HENDRIK ANTOON LORENTZ—1853–1928.

Hendrik Antoon Lorentz, one of the greatest scientific figures of our time, was born at the small town of Arnhem in Holland on July 18, 1853, and died at Haarlem on Saturday, February 4, 1928.

He attended Mr. Timmer's Primary School in Arnhem until he was thirteen, when he entered the newly-established High School. At the age of seventeen he passed the examination for admission to the University of Leyden. Two years later he returned to Arnhem to be a teacher in a public evening school and studied alone for his doctorate. He took this degree at the University of Leyden at the age of twenty-two, the subject of his thesis being 'The Theory of the Reflection and Refraction of Light.'

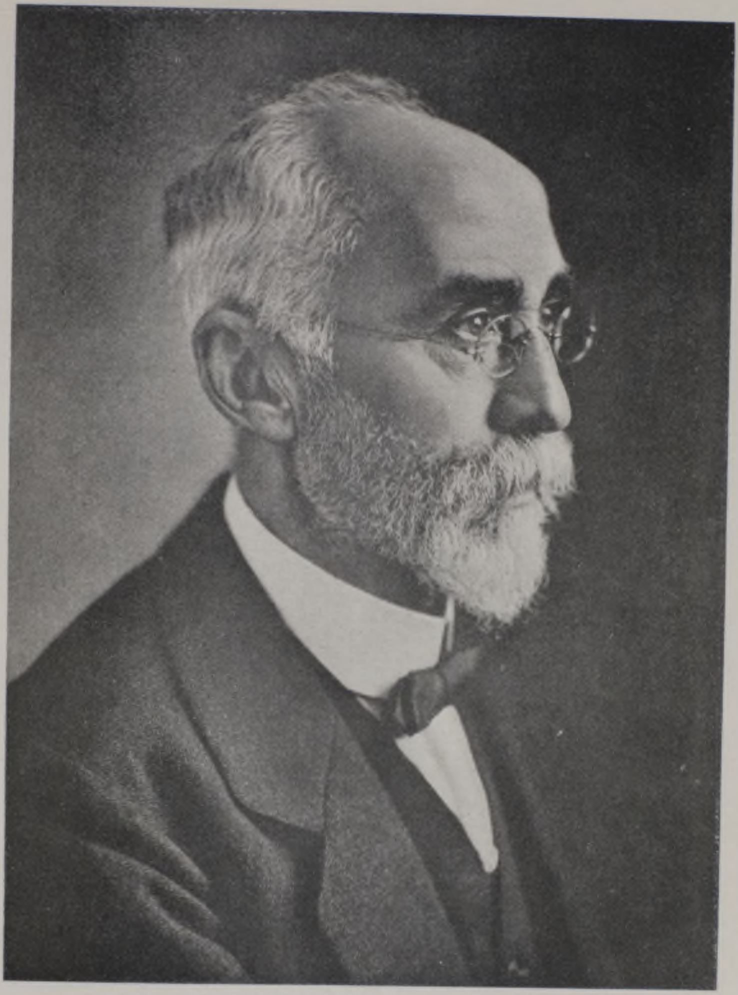
This was the most prominent outstanding problem of the electromagnetic theory of light which Maxwell had left unsolved. The natural way of attacking it was to follow the acoustical analogy and satisfy Green's conditions of the continuity of the displacements and tensions at the interface. There was, however, some latitude as to the transcription of the electromagnetic quantities into their mechanical equivalents. On Fresnel's formulation, at least, it appears that there are more conditions at the interface than can be satisfied without the inclusion of longitudinal waves which are precluded in optics.

Maxwell never made up his mind on this question. Lorentz resolved it by showing that the correct conditions to be satisfied at the boundary were the electromagnetic conditions of the continuities of the tangential components of the electric and magnetic intensities and the normal components of the electric and magnetic inductions respectively. Apart from Maxwell, he was largely influenced in this work by the writings of Helmholtz.

The power and importance of this dissertation was immediately recognised, and two years later Lorentz was called back to Leyden as Professor of Theoretical Physics in the University at the early age of twenty-four.

In 1892 Lorentz put forward and vindicated the theory of electrons in a paper ("La théorie électromagnétique de Maxwell et son application aux corps mouvants," 'Arch. Neérl.,' vol. 25, pp. 363–551), which both immediately and subsequently exerted a most profound influence on the development of theoretical physics.

Up to the time of Faraday and Maxwell all physical theories having any pretensions to fundamentality had been built on the application of Newtonian mechanics to the interaction of material particles. It was implicitly, if not explicitly, assumed that all physical phenomena would ultimately be found explicable in such terms provided the initial conditions could be adequately specified. This supposition, originally restricted to mechanics, where its



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consequences had been abundantly verified, gradually extended throughout the whole of physics with the firm establishment and generalisation of the principles of the conservation of energy and momentum. Faraday had, however, found that the phenomena of electrostatic and magnetic induction were not to be accounted for in terms of the more distant elements of electric charge or of magnetism, but that the properties of the intervening media had a profound result on the phenomena observed experimentally. For Faraday and Maxwell the field was just as important as the charge elements ; Maxwell's ' Electromagnetic Theory of Light ' was built fundamentally on it. In spite of its success in the equality of the ratio of the units with the velocity of light, the electromagnetic theory of light as left by Maxwell had some serious imperfections which his successors were not immediately able to remove. One of these had been effectively dealt with by Lorentz in his dissertation. Another lay in the fact that the coefficients which expressed the electric and magnetic quality of the medium were not constants, as the theory assumed, but depended on such variables as the frequency of the light. Thus the theory had not developed to the extent of accounting for dispersion, although Maxwell himself must have seen how to overcome this difficulty in a general way, since he published the essential features of the solution in the form of an examination question. A still more serious difficulty was met with in attempting to apply the theory to moving media. Both Maxwell and also Hertz, who subsequently attacked this problem, had come to the conclusion that the light in a moving medium should be convected with the full velocity of the medium, whereas it was known that this velocity was only shared to a limited extent ; the well-known formula of Fresnel had been well established experimentally.

It is the supreme merit of this work of Lorentz that he saw clearly the minimum assumptions which accounted for the essential facts and that he carried those assumptions through to their inevitable logical conclusions. His theory was not of the supple kind which by slight modifications here and there can be made to accommodate inconvenient facts overlooked or undiscovered at the time of its development. It was of the kind which must stand or fall by the truth or falsity of the fundamental assumptions on which it is built. Every subsequent investigation has only served to confirm its entire validity within the field of the classical physics. Within this range its applicability is complete, exact and unambiguous. It must thus be regarded as the culmination of the classical philosophy, and, so far as can reasonably be foreseen, it will always maintain this position.

The essential elements of Lorentz's theory which distinguish it from those of Maxwell and his other predecessors are the attribution to electricity of the properties of atomicity and universality in the composition of matter and the reduction of the various media to a single one, the aether. This aether, however, was quite different from the aethers of previous optical theories. It was always at rest and unaffected by the motion of material bodies through it. It is in fact hardly unfair to regard it merely as space, in which the electric and magnetic vectors could interact in accordance with Maxwell's specification.

Probably none of these conceptions were exactly new in 1892, but the synthesis at any rate was novel. From the beginning of his career Lorentz had been attracted by the hypothesis of small charged particles embedded in matter as the real seat of the reaction of the field intensities (see for example, 'Verh. d. Akad. van Wet.,' vol. 18 (1879)). This was, of course, not the first electron theory; the older electrodynamical theories of Weber, Riemann and Clausius implied the electronic feature in some form or another, but in these older theories the electrons acted directly on each other by forces at a distance. In Lorentz's theory the electrons only acted on each other through the aether in which they were embedded. This enabled Lorentz to adopt Maxwell's analysis for the cases in which it was known to be valid, that is to say, cases which did not include motional effects, refraction or dispersion, and he was thus led to the well-known field equations

$$\operatorname{div} \mathrm{E} = \rho, \quad \operatorname{div} \mathrm{H} = 0, \quad \operatorname{rot} \mathrm{E} = -\frac{1}{c}\dot{\mathrm{H}}, \quad \operatorname{rot} \mathrm{H} = \frac{1}{c}(\dot{\mathrm{E}} + \rho \mathrm{V})$$

To find the mechanical force on a current element in an electromagnetic field, he considered the case of a single charged particle moving in an atmosphere of similar particles; this led to the additional equation

$$\mathrm{F} = e\mathrm{E} + \frac{e}{c}(\mathrm{VH}).$$

These equations are satisfied by the field components or by a single electron in the free aether. To apply them to material media they must be averaged over the electrons present in the media in a manner appropriate to the conditions of the problem in hand. In considering the force on an electron in the interior of a dielectric placed in an electric field it is necessary to consider not only the force due to the actual charges on bodies at some distance, but also the force due to the doublets induced by the force acting on the electrons which help to constitute the medium. This leads directly to the idea of the polarisation P and it is found that the so-called fictitious charges of the old polarisation theory of Poisson represent real charges due to an accumulation of displaced electrons in this theory. After this process of averaging, the equations become

$$\operatorname{div} \mathrm{D} = \rho, \quad \operatorname{div} \mathrm{B} = 0, \quad \operatorname{rot} \mathrm{E} = -\frac{1}{c}\dot{\mathrm{B}}, \quad \operatorname{rot} \mathrm{H} = \frac{1}{c}i,$$

where D and B are the inductions and i represents the sum of the conduction, convection and displacement currents + rot ($\mathrm{P}w$). This last term was substituted by Lorentz for a term rot ($\mathrm{D}w$) which Hertz had added to Maxwell's equations; its correctness was established by the various experiments of Roentgen, Rowland and Eichenwald.

In Lorentz's hands this theory led directly and inevitably to the formula of Fresnel, to the accuracy of the first power of the aberrational constant, for the effect of the velocity of a moving dielectric on the speed of light travelling through it, as well as to the formulæ of the classical theory of dispersion. The former result is almost obvious from the fact that the motional effects are due to the induced fictitious polarisation charges which are proportional to the electric intensity multiplied by the difference between the square of the refractive index and unity. The displacement of the polarisation electrons in a periodic field of force must depend, in a manner well understood from the theory of forced vibrations, on the relation between the frequency of the field and the natural frequency of the electrons. These considerations lead at once to the required connection between the frequency of the field and the magnitude of the refractive index or dielectric constant. Lorentz's result that the motional effects are proportional to $\mu^2 - i$ (or $K - 1$), as opposed to a previous result of Hertz which made them proportional to the dielectric constant itself, was confirmed by specific tests made on charged condensers moving in a magnetic field by Blondlot and H. A. Wilson respectively.

There still remained one outstanding difficulty in the way of a stagnant aether, the negative result of the Michelson and Morley experiment. In an earlier paper Lorentz had proposed to overcome this by a compromise between the older theories of Fresnel and Stokes, an explanation rather forced and somewhat complicated. In 1892 Fitzgerald put forward the hypothesis that all moving bodies contracted their dimensions in the direction of motion in the ratio $(1 - v^2/c^2)^{\frac{1}{2}}$ to unity. This hypothesis which accounted for the negative result of the Michelson and Morley experiment was immediately adopted by Lorentz, who had no difficulty in making it harmonise with his general point of view.

The position at that time, as it is to-day and probably always will be, was that every experiment designed to demonstrate the effect of moving matter on electrical and optical phenomena led to a negative result unless relative motion of different material parts of the system was involved. The motion of the system relative to the aether or anything else made no difference provided the velocity was uniform for all its parts. The significance of this did not escape Lorentz and he proceeded to investigate what changes were necessary in the fundamental variables of the electromagnetic field, both dependent and independent, for the validity of this result to be general. In 1895 ('Versuch einer Theorie der elektrischen und optischen Erscheinungen in bewegten Körpern') he succeeded in showing that the fundamental equations retained their form unaltered in a transformation to axes moving with uniform velocity v parallel, let us say, to the x axis provided the time t' in the moving system was changed from t to a local time $t' = t - vx'/c^2$. The values to be taken for the dependent variables, the field intensities in the moving system, were those naturally required as a consequence of the views he had previously developed.

Although this result was only established to the accuracy of the first power of v/c, this was sufficient to cover all well-established cases except the Michelson and Morley experiment. By 1900 Larmor ('Aether and Matter') had succeeded in proving the theorem to be accurate to the order of v^2/c^2, and this accounted for the Michelson and Morley result and the Fitzgerald contraction. In 1903 ('Proc. Amst. Acad.,' vol. 6, p. 809) Lorentz showed further that for all values of v less than the velocity of light, electromagnetic and optical events in a moving system were independent of the (uniform) velocity of that system. This result is known as Lorentz's Principle of Correlation. It originated as a consequence of the conflict between Lorentz's fundamental theory of 1892 and the results of Michelson and Morley and of other types of experiment devised to test the same or similar questions. Its content is the same as that of the Restricted Principle of Relativity which it preceded and of which it must be regarded as an alternative and equivalent statement.

On Lorentz's theory the emission of light and heat by bodies was an immediate consequence of the vibrations and motions of the charged particles of which they were composed. The effects to be expected from any type of motion required in general elaborate analysis. Inasmuch, however, as the charged particles must normally be in some configuration of equilibrium in order to preserve the permanence of the material substance it was to be anticipated that a very common occurrence would be the execution of small oscillations about an equilibrium configuration. The effect of such oscillations would be the emission of light of the same frequency as the natural frequency of the oscillators. This was merely an application on the subatomic scale of Maxwell's principles which had already been carried out experimentally on the macroscopic scale by Hertz.

In 1896 Zeeman discovered that the frequencies of spectral lines were altered when the emission occurred in a powerful external magnetic field. The existence of a connection of precisely this kind had been a conviction of Faraday's, and both he and Tait had looked for it in the laboratory, but the fields at their disposal were inadequate. The theoretical explanation of the simplest type of this effect was immediately produced by Lorentz ('Phil. Mag.,' vol. 43, p. 232 (1897)). An examination of the data showed that the sources of emission of the light were negatively charged particles whose mass per unit charge had the same value as that for the carriers of the cathode rays whose true nature was being elucidated about that time by the work of J. J. Thomson. The Zeeman effect thus at once furnished the proof of the general existence in matter of a subatomic electrical atom, the electron. It had, of course, many other important consequences and has furnished what is probably the most powerful tool in the hands of the spectroscopic investigator. The importance of this discovery and its implications was immediately recognised and was signalised by the joint award to Lorentz and Zeeman of the Nobel prize for Physics in 1902.

The foregoing represents a mere outline of some of Lorentz's more important achievements. As Larmor has truly said: a survey of his whole life's work is a liberal education in the history of physical science during the past half century. There is hardly any fundamental question which his writings have not materially illuminated. One of the matters which engaged much of his attention was the emission of black body radiation as a function of temperature. His first method of attacking this problem was to analyse the radiation emitted during the motion of electrons in metals or any similar structure. He supplemented this later by using other methods. But in agreement with other investigators he always came to the same conclusion, namely, that provided the motions were to be fundamentally governed by the Newtonian dynamical principles there was no escape from the Rayleigh-Jeans formula which was in conflict with experiment. Another notable achievement was that of the calculation of the thermal and electrical properties of metals on the classical theory of metallic conductors ('Theory of Electrons,' p. 266). Among the other subjects which also claimed his attention may be specially mentioned the width of spectral lines, the theory of gravitation and the principle of relativity.

An early investigation of Lorentz dealt with the refractive index and specific inductive capacities of bodies as a function of the density. In this he arrived at a well-known formula sometimes called the Lorentz-Lorenz formula because it was also put forward independently and on different grounds by the Danish physicist, L. V. Lorenz. Whilst this formula is derived from Lorentz's electron theory it is not an inevitable consequence of that theory but involves the use of assumptions which are not essential to it. At this point the detailed structure of the individual molecules comes into play and the assumed conditions are probably too much simplified for it to be exactly applicable to real substances. Nevertheless it is correct in principle and is satisfactory as a first approximation. It is very curious that L. V. Lorenz should have anticipated very much earlier the one considerable omission from Lorentz's earlier formulations of his electron theory, namely, the introduction of the retarded potentials, which are vital in any case of accelerated motion. In point of fact Larmor had the earlier success in dealing with accelerated electrons ('Phil. Mag.,' vol. 14, p. 503 (1897)).

After holding the Leyden Professorship for 35 years, Lorentz in 1912 accepted an invitation to go to Haarlem as curator of the laboratory of the Teyler Institution. This relieved him of the more arduous part of his duties as

Professor at the University of Leyden, but right to the end of his long and active career he continued to go to Leyden once a week to deliver a lecture and to discuss outstanding problems with the students.

Apart from his papers in the scientific journals, Lorentz has enriched us with a large number of publications of more extended range. In addition to the 'Versuch einer Theorie der elektrischen und optischen Erscheinungen in bewegten Körpern' and the 'Theory of Electrons,' of which the essential content as well as the treatment is highly original, these include a number of surveys of various extended branches of physical knowledge. As a rule these were the fruit of some course of lectures delivered under some special conditions. They are of permanent value not only on account of the independence of the author's treatment but also on account of the accuracy and clearness of the exposition. He also found time to publish two textbooks which have been much appreciated on the Continent.

He was much concerned with the important national undertaking of draining the Zuider Zee, and after the war he devoted a great deal of attention to fostering international scientific relations, especially between the late belligerents.

One of the great events of Lorentz's life was the celebration on the 11th of December, 1900, at Leyden of the twenty-fifth anniversary of his doctorate. This was attended by many leading scientists from various countries who contributed a volume of memoirs in his honour. In 1926 the Senate of the University of Leyden made him an honorary Doctor of Medicine as a mark of appreciation of the trouble he had given himself in regard to the instruction of medical students. In the same year physicists all over the world commemorated the fiftieth anniversary of his doctorate by subscribing a fund for the creation of the Lorentz Foundation for the promotion of theoretical physics and of international intercourse among young physicists. The object of this was to send young men from the Netherlands to other countries and to invite young foreigners to the Dutch Universities. There were thousands of subscribers, large numbers of whom were not scientists.

That Lorentz was a man of remarkable intellectual powers is obvious from his writings, but he was pre-eminently one of those beings of whom a full appreciation is only to be obtained by personal contact. Although steeped in his own investigation of the moment, he always seemed to have in his immediate grasp its ramifications into every other corner of the universe. To those who knew him he gave the impression of having the power of bringing more of nature into focus in his mental vision at one time than any of his contemporaries. The singular clearness of his writings provides a striking reflection of his wonderful powers in this respect.

He was gifted with a manner of indescribable charm and a surprising modesty which was most attractive. In spite of concentration on the matters which were uppermost in his own mind he always seemed able to take an interest in the affairs, whatever their nature might be, of those around him. The writer well remembers the privilege of taking him round his own laboratory. No experiment was too unimportant for him not to wish to get a full understanding of it, which he gained with remarkable swiftness. Moreover, for every single student he had a kind and appropriate word of encouragement.

In the later years of his life a good deal of Lorentz's time and energy was occupied in delivering lectures and addresses in foreign countries and attending international scientific gatherings. Apart from his great achievements and high reputation, his peculiar powers made him an ideal president of such gatherings. He possessed and successfully employed the mental vivacity which is necessary to follow the interplay of discussion, the insight which is required to extract those statements which illuminate the real difficulties and the wisdom to lead the discussion along fruitful channels, and he did this so skilfully that the process was hardly perceptible. His linguistic powers were such that it was immaterial to him whether he spoke or listened in Dutch, English, French or German. He was adept in making singularly happy and often quite literary speeches in any one of those languages.

The writer was fortunate in being present at both the two international scientific gatherings which Lorentz attended shortly before his death, namely, the celebration at Como of the centenary of the death of Volta and the meeting of the Solvay Physics Conference at Brussels. His powers showed no perceptible diminution at either of these functions. At both he was distinguished by the alacrity of his appearance, almost that of youth, by his readiness, acuteness, and sound judgment in the debates, in which there seemed to be no subject which did not excite his interest, as well as by his kindness and friendliness with all who were present, both young and old.

For many years Lorentz had been president of the Solvay Conferences, at which a selected body of representatives of various nations meet in Brussels every three years to discuss some subject of outstanding importance in Physics. This position provides a particularly severe test on account not only of the linguistic difficulty but also of the intricacy of some of the subjects under discussion. It was remarked, however, with great satisfaction by the members present that the President accomplished his task as well as, if not better than, ever.

Lorentz received most of the honours which come to a man of the highest scientific achievements. He was elected a Foreign Member of the Royal Society in 1905 and was awarded the Rumford Medal in 1908 and the Copley Medal in 1918. He was very appreciative of his connection with the Society and delighted in recalling the close connection and intercourse between the natural philosophers of the Netherlands and England which existed in the early days of the Society. He was well known and very welcome in England. He attended the meetings of the British Association on several occasions, and, as recently as in 1923, he lectured at the Royal Institution and gave a number of lectures under the auspices of the University of London and the Anglo-Batavian Society. In the same year he received an honorary degree and delivered the Rede Lecture at Cambridge, taking as his subject Clerk Maxwell's Electromagnetic Theory, and in 1925 he gave an address to The Institute of Metals on 'The Motion of Electricity in Metallic Bodies.'

Lorentz died in the full vigour of his faculties; his years had produced no perceptible waning of the wonderful spirit. His death was sudden and unexpected; after a short and happily painless illness, he remained in good and genial spirits up to the last moment.

On July 15th, 1881, he married Alletta Catharina Kaiser. His wife took a great interest in his various activities and was the valued companion who accompanied him on all his journeys. He is survived by his widow and three children, one of whom is married to Prof. de Haas of Leiden and is known as the authoress of several papers on physics.

The funeral took place at Haarlem at noon on Friday, February 10. At the stroke of twelve the State telegraph and telephone services of Holland were suspended for three minutes as a revered tribute to the greatest man Holland has produced in our time. It was attended by many colleagues and distinguished physicists from foreign countries. The President, Sir Ernest Rutherford, represented the Royal Society and made an appreciative oration by the graveside.

O. W. R.