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Poincaré, the dynamics of the electron, and relativity

Poincaré, la dynamique de l'électron et la relativité

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A B S T R A C T

On 5 June 1905 Poincaré presented a Note to the Académie des Sciences entitled *Sur la dynamique de l'électron* ("On the dynamics of the electron"). After briefly recalling the context that led Poincaré to write this Note, we comment its content. We emphasize that Poincaré's electron model consists in assuming that the interior of the worldtube of the (hollow) electron is filled with a *positive cosmological constant*. We then discuss the several novel contributions to the physico-mathematical aspects of Special Relativity that are sketched in the Note, though they are downplayed by Poincaré, who describes them as having only completed the May 1904 results of Lorentz *dans quelques points de détail* ("in a few points of detail").

R É S U M É

Le 5 juin 1905, Poincaré présenta à l'Académie des sciences une Note intitulée « Sur la dynamique de l'électron ». Après avoir brièvement rappelé le contexte qui conduisit Poincaré à écrire cette Note, nous commentons son contenu. Nous soulignons que le modèle de l'électron proposé par Poincaré consiste à supposer que l'intérieur du tube d'univers de l'électron (creux) est rempli par une constante cosmologique positive. Nous exposons ensuite les contributions novatrices aux aspects physico-mathématiques de la relativité restreinte qui sont esquissées dans la Note. Ces contributions sont minimisées par Poincaré, qui décrit ses résultats comme ayant seulement complété les résultats de mai 1904 de Lorentz « dans quelques points de détail ».

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1. Context

In order to apprehend the meaning, and importance, of Poincaré's Note, in the 5 June 1905 issue of the *Comptes rendus* [1], it is necessary to recall its context.[1] For an access to Poincaré's works and archives, see [7]. See also the 2012 commemorative colloquium of the centenary of Poincaré's death at the French Academy of Sciences [8].

Poincaré gave sets of lectures on *Électricité et Optique*, at the Sorbonne, in 1888, 1890 and 1899. These lectures were part of his duty as holder of a chair of "Mathematical Physics and Probability Calculus" (*Physique mathématique et calcul des probabilités*). In his 1899 lectures (published as the last part of the book [9]) he expounded, in particular, Lorentz' approach to electrodynamics, which he considered as the most satisfactory one. Lorentz' approach had been developed a few years before, notably in Refs. [10,11]. Lorentz' 1892 paper [10] already implicitly contains the exact form (involving $1/\sqrt{1-v^2/c^2}$ factors) of the Lorentz transformation.[2] On the other hand, Lorentz' 1895 paper [11] works most of the time only to first order in v/c, but expounds in clearer physical terms the usefulness of defining what Lorentz called there the "local time", namely

$$t' \equiv t - \frac{1}{c^2}\mathbf{v}\cdot\bar{\mathbf{x}}\,, \tag{1}$$

where

$$\bar{\mathbf{x}} = \mathbf{x} - \mathbf{v}t\,, \tag{2}$$

denotes the usual (Galilean-transformed) spatial coordinates in a moving frame. In addition, in paragraphs 89–92, Lorentz recalls his earlier (1892) hypothesis (invented to explain the negative result of the Michelson–Morley experiment) according to which solid bodies moving with respect to the ether get contracted (in the direction of the motion) by a factor of $\simeq 1 - \frac{1}{2}\frac{v^2}{c^2}$.

Both in his 1899 lectures [9], and in his invited review talk on the *Relations entre la physique expérimentale et la physique mathématique* at the "Congrès international de physique" that took place in Paris in 1900, Poincaré expresses his dissatisfaction at Lorentz' approach, which is based on an accumulation of disconnected hypotheses (famously referred to by Poincaré as *coups de pouce*, i.e. "nudges"; see citation below). In particular, he writes about the Lorentz(–Fitzgerald) contraction hypothesis that (p. 536 of [9]):

> Cette étrange propriété semblerait un véritable « coup de pouce » donné par la nature pour éviter que le mouvement de la Terre puisse être révélé par des phénomènes optiques. Ceci ne saurait me satisfaire et je crois devoir dire ici mon sentiment : je considère comme très probable que les phénomènes optiques ne dépendent que des mouvements relatifs des corps en présence, sources lumineuses ou appareils optiques et *cela non pas aux quantités près de l'ordre du carré ou du cube de l'aberration, mais rigoureusement*. À mesure que les expériences deviendront plus exactes, ce principe sera vérifié avec plus de précision. Faudra-t-il un nouveau *coup de pouce*, une hypothèse nouvelle à chaque approximation ? Évidemment non : une théorie bien faite devrait permettre de démontrer le principe d'un seul coup dans toute sa rigueur. La théorie de Lorentz ne le fait pas encore. De toutes celles qui ont été proposées, c'est elle qui est le plus près de le faire. On peut donc espérer la rendre parfaitement satisfaisante sous ce rapport sans la modifier trop profondément.[3]

Let us also mention that, in his paper *La théorie de Lorentz et le principe de réaction* [12], written in 1900 at the occasion of the 25th anniversary of Lorentz' thesis, Poincaré discusses (as emphasized by O. Darrigol) the effect of an overall translation, at some speed v, on the synchronization of clocks by the exchange of electromagnetic signals. More precisely, he works only to *first order* in v, and notes that, if moving observers synchronize their watches by exchanging optical signals, and if they correct these signals by the transmission time under the (incorrect) assumption that the signals travel at the same speed in both directions, their watches will indicate not the "real time", but the "apparent time", say (denoting $\bar{x} \equiv x - vt$)

$$\tau = t - \frac{v\bar{x}}{c^2} + O(v^2). \tag{3}$$

His main point is that the "apparent time" τ coincides with the formal mathematical variable $t' \equiv t - \frac{v\bar{x}}{c^2} + O(v^2)$ introduced by Lorentz in 1895 under the name of "local time" (and used by him to show the invariance of Maxwell's theory under uniform translations, to first order in v).

[1] For wider, and more detailed, historical studies of Poincaré's contributions to electrodynamics, see [2–6]. See also Olivier Darrigol's text *Faut-il réviser l'histoire de la relativité ?* in the *Lettre de l'Académie des sciences* n° 14, hiver 2004, and in the *Bulletin de la SFP* (150) July–August 2005; available on http://www.academie-sciences.fr/archivage-site/activite/archive/dossiers/Einstein/Einstein-pdf/Darrigol-amp.pdf. See also Scott Walter's web page, http://scottwalter.free.fr/, for studies of several aspects of Poincaré's life and work, as well as Galina Weinstein's blog (https://myalberteinstein.com/2012/07/04/centenary-of-the-death-of-poincare-einstein-and-poincare-2012), and her papers, notably: "Poincaré's Dynamics of the Electron – A Theory of Relativity?" https://arxiv.org/pdf/1204.6576, and "A Biography of Henri Poincaré – 2012 Centenary of the Death of Poincaré" https://arxiv.org/pdf/1207.0759.

[2] See paragraph 138, pages 141–142 in [10] (one should only replace Lorentz' variable t' by $t'_{\rm new} = \sqrt{1-v^2/c^2}\,t'$ to get the exact Lorentz transformation).

[3] The italics are Poincaré's.