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Paul Ehrenfest as a mediator

(1) Introduction

In 1912, the 32 year old Austrian born theoretical physicist Paul Ehrenfest succeeded the famous Hendrik Antoon Lorentz as professor of theoretical physics in Leiden, the Netherlands. Immediately he introduced — parallel to his approach in research — an approach in teaching, which can be summarized best as: 'physics by means of communication.'

Although very original in his own research, he didn't operate at the top of his field. But in his teaching, his contacts with colleagues and even in his own research, he incessantly played the role of a mediator of knowledge. And in this way, he *was* an important physicist, despite his lack of own creative work. In this paper, I want to give some examples of his mediation.[1]

(2) Experimental test of relativity

Starting in Leiden in 1912, Ehrenfests inaugural lecture reflects his topic of interest of that time: relativity, in this case the special theory. Ehrenfest had already acquainted himself with Einstein, the two had become good friends, and several letters concerning relativity were exchanged. Ehrenfest had even drawn attention to an essential problem in relativity, which we now call the 'Ehrenfest Paradox'.[2] He thus was well informed about relativity, and in his talk he spoke about the difference between the theory of Einstein/Lorentz and the alternative emission theory of Ritz.[3]

The Swiss Walter Ritz had unfortunately died in 1909, but Ehrenfest didn't talk about Ritz' theory to honour his dearly departed friend. It just so happened that by 1912 the emission theory wasn't scrapped yet and was considered to be a serious alternative to Einstein's theory. Following Ritz' 1909 theory, the years 1910–1913 brought several further alternative emission theories by Comstock and by Tolman. Among physicists, a call for an experimental decision between the two types of theory emerged. Einstein was worried about the emission theories too, as several letters concerning possible experimental tests go back and forth between Einstein and Ehrenfest from April to May 1912.[4] Ehrenfest finally proposed a deciding experiment in his inaugural lecture.

In his example, Ehrenfest asked his listeners to envision a light source A at rest with respect to an inertial observer, and a light source B that was moving. The theory of Einstein and Lorentz predicted that the speed of light emitted by A should be *equal* to the speed of light emitted by B. Ritz' emission theory on the other hand predicted that the speed of light emitted by A and B should be *different*. Ehrenfest concluded that the experiment has never been tried as yet, because

> it needs an accuracy of measurement that we by means of our present instruments can not yet reach.[5]

The Leiden professor of astronomy De Sitter was listening to Ehrenfests talk, and set himself to the task of actually doing the experiment. He compared light coming from an eclipsing binary star, and

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[1] The author is preparing a PhD thesis on the Leiden years of Paul Ehrenfest, in which Ehrenfests mediation plays a key role.

[2] P. Ehrenfest, 'Gleichförmige Rotation starrer Körper und Relativitätstheorie', *Physikalische Zeitschrift* 10 (1909), p. 918.

[3] P. Ehrenfest, *Zur Krise der Lichtaether-Hypothese* (Leiden 1912)

[4] A. Einstein to P. Ehrenfest, see: *Einstein Papers Vol. 5*, doc. nrs. 384, 390, 394.

[5] P. Ehrenfest, *Zur Krise der Lichtaether-Hypothese* (Leiden 1912), p. 18.

found a convincing result in favour of the Einstein/Lorentz theory.[6] Because of Ehrenfest attention of the experimental problem, a solution was found, which was soon regarded as the most compelling evidence against emission theories in general.

(3) Four-dimensional space-time

This was not the only mediating role that Ehrenfest played in the work of De Sitter. De Sitter attended the famous Monday morning lectures by Lorentz and thus learned the theory of general relativity directly after its genesis. Ehrenfest invited Einstein to come to Leiden in September 1916, and brought De Sitter and Einstein together. As a result of their meeting, they engaged in a discussion on the role of boundary conditions in determining the metric field.[7]

De Sitter argued that Einsteins proposal of distant masses determining the metric field was no more satisfactory then absolute space. He set himself to the task to critically evaluate Einsteins results. In short, Einstein’s solution was three-dimensional, with an independent time component. Talking with Ehrenfest, who was deeply involved in General Relativity, Ehrenfest mentioned to De Sitter that he at one time already in 1912 had tried to use a four-dimensional spherical space-time, but that he had had terrible difficulties with the concept of time in this model, and eventually dropped the whole idea.[8] De Sitter gratefully took up Ehrenfests suggestion and *did* obtain a solution to the problem, proving that Einstein’s equation could yield a vacuum solution — the famous ‘De Sitter Solution’.

(4) Dimensionality

This previous example illustrates the strong interest that Ehrenfest had always had in the concept of dimensionality. Therefore, when the opportunity came to receive the Finnish physicist Gunnar Nordström as a guest in Leiden, Ehrenfest seized it with both hands.

Nordström in 1914 had proposed a five-dimensional alternative to Einstein’s theory of relativity, partially in cooperation with Einstein. By 1916 he had abandoned his theory, but instead he made relevant contributions to general relativity. He stayed at Ehrenfests house for three years, and they regularly spoke about things like N-dimensional space and multi-dimensional Maxwell theory. These discussions led to an article in which Ehrenfest proved that the planets could only describe closed orbits in a three-dimensional space or in a four-dimensional space-time. Ehrenfest, who taught physics by triggering ideas and giving comments to the work of others, in his turn, helped Nordström with his work on general relativity.[9]

When Ehrenfest in 1926 learned from the five-dimensional work of Oskar Klein, he immediately invited Klein to come to Leiden that June. During the entire summer Ehrenfest and his assistant Uhlenbeck spoke with Klein about his work. After his visit Klein wrote two articles, in which he stated for the first time the possibility to curl up the fifth dimension — the so-called ‘compactification’ — in order to safeguard the use of the fifth dimension without having to alter any physical law. This was his way around the problems that Ehrenfest had foreseen in his 1917 article.[10] Ehrenfests knowledge and his contacts with for example Einstein made it possible for him to act as a mediator of knowledge for Nordström and Klein.

[6] W. de Sitter, ‘A proof of the constancy of the velocity of light’, *Proceedings KAW* 15 (1913), p. 1297–1298; W. de Sitter, ‘On the constancy of the velocity of light’, *Proceedings KAW* 16 (1913), p. 395–396; W. De Sitter, ‘Ein astronomischer Beweis für die Konstanz der Lichtgeschwindigkeit’, *Physikalische Zeitschrift* 14 (1913), p. 429; W. de Sitter, ‘Über die Genauigkeit, innerhalb welcher die Unabhängigkeit der Lichtgeschwindigkeit von der Bewegung der Quelle behauptet werden kann’, *Physikalische Zeitschrift* 14 (1913), p. 1267.

[7] W. de Sitter, ‘On the relativity of rotation in Einstein’s theory’, *Proceedings KAW* 19 (1916), p. 527–532; W. de Sitter, ‘On the relativity of inertia. Remarks concerning Einstein’s latest hypothesis ’, *Proceedings KAW* 19 (1917), p. 1217–1225; W. de Sitter, ‘On the curvature of space’, *Proceedings KAW* 20 (1917), p. 229–242. See also: P. Kerszberg, *The invented universe: The Einstein–De Sitter controversy (1916–17) and the rise of relativistic cosmology* (Oxford 1989), p. 102–135.

[8] P. Ehrenfest to W. de Sitter, april 18, 1917. De Sitter Archive, Leiden, The Netherlands, Box 31.

[9] P. Halpern, ‘Nordström, Ehrenfest, and the role of dimensionality in physics’, *Physics in Perspective* 6 (2004), p. 390–400.

[10] O. Klein, ‘The atomicity of electricity as a quantum theory law’, *Nature* 118 (1926), p. 515; O. Klein, ‘Quantentheorie und fünfdimensionale Relativitätstheorie’, *Zeitschrift für Physik* 37 (1926), p. 895–906.

(5) Science and practical use

Something different now. In the previous examples we have seen Ehrenfest operate as a theoretical physicist. But although the university was still under the spell of pure science, Ehrenfest developed strong ties with Dutch industry by conducting lectures at the Physical Laboratory of the Dutch electronics factory Philips.

During the First World War, the Physical Laboratory — or ‘NatLab’ — became one of the primary employers of Dutch physicists. To guarantee a high level of research, Philips needed to draw the best physicists, but also to keep them informed of the latest developments in physics. For this, Ehrenfest was called up in 1920. From 1923 onward, Ehrenfest used his extensive international network to invite many famous foreign colleagues to the NatLab colloquium.

Ehrenfest was more or less driven to the NatLab colloquia because of the money he earned with the lectures — he had serious financial problems because of a high mortgage and his inheritance was depleted because of the Russian Revolution. Nevertheless, he was charmed by the career opportunities he saw for young physicists in industry, and his mediation made it possible for many students to obtain a job at the NatLab. He send students over to the experimental physicist Leonard Ornstein at Utrecht University, to enable them to obtain some training in practical research. Ornstein was renowned for doing — besides the fundamental research — also practical research for industrial companies. Ehrenfest recognized the value his theoretical students had for industry, if only they also had some practical skill.[11] At one time Ehrenfest even called upon his Leiden colleagues to obtain an extraordi-nary professorship for Gilles Holst, the director of NatLab.[12] This led to closer ties with NatLab and greatly enhanced industrial career opportunities for students.

(6) Econometrics

The start of Ehrenfests NatLab colloquia — although a necessary evil in the beginning — indicated a shift of interest toward more practical uses of science, which also had its impact on the research done at Ehrenfests institute for theoretical physics. Before Ehrenfest developed more utilitarian tendencies, he at one time was struck by the analogy between economy and physics, and in 1918 he pursued the path of ‘Öko-dynamik’, or ‘Eco-dynamics’, as he called this merge between economics and thermodynamics.

After working on his ‘Öko-dynamik’ for half a year, he returned to physics and never published anything about his work on economics. He left this to his student Tinbergen. Jan Tinbergen became an assistant of Ehrenfest in 1923. Tinbergen was a socialist, who called upon his fellow socialist students to prepare themselves for their future leading role in society by studying economy.[13]

Seeing that Tinbergen was more interested in economy than in physics, he began to stimulate his student to take up the economic work Ehrenfest had done in 1918. This was not just because of the analogy between physics and economics, but Ehrenfests interest in social problems strongly inclined after his recent visit to the United States.[14] At first, Ehrenfest tried to convince his American colleagues of the necessity of fundamental research. But gradually, he was convinced himself by the use of a more practical approach in research.

After his visit, Ehrenfest started to inform Tinbergen about economical concepts, and finally suggested that Tinbergen should compare physical and economical equations in his thesis. In 1929 Tinbergen got his PhD with his thesis, which was more economical then physical in content.[15]

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[11] H. Heijmans, ‘Wetenschap en industrie. L.S. Ornsteins opvattingen over toegepaste natuurkunde’, in: B. Theunissen and F. van Lunteren (eds.), *Zuivere wetenschap en praktisch nut. Visies op de maatschappelijke betekenis van wetenschappelijk onderzoek rond 1900*, theme number *Gewina* 17 (1994), p. 177–190, esp. P. 189.

[12] ‘Verklaaring der Hoogleraaren der Natuurkunde’, 12 December 1928, Ehrenfest Archive Leiden, inv. nr. ESC: 8, section 4; P. Ehrenfest to A.D. Fokker, 3 October 1928, Ehrenfest Archive Leiden, inv. nr. ESC:4, section 4.

[13] J. Tinbergen, ‘Verstand of gevoel’, *Kentering* 1 (1924) 24–25; J. Tinbergen, ‘Wiskunde – grenswaarde – Marx’, *Kentering* 1 (1925), p. 65–68.

[14] M.J. Klein, ‘Osservando l’America: la visita di P. Ehrenfest negli USA’, in: G. Battimelli, M. De Maria, A. Rossi (eds.), *La ristrutturazione delle scienze tra le due guerre mondiali Vol. 2* (1985), p. 9–24.

[15] J. Tinbergen, *Minimumproblemen in de natuurkunde en ekonomie*, Thesis (Amsterdam 1929)

For Tinbergen's development as an economist, Ehrenfest was of key importance in enabling and stimulating Tinbergen in his economical work. Ehrenfest stayed Tinbergens mentor until the formers death in 1933, and Tinbergen mentioned the 'inspired discussions' he had with Ehrenfest. Ehrenfests hand can also be seen in Tinbergen's famous analyses of the shipbuilding cycle, in which Tinbergen used the invention of his mentor, the adiabatic principle, to describe the periodic behaviour of the cycle.[16] Thus under the guidance of Ehrenfest, Tinbergen became one of the most important post-war economists in the Netherlands, and was awarded the first Nobel Prize in economics in 1969.

(7) Contacts with Eastern Europe

Ehrenfests mediation sublimated in a more direct way just after the First World War had ended. During the war, Russian physicists where virtually cut off from their Western colleagues. No foreign magazines, literature and letters could be exchanged for a long time. Travelling to and from the West was made impossible.[17]

In 1918 the Russian physicist Krutkow restored contact with Ehrenfest.[18] Ehrenfest had lived in Russia, together with his Russian wife, for a fairly long time. Ehrenfest knew a lot of people there and sympathised with their fate. Immediately he tried to do everything in his power to stimulate a revival of the dormant Russian physics.

He started to send articles and books over to bring his Russian colleagues up to date, and he encouraged his fellow physicists to do the same.[19] He encouraged promising young Russian physicists to come to Leiden. Between 1919 and 1921, Viktor Trkal, Paul Epstein and Georg Breit worked with Ehrenfest, and with each of them he published a paper.

In 1924, Ehrenfest himself was even approached to take up a chair in physics at Moscow. Although he was aware of the fact that he could do much good there, he couldn't abandon his chair in Leiden. He tried to get the chair appointed to his student Jan Burgers, who was enthusiastic about it, but the health of Burgers' wife was to poor at the time to accept a foreign position. Ehrenfest also pushed other students like Hans Kramers to visit Russia.[20]

In 1924 Ehrenfest visited Russia for the first time after his departure from Russia in 1912. He stayed for two and a half months to give lectures about the newest developments in quantum theory. A year later he arranged for sponsorship by the International Education Board. This enabled young talented Russian physicists to travel to the most important physical institutes in the West. The first to do this was Yakov Frenkel, who travelled to Pauli, Einstein and Born. In his tracks came Fock, Landau and Gamow.[21]

(8) The adiabatic principle

After the examples of relativity, multi-dimensionality and econometrics, I want to conclude with some remarks concerning Ehrenfests work on quantum theory and show that — even in his own work — mediation played a major role.

Ehrenfest started a quest for a concept that could formulate quantum rules in a more general way then the often more or less *ad hoc* assumptions that were so often made. In 1912 he found a solution in what he called the 'adiabatic invariance'. Ehrenfest applied it to diatomic gasses in 1913, finding the

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[16] M. Boumans, 'Paul Ehrenfest and Jan Tinbergen: A case of limited physics transfer', in: N. de Marchi (ed.), *Non-natural social science: Reflecting on the enterprise of 'More heat than light'*, *History of Political Economy* 25, Annual Supplement (Durham and London 1993), p. 131–156; J. Tinbergen, 'Ein Schiffbauzyklus?', *Weltwirtschaftliches Archiv* 34 (1931) 152–164; J. Tinbergen, 'Bestimmung und Deutung von Angebotskurven: Ein Beispiel', *Zeitschrift für Nationalökonomie* 1 (1930), p. 669–679.

[17] P.R. Josephson, *Physics and politics in revolutionary Russia* (Berkeley 1991), p. 72–86.

[18] P. Ehrenfest to J. Burgers, October 2, 1918. Apparently, Krutkow had written to Ehrenfest on September 14, 1918. Archive for the History of Quantum Physics, Microfilm 75.

[19] See for instance: P. Ehrenfest to N. Bohr, August 19, 1920. Archive for the History of Quantum Physics, Microfilm BSC 2.

[20] P. Ehrenfest to H. Kramers, September 9, 1920. Archive for the History of Quantum Physics, Microfilm 8.

[21] P.R. Josephson, *Physics and politics in revolutionary Russia* (Berkeley 1991), p. 131–132, here p. 113–116.

quantum rules that expressed the angular momentum of a rotating dipole.[22] In 1916 Ehrenfest showed that Sommerfelds quantum rules for a non-relativistic electron could be derived by using the adiabatic hypotheses.[23] Sommerfeld however, was not impressed. Because the adiabatic hypotheses could not be applied to relativistic models of the hydrogen atom, he didn't believe the adiabatic hypotheses to be a success.[24] Because of this criticism the emotional vulnerable Ehrenfest became rather depressed, ceasing to work on this idea for a while.

He did stimulate his student Jan Burgers however, to take up the problem. In a set of three consecutive articles, Burgers showed that the quantum conditions that were formulated by Epstein and Schwartzschild — both extensions of the quantum conditions of Sommerfeld — also were adiabatic invariants.[25] The adiabatic principle brought improved coherence to the old quantum theory. One still did not know why any system was quantized but at least the quantization of vastly distinct systems could be linked. Bohr, Einstein, Born, Fock, Fermi, Dirac and Pauli all wrote on the adiabatic hypothesis.[26] It was Ehrenfests idea, but its potential was only fully realized after the publication of Burgers' work in 1917. The collaboration of Ehrenfest and Burgers was critical to their success. After Burgers' synthesis, Einstein wrote to Ehrenfest that their work was thought highly of in Berlin[27], and Bohr made use of the adiabatic principle in his work from 1918 on.

Just *how* crucial the cooperation between Ehrenfest and Burgers was, can be seen in their correspondence.[28] In December 1918 Krutkow send Ehrenfest an article about adiabatic invariants. Ehrenfest judged the article as being sloppy, but couldn't say much more about it. He asked Burgers how *he* judged it and asked him to please help him. In 1923 this was repeated: after a question concerning a proof Burgers wrote about in his thesis of 1918, which Ehrenfest himself had supervised, Burgers had tried to explain the proof to Ehrenfest. Ehrenfest wrote that he could follow it intuitively, but couldn't figure it out. Ehrenfest invited himself over to Burgers' laboratory, asking for Burgers' help. One month later Ehrenfest was in utter despair, and ended his plea with the simple cry: "Help!".

Ehrenfest might have had the intuition and the critical skills to recognize a good idea, but Burgers had the calculating power which Ehrenfest lacked.

(9) A spinning electron

The next episode is a good illustration of Ehrenfests intuitive way of handling ideas. Because it was a crucial aspect of Ehrenfests teaching to make sure his students were informed about the most recent developments in physics, Ehrenfest in 1925 appointed his student Goudsmit to the task of informing his other student Uhlenbeck on the latest developments.[29]

Goudsmit and Uhlenbeck started reading the latest articles, including the one in which Pauli first stated his exclusion principle. In this article, *four* quantum numbers were attributed to the electron in a rather formal way. Uhlenbeck and Goudsmit, thoroughly acquainted with physical representations by Ehrenfest, were instilled with the image that each quantum number represented a degree of freedom. A point electron only had three degrees of freedom; a fourth one was only imaginable if the electron was assumed to *rotate*.

[22] P. Ehrenfest, 'Bemerkungen betreffs der spezifische Wärme zweiatomiger Gase', *Verhandlungen der Deutschen physikalischen Gesellschaft* 15 (1913), p. 451–457.

[23] P. Ehrenfest, 'On adiabatic changes of a system in connection with the quantum theory', *Proceedings AA* 19 (1916) 576–597.

[24] A. Sommerfeld to P. Ehrenfest, November 16, 1916. In: *Arnold Sommerfeld, Wissenschaftlicher Briefwechsel Band 1 1892–1918* (München 2000) doc. nr. 265.

[25] J.M. Burgers, 'Adiabatische invarianten bij mechanische systemen I', *Verslagen KAW* 25 (1917), p. 849–857; J.M. Burgers, 'Adiabatische invarianten bij mechanische systemen II', *Verslagen KAW* 25 (1917), p. 918–922; J.M. Burgers, 'Adiabatische invarianten bij mechanische systemen III', *Verslagen KAW* 25 (1917), p. 1055–1061.

[26] P. Leclercq, *De adiabatische hypothese. Ontwikkeling en toepassing in de kwantummechanica*, unpublished Masters' thesis (Utrecht University 2006).

[27] A. Einstein to P. Ehrenfest, December 6, 1918. *Einstein Papers Vol. 8B*, doc. nr. 664.

[28] P. Ehrenfest to J. Burgers, December 13, 1918; February 7, 1923; February 13, 1923; March 23, 1923. *Archive for the History of Quantum Physics*, Microfilm 75.

[29] For this episode, see: G.E. Ehlenbeck, *Oude en nieuwe vragen der natuurkunde* (Amsterdam 1955), p. 8–11.

Ehrenfest was immediately charmed by the idea, despite of the inherent problems. To explain the anomalous Zeeman Effect, the spinning electron needed a magnetic moment that was two times bigger then the angular momentum of the circular orbit around the atomic nucleus. Ehrenfest showed that the needed factor two could be calculated in a classical way, although the electron needed to spin with a velocity that was much bigger then the speed of light. Consulting Lorentz, they found that the magnetic energy of the spinning electron was *so* large, that the mass of the electron would be many times larger then that of the proton.

Uhlenbeck and Goudsmit didn't dream to go public with their idea. But Ehrenfest asked his students to write a short paper for *Naturwissenschaften*, and give it to him right away, despite the problems of the model. When Uhlenbeck and Goudsmit after some time started to seriously doubt their decision to publish a result that was so problematic, they asked Ehrenfest not to publish it. To their surprise, Ehrenfest exclaimed:

> I have sent in your paper already; you are both young enough to be able to afford one stupidity![30]

But Ehrenfest never dared to do such a thing by himself, not even in *his* younger years. He was painfully precise and didn't dare to publish anything that even had the faintest possibility to be flawed. Neither Ehrenfest, nor Uhlenbeck and Goudsmit would have separately published such a problematic idea, but it *did* happen when the three of them worked together on it.

(10) Conclusion

In this paper, I have given several examples in which Ehrenfest played the role of a mediator of knowledge. Ehrenfest himself mentioned his "ability to *conduct*"; although what he wanted to do was "compose". But already just after finishing his PhD thesis, Ehrenfest mentioned his inability to really calculate anything. During his years in Leiden, he made several essential contributions to quantum physics, but he never really belonged to the top of his field. He was aware of this, and did everything in his power to be a good teacher instead. This also meant that he used his critique and his own ideas to stimulate others. Perhaps this is formulated best by Ehrenfests student of the first hour, Jan Burgers, who said:

> Ehrenfest, so to say, distributed all that which was living and active in him. Sometimes it looked […] as if he gave away everything he had found or observed, without building up a reserve, a kind of stronghold, within himself.[31]

So it can be said that it may be that Ehrenfest himself wasn't luminous, but because of his mediating properties he certainly was a conductor of light.

[30] "Ich habe ihren Brief schon längst abgesandt; Sie sind beide jung genug om sich eine Dummheit leisten zu können!" Cited in: G.E. Ehlenbeck, *Oude en nieuwe vragen der natuurkunde* (Amsterdam 1955), p. 10–11.

[31] F. Alkemade, 'Biography', in: F.T.M. Nieuwstadt and J.A. Steketee (eds.), *Selected papers of J.M. Burgers* (Dordrecht/Boston/London 1995) p. xi–cix, esp. p. xv.