electricity alone. The very last time I saw him at work in the Royal Institution was in an underground cellar, which he had chosen for freedom from disturbance; and he was arranging experiments to test the time of propagation of magnetic force from an electromagnet through a distance of many yards of air to a fine steel needle polished to reflect light; but no result came from those experiments. About the same time or soon after, certainly not long before the end of his working time, he was engaged (I believe at the shot tower near Waterloo Bridge on the Surrey side) in efforts to discover relations between gravity and magnetism, which also led to no result.

Absolutely nothing has hitherto been done for gravity either by experiment or observation towards deciding between

[1] *Electrostatics and Magnetism*, Sir W. Thomson, Arts. I. (1842) and II. (1845), particularly § 25 of Art. II.

[2] 1837. *Experimental Researches*, 1161-1306.

Newton and Bernoulli, as to the question of its propagation through a medium, and up to the present time we have no light, even so much as to point a way for investigation in that direction. But for electricity and magnetism Faraday's anticipations and Clerk-Maxwell's splendidly developed theory have been established on the sure basis of experiment by Hertz's work, of which his own most interesting account is now presented to the English reader by his translator, Professor D. E. Jones. It is interesting to know, as Hertz explains in his introduction, and it is very important in respect to the experimental demonstration of magnetic waves to which he was led, that he began his electric researches in a problem happily put before him thirteen years ago by Professor von Helmholtz, of which the object was to find by experiment some relation between electromagnetic forces and dielectric polarisation of insulators, without, in the first place, any idea of discovering a progressive propagation of those forces through space.

It was by sheer perseverance in philosophical experimenting that Hertz was led to discover (VII., p. 107 below) a finite velocity of propagation of electromagnetic action, and then to pass on to electromagnetic waves in air and their reflection (VIII.), and to be able to say, as he says in a short reviewing sentence at the end of VIII.: "Certainly it is a fascinating idea that the processes in air which we have been investigating, represent to us on a million-fold larger scale the same processes which go on in the neighbourhood of a Fresnel mirror or between the glass plates used for exhibiting Newton's rings."

Professor Oliver Lodge has done well, in connection with Hertz's work, to call attention[1] to old experiments, and ideas taken from them, by Joseph Henry, which came more nearly to an experimental demonstration of electromagnetic waves than anything that had been done previously. Indeed Henry, after describing experiments showing powerful enough induction due to a single spark from the prime conductor of an electric machine to magnetise steel needles at a distance of 30 feet in a cellar beneath with two floors and ceilings intervening, says that he is "disposed to adopt the hypothesis of an electrical plenum," and concludes with a short reviewing sentence, "It

[1] *Modern Views of Electricity*, pp. 369-372.

may be further inferred that the diffusion of motion in this case is almost comparable with that of a spark from a flint and steel in the case of light."

Professor Oliver Lodge himself did admirable work in his investigations regarding lightning rods,[1] coming very near to experimental demonstration of electromagnetic waves; and he drew important lessons regarding "electrical surgings" in an insulated bar of metal "induced by Maxwell's and Heaviside's electromagnetic waves," and many other corresponding phenomena manifested both in ingenious and excellent experiments devised by himself and in natural effects of lightning.

Of electrical surgings or waves in a short insulated wire, and of interference between ordinary and reflected waves, and positive electricity appearing where negative might have been expected, we hear first it seems in Herr von Bezold's "Researches on the Electric Discharge" (1870), which Hertz gives as the Third Paper in the present series, with interesting and ample recognition of its importance in relation to his own great work.

Readers of the present volume will, I am sure, be pleased if I call their attention to two papers by Prof. G. F. Fitzgerald which I heard myself at the meeting of the British Association at Southport in 1883. One of them is entitled, "On a Method of producing Electromagnetic Disturbances of comparatively Short Wave-lengths." The paper itself is not long, and I quote it here in full, as it appeared in the *Report of the British Association*, 1883: "This is by utilising the alternating currents produced when an accumulator is discharged through a small resistance. It is possible to produce waves of as little as two metres wave-length, or even less." This was a brilliant and useful suggestion. Hertz, not knowing of it, used the method; and, making as little as possible of the "accumulator," got waves of as little as *twenty-four centimetres* wave-length in many of his fundamental experiments. The title alone of the other paper, "On the Energy lost by Radiation from Alternating Currents," is in itself a valuable lesson in the electromagnetic theory of light, or the undulatory theory of magnetic disturbance. The reader of the present volume

[1] *Lightning Conductors and Lightning Guards*, Oliver J. Lodge, D.Sc., F.R.S. Whittaker and Co.

will be interested in comparing it with the title of Hertz's Eleventh Paper; but I cannot refer to this paper without expressing the admiration and delight with which I see the words "rectilinear propagation," "polarisation," "reflection," "refraction," appearing in it as sub-titles.

During the fifty-six years which have passed since Faraday first offended physical mathematicians with his curved lines of force, many workers and many thinkers have helped to build up the nineteenth-century school of *plenum*, one ether for light, heat, electricity, magnetism; and the German and English volumes containing Hertz's electrical papers, given to the world in the last decade of the century, will be a permanent monument of the splendid consummation now realised.

KELVIN.

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