Hendrik Antoon Lorentz, the Ether, and the General Theory of Relativity

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1. Introduction

From the early days of the development of the general theory of relativity the Dutch physicist Hendrik Antoon Lorentz showed a lively and active interest in this theory of gravitation. He devoted much time and energy to understanding the theory and made several important contributions himself. In this paper I will discuss Lorentz's work in the field of general relativity; in addition I will address the question of the apparent discrepancy between Lorentz's enthusiasm for the general theory of relativity and his belief in the existence of an ether. It is well known that until his death in 1928 Lorentz kept insisting on the usefulness of an ether. In spite of his often-expressed admiration for Einstein's special theory of relativity, he preferred his own ether-based 'theory of electrons'. Lorentz admitted that his theory and the special theory of relativity had the same empirical consequences and that the ether could not be experimentally detected, but he maintained that some kind of ether was needed as carrier of the electromagnetic field. As he said in his *Theory of Electrons*: "I cannot but regard the ether, which can be the seat of an electromagnetic field with its energy and its vibrations, as endowed with a certain degree of substantiality, however different it may be from all ordinary matter."[1] In the light of this and many similar statements it seems remarkable that Lorentz occupied himself with the general theory of relativity, in which the ether played no role whatsoever. I will show that, in fact, Lorentz's point of view was not inconsistent, and that he had the same objections against the general theory as against the special theory.

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[1] Lorentz (1909), p. 230. There are many more examples of Lorentz expressing himself in this way. For a discussion of Lorentz's electron theory, see Goldberg (1969), Hirosige (1966, 1969), McCormmach (1970, 1973), and Schaffner (1969).

I use below the following abbreviations:

EAL Ehrenfest Archive. Museum Boerhaave, Leiden, The Netherlands.
ECL Einstein Collection. Museum Boerhaave, Leiden, The Netherlands.
LAH Lorentz Archive, Algemeen Rijksarchief, The Hague, The Netherlands.

He was, on the other hand, so much impressed by the beauty and the originality of the theory, that he almost naturally became involved in its development, and became one of its first ardent propagandists in the Netherlands.[2]

2. Lorentz's early contributions

Not very long after the publication in 1913 of ALBERT EINSTEIN'S & MARCEL GROSSMANN'S "Entwurf einer verallgemeinerten Relativitätstheorie und einer Theorie der Gravitation"[3], LORENTZ began to study this first version of the general theory of relativity. He filled many pages of his scientific notebooks with calculations, working hard to understand the mathematical intricacies of the theory and trying to verify its conclusions. He carefully checked the transformation properties of the main formulas and in the process came to the conclusion that the field equations were only covariant for arbitrary transformations if the energy-momentum tensor was symmetric.[4] LORENTZ communicated this result to EINSTEIN, as can be inferred from a remark in one of his notebooks and from two letters EINSTEIN wrote to LORENTZ, in reply to two letters that are now lost.[5] In his letters, EINSTEIN expressed his pleasure at LORENTZ'S interest and tried to make plausible that the tensor was indeed symmetric.[6]

For more than a year after this exchange of letters there are no outward signs of LORENTZ'S actively working on general relativity. But after EINSTEIN published his paper "Die formale Grundlage der allgemeinen Relativitätstheorie"[7] in November 1914 LORENTZ set to work again. His activities resulted in an enormous amount of calculation (several hundred pages) and in the publication of a paper in which EINSTEIN'S field equations were derived from a variational principle.[8] Although LORENTZ'S notation is at times somewhat cumbersome, the paper shows a clear insight into the theory and a firm grasp of its formalism. The lack of any criticism of its foundations, moreover, seems to indicate complete agreement with the fundamental assumptions of the theory.

This impression, however, is not quite correct. Just before LORENTZ'S paper was submitted (at the end of January 1915), an exchange of letters took place between LORENTZ and EINSTEIN from which it becomes clear that LORENTZ had fundamental objections to EINSTEIN'S point of view. Two letters are involved,

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[2] LORENTZ lectured on general relativity from March to June 1916. Among his audience were PAUL EHRENFEST and WILLEM DE SITTER; the latter played a crucial role in making the theory known in England through his papers in the *Monthly Notices of the Royal Astronomical Society*.

[3] The paper first appeared as a separatum, EINSTEIN & GROSSMANN (1913a), and then, with some additional remarks, in a journal, EINSTEIN & GROSSMANN (1913b).

[4] LAH 269, pp. 188–201.

[5] LAH 270, p. 65; EINSTEIN to LORENTZ, 14 Aug. 1913 and 16 Aug. 1913 (LAH 21).

[6] EINSTEIN uses the argument that a symmetric tensor expresses the equivalence of energy and mass in the simplest way. EINSTEIN to LORENTZ, 16 Aug. 1913 (LAH 21).

[7] EINSTEIN (1914).

[8] LORENTZ (1915).

one from LORENTZ, and a reply from EINSTEIN.[9] Of LORENTZ'S letter only a draft is available, but from EINSTEIN'S reply we can conclude that the actual letter was very similar in content to the draft. Both letters merit careful attention, because they very clearly illustrate the fundamentally different attitudes of LORENTZ and EINSTEIN toward the foundations of physics.

The first paragraphs of LORENTZ'S letter contain a rather technical exposition of a mathematical difficulty LORENTZ had encountered in EINSTEIN'S paper of November 1914. Then the discussion proceeds toward a more fundamental point: the idea of general covariance. This idea plays an important role in the paper of November 1914. In one of the introductory sections EINSTEIN strongly argues that a theory of gravitation should be generally covariant, in the sense that its laws are invariant under arbitrary coordinate transformations. The theory presented in the paper, however, does not meet this requirement: the field equations allow only a restricted set of coordinate transformations. In order to justify this result, EINSTEIN presents an argument that is known as the 'hole argument'. The argument, the first version of which dates from 1913,[10] runs as follows.[11] Consider a finite space-time region Σ, in which no material processes take place, so that the physical happenings within Σ are fully determined by the quantities $g_{\mu\nu}$. In the coordinate system K these quantities are given as functions of x_α; symbolically, $g_{\mu\nu} = G(x_\alpha)$. Introduce a new coordinate system K', which coincides with K outside Σ, but deviates from it inside this region, in such a way that the corresponding field $g'_{\mu\nu}$ and its derivatives are everywhere continuous. It may be written as $g'_{\mu\nu} = G'(x'_\alpha)$. If in G' the argument x'_α is replaced by x_α, a new gravitational field relative to K is created that differs from the original one. In the case of generally covariant field equations, both $G(x_\alpha)$ and $G'(x_\alpha)$ are solutions of the field equations with respect to K; they describe the same physical situation but are different inside Σ (they coincide on its boundary). Thus in the case of generally covariant field equations the source term (the material energy-momentum tensor) does not uniquely determine the gravitational field. EINSTEIN'S (incorrect) conclusion (and justification of the failure of the field equations he has derived to be covariant) is that covariant field equations are not allowed. One has to restrict oneself to a limited set of coordinate transformations, determined by the demand that the gravitational field is uniquely fixed by the energy-momentum tensor.

In his letter to EINSTEIN, LORENTZ brings up the subject of general covariance because he disagrees with EINSTEIN on this point. He claims that it is always possible to select a coordinate system that is preferable over all others, not only for mathematical reasons (the simplicity of the formulas), but also on physical grounds. As an example he writes down NEWTON'S second law for a body in the vicinity of the earth:

$$\frac{d^2x}{dt^2} = -\alpha \frac{x}{r^3}, \quad \text{etc.} \tag{1}$$

[9] LORENTZ to EINSTEIN, Jan. 1915 (draft) (LAH 286); EINSTEIN to LORENTZ, 23 Jan. 1915 (LAH 21).

[10] EINSTEIN & GROSSMANN (1913b), pp. 260–261.

[11] EINSTEIN (1914), p. 1067. A detailed analysis of the 'hole argument' and the role it played in the development of EINSTEIN'S thought can be found in NORTON (1984).

In the coordinate system chosen here ('system I') the earth rotates with angular velocity ω. If we transform to a coordinate system that rotates with the earth, the equations become more complicated:

$$\frac{d^2x'}{dt^2} = -\alpha\frac{x'}{r^3} + 2\omega\frac{dy'}{dt} + \omega^2 x', \quad \text{etc.} \tag{2}$$

LORENTZ now remarks that the additional terms in equation (2) do not have a clear physical interpretation, for instance in terms of gravitating bodies. Therefore, system I is to be preferred, not only because the equations are more simple, but also on physical grounds. As LORENTZ puts it:

> "We might imagine that for a long time people were in possession only of equations (2), and had tormented themselves over an 'interpretation' of the terms $2\omega\, dy'/dt$, $\omega^2 x'$, etc. If somebody then comes along, and by introduction of coordinate system I reduces equations (2) to those of (1), everyone will hail this as a real solution and would prefer system I."[12]

LORENTZ then points out that EINSTEIN's theory, since it is not generally covariant, also implies a preference for certain coordinate systems. A little further on, he concludes that EINSTEIN apparently feels more strongly about covariance than he does, and he questions EINSTEIN's assertion that all coordinate systems should be equivalent with the words: "Are you not going rather too far here, in laying down a personal viewpoint as self-evident?"[13] Not surprisingly, this remark is followed by a defense of the existence of the ether: "You are right in what you say only because you do not wish to hear of an ether at all. This view may eventually be preferable to the old one, but it is not the only possible view."[14]

EINSTEIN took LORENTZ's objections seriously. The first part of his reply is devoted to LORENTZ's mathematical difficulty; it is followed by a lengthy discussion of general covariance. EINSTEIN gives two reasons why general (non-linear) coordinate transformations should be allowed in physics. The first reason is a physical one: the principle of equivalence demands the admissibility of such transformations. The second reason has, in EINSTEIN's words, an epistemological character. He claims that singling out a particular coordinate system as preferable over all others is arbitrary and therefore undesirable, since one can never give a valid empirical (physical) justification for it. In EINSTEIN's words: "A world-

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[12] "Wir können uns vorstellen, man sei eine Zeit lang nur im Besitz der Gleichungen (2) gewesen und habe sich mit einer 'Deutung' der Glieder $2\omega\, dy'/dt$, $\omega^2 x'$ u.s.w. gequält. Käme dann einer, der durch Einführung des Koordinatensystems I die Gleichungen (2) auf (1) zurückführt, so würde ein jeder das als eine wirkliche Erlösung begrüssen, und jeder würde das System I vorziehen." LORENTZ to EINSTEIN, Jan. 1915 (draft) (LAH 286).

[13] "Gehen Sie hier nicht etwas zu weit, indem Sie eine persönliche Auffassung als selbstverständlich hinstellen?" *Ibid.*

[14] "Sie haben mit Ihrer Bemerkung nur recht, weil Sie von einem Äther überhaupt nicht wissen wollen. Diese Auffassung mag am Ende der Früheren vorzuziehen sein, aber sie ist doch nicht die einzig mögliche." *Ibid.*

picture that dispenses with such arbitrary choices is in my view preferable."[15] EINSTEIN admits that the restricted covariance of his theory does in fact imply a distinction between various coordinate systems, but the difference is that his "choice of coordinates does not presuppose anything of a physical kind about the world".[16]

3. The final version of the general theory of relativity

At the end of November 1915 EINSTEIN submitted the paper that contained the final, generally covariant form of the general theory of relativity.[17] A month later, both LORENTZ and PAUL EHRENFEST (LORENTZ's successor in Leiden) had already gone deeply into the theory and were exchanging letters on the difficulties they encountered. They also both corresponded with EINSTEIN; although none of the letters they wrote to EINSTEIN during this period has been preserved, the particular 'triangular' character of the correspondence allows a partial reconstruction of its contents.[18]

Not surprisingly, the difficulties LORENTZ and EHRENFEST struggled with had to do with general covariance. EHRENFEST noticed that the core of the theory lay in two sets of equations: the field equations, and the law of conservation of energy-momentum, which had been postulated separately. He wondered if one could eliminate the energy-momentum tensor from these two sets and derive an equation that contained the metric tensor only, and he asked whether such an equation would restrict the possible forms of the metric tensor and thus define one or more preferred coordinate systems.[19] EHRENFEST subsequently succeeded in eliminating the energy-momentum tensor, but neither he nor LORENTZ could determine the implications of the equation derived in this way.[20] We now know that all metric tensors satisfy EHRENFEST's equation: he had derived the contracted BIANCHI identities. EINSTEIN's first reaction was that, since the equation was generally covariant, it could not impose any restrictions on the choice of possible coordinate systems.[21] Shortly afterwards he reached the conclusion that the relation was in

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[15] "Ein Weltbild, welches ohne eine derartige Willkür auskommt ist nach meiner Meinung vorzuziehen." EINSTEIN to LORENTZ, 23 Jan. 1915 (LAH 21).

[16] "[...] Koordinatenwahl physikalisch nichts über die Welt voraussetzt." *Ibid.*

[17] EINSTEIN (1915d). This was the last of a series of four papers on general relativity, all published in November 1915 (EINSTEIN (1915a–d)).

[18] The letters exchanged between LORENTZ, EHRENFEST, and EINSTEIN during this period are: LORENTZ to EHRENFEST 23 Dec. 1915, 26 Dec. 1915, 9 Jan. 1916, 10/11 Jan. 1916, 12 Jan. 1916, 18 Jan. 1916, 22 Jan. 1916, 28 Jan. 1916, 2 Feb. 1916 (all EAL); EHRENFEST to LORENTZ 23 Dec. 1915, 24 Dec. 1915, 9 Jan. 1916, 12/13 Jan. 1916, 25 Jan. 1916 (all LAH 20); EINSTEIN to LORENTZ 1 Jan. 1916, 17 Jan. 1916, 19 Jan. 1916 (all LAH 21); EINSTEIN to EHRENFEST 26 Dec. 1915, 29 Dec. 1915, 3 Jan. 1916, 5 Jan. 1916, 17 Jan. 1916, undated (winter 1916) (all EAL).

[19] EHRENFEST to LORENTZ, 23 Dec. 1915 (LAH 20).

[20] EHRENFEST to LORENTZ, 24 Dec. 1915 (LAH 20); LORENTZ to EHRENFEST, 26 Dec. 1915 (EAL).

[21] EINSTEIN to EHRENFEST, 29 Dec. 1915 (EAL).

fact an identity[22]. It was not until much later that EINSTEIN and others realized how fundamental the BIANCHI identities were: with their help the law of conservation of energy-momentum can be derived from the field equations instead of having to be postulated.[23]

LORENTZ'S problems with general covariance took the form of a somewhat puzzling objection. In a letter to EHRENFEST he reports on having written to EINSTEIN to ask his opinion on a problem that he has encountered and that he formulates as follows (the equations (A) he refers to are the field equations):

> "I confine myself to the 'matter-free' field [...]. From the circumstance that the equation (A) [...] is covariant with respect to certain substitutions, it follows that from one solution I can deduce others. If *e.g.* I have the solution $g_{\mu\nu} = F(x_\alpha)$ (symbolically expressed), and replace x_α by x'_α, then by the transformation formulas I can provide the values of $g'_{\mu\nu}$. I can express them in x'_α; suppose $g'_{\mu\nu} = F'(x'_\alpha)$. Then $g_{\mu\nu} = F'(x_\alpha)$ will also satisfy equations (A). This is a new solution, differing from the first."[24]

LORENTZ then actually constructs such a new solution, starting from a given one, and shows that it is physically different: in the original case particles move along straight lines, whereas this is not the case for the new solution. His conclusion is:

> "From the above it follows, it seems to me, that in the case we are considering of the matter-free field the equations (A) together with continuity and the conditions at infinity are insufficient to determine the field; in contrast with Laplace's equation $\Delta\varphi = 0$, which in view of the subsidiary conditions requires that $\varphi = 0$."[25]

What is puzzling about this objection is that LORENTZ here essentially repeats EINSTEIN'S 'hole argument'. Was he aware of this? The phrasing of his letter to EHRENFEST suggests he was not. It also seems unlikely for another reason: If LORENTZ had been aware of it, it should have become clear to him that EINSTEIN obviously no longer believed in the 'hole argument', since the theory of Novem-

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[22] EINSTEIN to EHRENFEST, 3 Jan. 1916 (EAL).

[23] See, *e.g.*, PAIS (1982), pp. 274–278.

[24] "Ik bepaal mij tot het 'materievrije' veld [...]. Uit de omstandigheid dat de vergelijking (A) [...] tegenover zekere substituties covariant is, volgt dat ik uit ééne oplossing andere kan afleiden. Heb ik b.v. een oplossing $g_{\mu\nu} = F(x_\alpha)$ (symbolisch voorgesteld), en voer ik in plaats van x_α x'_α in, dan kan ik door de transformatieformules de waarden der $g'_{\mu\nu}$ aangeven. Ik kan die in x'_α uitdrukken; stel $g'_{\mu\nu} = F'(x'_\alpha)$. Dan zal ook $g_{\mu\nu} = F'(x_\alpha)$ aan de vergelijkingen (A) voldoen. Dit is een nieuwe van de eerste verschillende oplossing." LORENTZ to EHRENFEST, 9 Jan. 1916 (EAL).

[25] "Mij dunkt dat uit het bovenstaande volgt dat in het beschouwde geval van het materievrije veld de vergelijkingen (A) met de doorlopendheid en de voorwaarden in het oneindige niet voldoende zijn om het veld te bepalen; in tegenstelling met de verg. van Laplace $\Delta\varphi = 0$, die in verband met de bijkomstige voorwaarden eischt dat $\varphi = 0$ is." *Ibid.*

ber 1916 was generally covariant. In any case, one thing is clear: LORENTZ still questioned the need for general covariance. Neither EINSTEIN's papers, nor a recent letter in which EINSTEIN explained why he had returned to general covariance had been able to take away his doubts.[26]

The day after LORENTZ had written to EINSTEIN, however, he read a letter from EINSTEIN to EHRENFEST that cleared everthing up.[27] In his letter, EINSTEIN defends general covariance by pointing out that the only essential elements in physics are coincidences in space-time; coordinates are only of secondary importance. The gravitational field does not have to be uniquely determined, as long as all coincidences, such as the formation of a black spot at a certain point on a photographic plate, are described correctly. This argument quickly convinced LORENTZ. As he wrote to EHRENFEST: "I had read only a part of it [*i.e.* EINSTEIN's letter] when it dawned on me and I saw that he was entirely right. I wrote to him straight away to retract my objections of yesterday."[28] And at the end of the letter he wrote: "I have congratulated Einstein on his brilliant results."[29]

Now that the main obstacle was out of the way, LORENTZ wasted no time; during the following months he wrote a series of papers in which he formulated a variational principle for the general theory of relativity and developed the theory on the basis of this principle.[30] Although EINSTEIN himself[31], and also HILBERT[32], had used variational principles before, LORENTZ took a somewhat different approach, which is much more geometrical in nature. One needs much geometrical intuition to follow LORENTZ's reasoning; this is perhaps the reason why very few people have used his approach.[33]

The problem of general covariance might have been settled, but LORENTZ's ideas about the existence of an ether had not been shaken. For him, admitting general coordinate transformations did not mean that all coordinate systems were fully equivalent. The possibility always remained to choose a preferred coordinate system, which one might then think of as being connected to the 'ether'. In a letter to EINSTEIN, written in June 1916, LORENTZ clearly states his point of view.[34] He starts by describing a 'fictional' experiment: in two closed wires that

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[26] EINSTEIN to LORENTZ, 1 Jan. 1916 (LAH 21). In this letter EINSTEIN gives three arguments why he has returned to general covariance: 1. The perihelion motion of Mercury came out too small; 2. The equations were not covariant for transformations corresponding to uniform rotation; 3. The Lagrangian could be chosen entirely arbitrarily. He does not mention the 'hole argument'.

[27] EINSTEIN to EHRENFEST, 5 Jan. 1916 (EAL). It was enclosed in EHRENFEST to LORENTZ, 9 Jan. 1916 (LAH 20).

[28] "Ik had nog maar een gedeelte daarvan gelezen toen mij een licht opging en ik zag dat hij geheel gelijk heeft. Ik heb hem aanstonds geschreven om mijne bedenkingen van gisteren te herroepen." LORENTZ to EHRENFEST, 10/11 Jan. 1916 (EAL).

[29] "Ik heb Einstein met zijne schitterende uitkomsten gelukgewenscht." *Ibid.*

[30] LORENTZ (1916).

[31] EINSTEIN (1915a).

[32] HILBERT (1915).

[33] See, *e.g.*, FOKKER (1929).

[34] LORENTZ to EINSTEIN, 6 Jun. 1916 (ECL).

run around the earth along the equator electromagnetic waves are generated in such a way that the waves in the two wires run in opposite directions.[35] In a coordinate system fixed to the earth the waves propagate with different speeds in the two wires; in a system in which the speeds are equal the earth performs a rotation. A convenient way to describe this phenomenon, LORENTZ points out, is to introduce an ether as carrier of the waves. He then goes on:

> "If we adopt this standpoint, we may say that the experiment has shown us the motion of the earth relative to the ether. If, then, we have thereby acknowledged the possibility of establishing a relative *rotation*, we should not reject in advance the possibility of also obtaining indications of a relative *translation*, *i.e.* we should not set up the basic principle of relativity theory as a *postulate*. We would need, rather, [...] to seek the answer to the question in the observations."[36]

According to LORENTZ, the relativity principle is a hypothesis, framed on the basis of experimental results, and always open to refutation.

It is worthwhile to analyze LORENTZ's argument a little more closely. For LORENTZ, the existence of physical effects due to accelerated motion shows that these motions have an 'absolute' character, where 'absolute' has to be understood as relative to the ether.[37] From this it follows, although it is not explicitly stated, that uniform translations are also 'absolute'. This argument shows a striking resemblance to the argument NEWTON gives in the *Scholium* on space and time in Book 1 of the *Principia*.[38] Like LORENTZ, NEWTON first describes physical effects due to accelerated motion—in this case the dynamical effects that can be observed in a rotating bucket filled with water. From their occurrence he then infers the existence of absolute space and the absolute character of both accelerated and uniform translatory motion.[39]

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[35] Although in his letter LORENTZ refers to an experiment performed by ERNST LECHER, his 'experiment' resembles one carried out by GEORGES SAGNAC. See LECHER (1890) and SAGNAC (1914).

[36] "Stellen wir uns auf diesen Standpunkt, so können wir sagen, der Versuch habe uns die relative Bewegung der Erde gegen den Äther gezeigt. Haben wir dann in dieser Weise die Möglichkeit anerkannt, eine relative *Rotation* zu konstatieren, so dürfen wir nicht von vornherein die Möglichkeit leugnen, auch Andeutungen einer relativen *Translation* zu erhalten, d.h. wir dürfen den Grundsatz der Relativitätstheorie nicht als *Postulat* hinstellen. Wir müssen vielmehr [...] die Beantwortung der Frage in den Beobachtungen suchen." LORENTZ to EINSTEIN, 6 June 1916 (ECL).

[37] It should be emphasized that LORENTZ did not adhere to the idea of absolute space. In LORENTZ (1895) (sect. 2), for instance, he states that it is meaningless to talk about absolute rest of the ether and that the expression 'the ether is at rest' only means that the different parts of the ether do not move with respect to each other.

[38] See STEIN (1977) for a discussion of NEWTON's argument and a critical review of later developments.

[39] There is another instance where LORENTZ's reasoning makes one think of NEWTON. In LORENTZ to EINSTEIN, Jan. 1915 (draft) (LAH 286) LORENTZ introduces a world-spirit' ('Weltgeist') that permeates a physical system, without being tied to a particular

Not surprisingly, EINSTEIN was not convinced by LORENTZ'S reasoning. In his reply[40] he admits that the general theory of relativity is closer to an ether hypothesis than the special theory. But the 'ether' he refers to is the metric field, which is something different from the immobile 'substantial' ether LORENTZ has in mind.[41] As a consequence, one can distinguish between accelerated and non-accelerated motion: in a part of space where $g_{\mu\nu}$ = constant, a linear coordinate transformation (corresponding to non-accelerated motion) has no influence on $g_{\mu\nu}$, whereas nonlinear transformations (accelerated motion) change $g_{\mu\nu}$. Thus non-accelerated motion produces no changes in the gravitational field and cannot be detected.

4. The later years

In the following years LORENTZ inspired several of his students and former students to work in the field of general relativity[42] and made some further contributions himself.[43] Though he kept insisting on the existence of an ether, he was not dogmatic about it and on many occasions expressed his admiration for EINSTEIN'S achievements. His attitude is very clearly illustrated by the statement with which he concluded a series of lectures given at the California Institute of Technology in 1922:

> "As to the ether (to return to it once more), though the conception of it has certain advantages, it must be admitted that if Einstein had maintained it he certainly would not have given us his theory, and so we are very grateful to him for not having gone along the old-fashioned roads."[44]

Why LORENTZ kept insisting on the existence of an ether is a question that is not so easy to answer. His attitude may show a certain conservatism, perhaps even stubbornness. But it should be kept in mind that from the earliest years of LORENTZ's career the concept of an ether had played a fundamental role in his work on electromagnetic theory. LORENTZ's idea of a separation between ether and matter, formulated for the first time in the dissertation[45] and worked out during the following decades, had proven to be immensely fruitful for the develop-

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place. According to LORENTZ, such a spirit could directly 'feel' all events occurring in the system under consideration, and would therefore be able to single out a preferred coordinate system. In *Query* 28 of his *Opticks* NEWTON formulates the following idea: "[...] does it not appear from Phaenomena that there is a Being incorporeal, living, intelligent, omnipresent, who in infinite Space, as it were in his Sensory, sees the things themselves intimately, and throughly perceives them [...]."

40 EINSTEIN to LORENTZ, 17 June 1916 (LAH 21).

41 This idea was developed in some more detail in a lecture EINSTEIN gave in Leiden on 27 October 1920. See EINSTEIN (1920).

42 *E.g.* A. D. FOKKER and J. DROSTE.

43 LORENTZ & DROSTE (1917); LORENTZ (1923).

44 LORENTZ (1927), p. 221.

45 LORENTZ (1875).

ment and clarification of electromagnetism.[46] The concept of the ether must have been very dear to LORENTZ, and it does not seem to be out of character for a man like him to remain true to it to the very end.[47]

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Bibliography

The following abbreviations are used:

AJP *American Journal of Physics.*
CP H. A. LORENTZ, *Collected Papers*, 9 vols. (The Hague: Nijhoff, 1934–39).
HSPS *Historical Studies in the Physical Sciences.*
Proc. *Proceedings of the Section of Sciences, Koninklijke Akademie van Wetenschappen te Amsterdam.*
SB *Sitzungsberichte der Preussischen Akademie der Wissenschaften (Berlin).*
Versl. *Verslagen van de Gewone Vergaderingen der Wis- en Natuurkundige Afdeeling, Koninklijke Akademie van Wetenschappen te Amsterdam.*

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[46] See, *e.g.*, HIROSIGE (1966, 1969). LORENTZ very consciously separated ether and matter, as becomes clear from an undated unpublished document (LAH 264), in which he states that he made a distinction between ether and matter in the hope that this would facilitate the treatment of light propagation in bodies that move through the ether without dragging it along.

[47] For a very interesting analysis of LORENTZ's personality, see MCCORMMACH (1973), p. 490. MCCORMMACH emphasizes that LORENTZ was able to make a fair and critical judgement of the work of others, while in his own work he showed strong preferences for certain approaches.

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