Part I

Perspectives on the 1927 Solvay conference

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Historical introduction

> Quantum reconciliation very [added, deleted] unpleasant [deleted] tendency [deleted] retrograde [deleted] questionable [added, deleted] idea [deleted] flippant [deleted] title leads to misunderstanding.
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> *(Ehrenfest, on the conference plans*[1]*)*

> The conference was surely the most interesting scientific conference I have taken part in so far.
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> *(Heisenberg, upon receipt of the conference photograph*[2]*)*

The early Solvay conferences were remarkable occasions, made possible by the generosity of Belgian industrialist Ernest Solvay and, with the exception of the first conference in 1911, planned and organised by the indefatigable Hendrik Antoon Lorentz. In this chapter, we shall first sketch the beginnings of the Solvay conferences, Lorentz's involvement and the situation in the years leading up to 1927 (Sections 1.1 and 1.2). Then we shall describe specifically the planning of the fifth Solvay conference, both in its scientific aspects (Section 1.3) and in its more practical aspects (Section 1.4). Section 1.5 presents the day-by-day progress of the conference as far as it can be reconstructed from the sources, while Section 1.6 follows the making of the volume of proceedings, which is the main source of original material from the fifth Solvay conference and forms Part III of this book.

1.1 Ernest Solvay and the Institute of Physics

Ernest Solvay had an extensive record of supporting scientific, educational and social initiatives, as Lorentz emphasises in a two-page document written in September 1914, during the first months of the First World War:[3]

> I feel bound to say some words in these days about one of Belgium's noblest citizens, one of the men whom I admire and honour most highly. Mr Ernest Solvay ... is the founder

of one of the most flourishing industries of the world, the soda manufacture based on the process invented by him and now spread over Belgium, France, England, Germany, Russia and the United States. . . . The fortune won by an activity of half a century has been largely used by Mr Solvay for the public benefit. In the firm conviction that a better understanding of the laws of nature and of human society will prove one of the most powerful means for promoting the happiness of mankind, he has in many ways and on a large scale encouraged and supported scientific research and teaching.

Part of this activity was centred around the project of the Cité Scientifique, a series of institutes in Brussels founded and endowed by Ernest Solvay and by his brother Alfred Solvay, which culminated in the founding of the Institutes of Physics and of Chemistry in 1912 and 1913.[a]

This project had originally developed through the chance encounter between Ernest Solvay and Paul Héger, physician and professor of physiology at the Université Libre de Bruxelles (ULB), and involved a collaboration between Solvay, the ULB and the city of Brussels. In June 1892, it was agreed that Solvay would construct and equip two Institutes of Physiology on land owned by the city in the Parc Léopold in Brussels.[b] There soon followed in 1893–4 an Institute for Hygiene, Bacteriology and Therapy, funded mainly by Alfred Solvay, and a School of Political and Social Sciences, founded by Ernest Solvay in 1894, which moved to the Cité Scientifique in 1901, and to which a School of Commerce was added in 1904.

The idea for what became known as the first Solvay conference in physics goes back to Wilhelm Nernst and Max Planck,[c] who around 1910 considered that the current problems in the theory of radiation and in the theory of specific heats had become so serious that an international meeting (indeed a 'council') should be convened in order to attempt to resolve the situation. The further encounter between Nernst and Solvay provided the material opportunity for the meeting, and by July 1910, Nernst was sending Solvay the detailed proposals. He had also secured the collaboration of Lorentz (who was eventually asked to preside), of Knudsen and naturally of Planck, who wrote:

. . . anything that may happen in this direction will excite my greatest interest and . . . I promise already my participation in any such endeavour. For I can say without exaggeration that in fact for the past 10 years nothing in physics has so continuously stimulated, excited and irritated me as much as these quanta of action.[d]

[a] The following material on the Cité Scientifique is drawn mainly from Despy-Meyer and Devriese (1997).
[b] One was to become property of the city and given in use to the ULB, while the other was to be leased for 30 years to and run by Solvay himself.
[c] In the rest of this and in part of the following sections, we draw on an unpublished compendium of the contents of the IIPCS archives by J. Pelseneer.[4]
[d] Exquisite ending in the original: '. . . dass mich seit 10 Jahren im Grunde nichts in der Physik so ununterbrochen an-, er-, und aufregt wie diese Wirkungsquanten'.[5]

The first Solvay conference took place between 30 October and 3 November 1911. Lorentz set up a committee to consider questions relating to the new experimental research that had been deemed necessary during the conference. This committee included Marie Curie, Brillouin, Warburg, Kamerlingh Onnes, Nernst, Rutherford and Knudsen. Lorentz in turn was asked to be the president. Further, at the end of the conference, Solvay proposed to Lorentz the idea of a scientific foundation. Lorentz's reply to Solvay's proposals, of 4 January 1912, includes extremely detailed suggestions on the functions and structure of the foundation, all of which were put into practice and which can be summarised as follows.[6]

The foundation would be devoted principally to physics and physical chemistry, as well as to questions relating to physics from other sciences. It would provide international support to researchers ('a Rutherford, a Lenard, a Weiss') in the form of money or loan of scientific instruments, and it would provide scholarships for young Belgian scientists (both men and women) to work in the best laboratories or universities, mostly abroad. The question of a link between the foundation and the 'Conseil de physique' was left open, but Lorentz suggested to provide meeting facilities if Solvay wished to link the two. Lorentz suggested instituting an administrative board (consisting of a Solvay family member or appointee, an appointee of the King, and a member of the Belgian scientific establishment) and a scientific committee (which could initially be the one he had formed during the first Solvay conference). Finally, Lorentz suggested housing the foundation in an annex of one of the existing institutes in the Cité Scientifique.

During January, Solvay sent Paul Héger to Leiden to work with Lorentz on the statutes of the foundation, which Lorentz sent to Solvay on 2 February. Solvay approved them with hardly any modifications (only such as were required by the Belgian legislation of the time). The foundation, or rather the 'Solvay International Institute of Physics', was officially established on 1 May 1912, thus predating by several years the establishment of the comparable Belgian state institutions (Fondation Universitaire, 1920; Fonds National de la Recherche Scientifique, 1928). In this connection, Lorentz hoped 'that governments would understand more and more the importance of scientific research and that in the long run one will arrive at a satisfactory organisation, independent of the individual efforts of private persons',[7] a sentiment echoed by Solvay himself.[8]

The institute, which Solvay had endowed for 30 years, could soon boast of remarkable activity in supporting scientific research. The numerous recipients of subsidies granted during the first two years until the First World War included Lebedew's laboratory, von Laue, Sommerfeld, Franck and Hertz, W. L. Bragg (who was later to become president of the scientific committee), Stark, and Wien. In 1913, an Institute of Chemistry followed suit, organised along similar lines to the Institute of Physics.

1.2 War and international relations

The first meeting of the scientific committee, for the planning of the second Solvay conference, took place on 30 September and 1 October 1912. The conference was held the following year, but the activities of the institute were soon disrupted by the start of the First World War, in particular the German invasion of Belgium.

Immediate practical disruption included the fear of requisitions, the difficulty of communication between the international membership of the scientific committee and, with regard to the publication of the proceedings of the second Solvay conference, the impossibility of sending Lorentz the proofs for correction and the eventual prospect of German censorship.[a]

The war, however, had longer-term negative implications for international intellectual cooperation. In October 1914, a group of 93 representatives of German science and culture signed the manifesto 'An die Kulturwelt!', denying German responsibilities in the war.[b] Among the signatories were both Nernst and Planck. This manifesto was partly responsible for the very strong hostility of French and Belgian scientists and institutions towards renewal of scientific relations with Germany after the war.

No Germans or Austrians were invited to the third Solvay conference of 1921. The only exception (which remained problematic until the last minute) was Ehrenfest, who was Austrian, but who had remained in Leiden throughout the war as Lorentz's successor. Similarly, no Germans participated in the fourth Solvay conference of 1924. French and Belgian armies had occupied the Ruhr in January 1923, and the international situation was particularly tense. Einstein had (temporarily) resigned from the League of Nations' Committee on Intellectual Cooperation, and wrote to Lorentz that he would not participate in the Solvay conference because of the exclusion of the German scientists, and if he could please make sure that no invitation was sent.[9] Bohr also declined to participate in the conference apparently because of the continued exclusion of German scientists (Moore 1989, p. 157). Schrödinger, however, who was Austrian and working in Switzerland, was invited.[c]

[a] The proceedings of the first Solvay conference had had both a French and a German edition. Those of the second Solvay conference were printed in three languages in 1915, but never published in this form and later mostly destroyed. Only under the changed conditions after the war, in 1921, were the proceedings published in a French translation (carried out, as on later occasions, by J.-É. Verschaffelt).

[b] The main claims of the manifesto were: '. . . *It is not true* that Germany is the cause of this war. . . . *It is not true* that we have wantonly [freventlich] infringed the neutrality of Belgium. . . . *It is not true* that the life and property of a single Belgian citizen has been touched by our soldiers, except when utter self-defence required it. . . . *It is not true* that our troops have raged brutally against Leuven. . . . *It is not true* that our conduct of war disregards the laws of international right. . . . *It is not true* that the struggle against our so-called militarism is not a struggle against our culture. . ..' (translated from Böhme 1975, pp. 47–9).

[c] Van Aubel (a member of the scientific committee) objected strongly in 1923 to the possibility of Einstein being invited to the fourth Solvay conference, and resigned when it was decided to invite him. It appears he was convinced to remain on the committee.[10]

Einstein had distinguished himself by assuming a pacifist position during the war.[a] Lorentz was pointing out Einstein's exceptional case to Solvay already in January 1919:

> However, in talking about the Germans, we must not lose sight of the fact that they come in all kinds of nuances. A man like Einstein, the great and profound physicist, is not 'German' in the sense one often attaches to the word today; his judgement on the events of the past years will not differ at all from yours or mine.[11]

In the meantime, after the treaty of Locarno of 1925, Germany was going to join the League of Nations, but the details of the negotiations were problematic.[b] As early as February 1926, one finds mention of the prospect of renewed inclusion of German scientists at the Solvay conferences.[13] In the same month, Kamerlingh Onnes died, and at the next meeting of the scientific committee, in early April (at which the fifth Solvay conference was planned), it was decided to propose both to invite Einstein to replace Onnes and to include again the German scientists.

On 1 April, Charles Lefébure, then secretary of the administrative commission, wrote to commission members Armand Solvay and Jules Bordet,[c] enquiring about the admissibility of 'moderate' figures like Einstein, Planck[d] and others.[16] On 2 April, Lorentz himself had a long interview with the King, who gave his approval.

Thus, finally, Lorentz wrote to Einstein on 6 April, informing him of the unanimous decision by the members of the committee present at the meeting,[e] as well as of the whole administrative commission, to invite him to succeed Kamerlingh Onnes. The Solvay conferences were to readmit Germans, and if Einstein were a member of the committee, Lorentz hoped this would encourage the German scientists to accept the invitation.[17] Einstein was favourably impressed by the positive Belgian attitude and glad to accept the invitation under the altered conditions.[18] Lorentz proceeded to invite the German scientists, 'not because there

[a] For instance, Einstein was one of only four signatories of the counter-manifesto 'Aufruf an die Europäer' (Nicolai 1917). Note also that Einstein had renounced his German citizenship and had become a Swiss citizen in 1901, although there was some uncertainty about his citizenship when he was awarded the Nobel prize (Pais 1982, pp. 45, 503–4).

[b] Lorentz to Einstein on 14 March 1926: 'Things are bad with the League of Nations; if only one could yet find a way out until the day after tomorrow'.[12] Negotiations provisionally broke down on 17 March, but Germany eventually joined the League in September 1926.

[c] Lefébure was the appointee of the Solvay family to the administrative commission, and as such succeeded Eugène Tassel, who had been a long-standing collaborator of Ernest Solvay since 1886, and had died in October 1922. Armand Solvay was the son of Ernest Solvay, who had died on 26 May 1922. Bordet was the royal appointee to the commission, and had just been appointed in February 1926, following the death of Paul Héger.[14]

[d] According to Lorentz, Planck had always been helpful to him when he had tried to intervene with the German authorities during the war. Further, Planck had somewhat qualified his position with regard to the Kulturwelt manifesto in an open letter, which he asked Lorentz to publish in the Dutch newspapers in 1916. On the other hand, he explicitly ruled out a public disavowal of the manifesto in December 1923.[15]

[e] Listed as Marie Curie, Langevin, Richardson, Guye and Knudsen (with two members absent, W. H. Bragg and Van Aubel).

should be such a great haste in the thing, rather to show the Germans as soon as possible our good will',[19] and sent the informal invitations to Born, Heisenberg and Planck (as well as to Bohr) in or around June 1926.[20]

As late as October 1927, however, the issue was still sensitive. Van Aubel (who had not been present at the April 1926 meeting of the scientific committee) declined the official invitation to the conference, apparently because of the presence of the German scientists.[21] Furthermore, it was proposed to release the list of participants to the press only after the conference to avoid public demonstrations. Lorentz travelled in person to Brussels on 17 October to discuss the matter.[22]

Lorentz's own position during and immediately after the war, as a physicist from one of the neutral countries, had possibly been rather delicate. In the text on Ernest Solvay from which we have quoted at the beginning of this chapter, for instance, he appears to be defending the impartiality of the policies of the Institute of Physics in the years leading up to the war. Lorentz started working for some form of reconciliation as soon as the war was over, writing as follows to Solvay in January 1919:

> All things considered, I think I must propose to you not to exclude formally the Germans, that is, not to close the door on them forever. I hope that it may be open for a new generation, and even that maybe, in the course of the years, one may admit those of today's scholars who one can believe regret sincerely and honestly the events that have taken place. Thus German science will be able to regain the place that, despite everything, it deserves for its past.[23]

It should be noted that Lorentz was not only the scientific organiser of the Solvay institute and the Solvay conferences, but also a prime mover behind efforts towards international intellectual cooperation, through his heavy involvement with the Conseil International de Recherches, as well as with the League of Nations' Committee on Intellectual Cooperation, of which he was a member from 1923 and president from 1925.[a]

Lorentz's figure and contributions to the Solvay conferences are movingly recalled by Marie Curie in her obituary of Lorentz in the proceedings of the fifth Solvay conference (which opens Part III of this volume).

1.3 Scientific planning and background

What was at issue in the remark that heads this chapter,[b] scribbled by Ehrenfest in the margin of a letter from Lorentz, was the proposed topic for the fifth

[a] The Conseil International de Recherches (founded in 1919) has today become the International Council for Science (ICSU). The Committee on Intellectual Cooperation (founded in 1922) and the related International Institute of Intellectual Cooperation (inaugurated in Paris in 1926) were the forerunners of UNESCO.[24]

[b] In the original: 'Quantenverzoening <{zeer} antipathik<e>> <tendentie> <retrograde> <{bedenkelijk<e>}> <idee> <loszinnige> [?] titel wekt misverstand'. Many thanks to Mark van Atten for help with this passage.

Solvay conference, namely 'the conflict and the possible reconciliation between the classical theories and the theory of quanta'.[25] Ehrenfest found the phrasing objectionable in that it encouraged one to 'swindle away the fruitful and suggestive harshness of the conflict by most slimy unclear thinking, quite in analogy with what happened also even after 1900 with the mechanical ether theories of the Maxwell equations', pointing out that 'Bohr feels even more strongly than me against this slogan [Schlagwort], precisely because he takes it so particularly to heart to find the foundations of the future theory'.[26]

Lorentz took Ehrenfest's suggestion into account, and dropped the reference to reconciliation both from the title and from later descriptions of the focus of the meeting.[a]

The meeting of the scientific committee for the planning of the fifth Solvay conference took place in Brussels on 1 and 2 April 1926. Lorentz reported a few days later to Einstein:

> As the topic for 1927 we have chosen 'The quantum theory and the classical theories of radiation', and we hope to have the following reports or lectures:
> *1* W. L. Bragg. New tests of the classical theory.
> *2* A. H. Compton. Compton effect and its consequences.
> *3* C. T. R. Wilson. Observations on photoelectrons and collision electrons by the condensation method.
> *4* L. de Broglie. Interference and light quanta.
> *5* (short note): Kramers. Theory of Slater–Bohr–Kramers and analogous theories.
> *6* Einstein. New derivations of Planck's law and applications of statistics to quanta.
> *7* Heisenberg. Adaptation of the foundations of dynamics to the quantum theory.[28]

Another report, by the committee's secretary Verschaffelt,[29] qualifies point *5*, making it conditional on Kramers judging that it is still useful; it further lists a few alternative speakers: Compton or Debye for *2*, Einstein or Ehrenfest for *6*, and Heisenberg or Schrödinger for *7*.[b]

Thus, the fifth Solvay conference, as originally planned, was to focus mainly on the theory of radiation and on light quanta, including only one report on the new quantum theory of matter. The shift in focus between 1926 and 1927 was clearly due to major theoretical advances (for example by Schrödinger and Dirac) and new experimental results (such as the Davisson–Germer experiments), and it can be partly followed as the planning of the conference progressed.

[a] To Bohr in June 1926: '... the conflict between the classical theories and the quantum theory ....'; to Schrödinger in January 1927: '... the contrast between the current and the earlier conceptions [Auffassungen] and the attempts at development of a new mechanics'.[27]
[b] For details of the other participants, see the next section.

Schrödinger's wave mechanics was one of the major theoretical developments of the year 1926. Einstein, who had been alerted to Schrödinger's first paper by Planck (cf. Przibram 1967, p. 23), suggested to Lorentz that Schrödinger should talk at the conference instead of himself, on the basis of his new 'theory of quantum states', which he described as a development of genius of de Broglie's ideas.[30] While it is unclear whether Lorentz knew of Schrödinger's papers by the time of the April meeting,[a] Schrödinger was listed a week later as a possible substitute for Heisenberg, and Lorentz himself was assuring Einstein at the end of April that Schrödinger was already being considered, specifically as a substitute for the report on the new foundations of dynamics rather than for the report on quantum statistics.[b]

Lorentz closely followed the development of wave mechanics, indeed contributing some essential critique in his correspondence with Schrödinger from this period, for the most part translated in Przibram (1967) (see Chapter 4, especially Sections 4.3 and 4.4, for some more details on this correspondence). Lorentz also gave a number of colloquia and lectures on wave mechanics (and on matrix mechanics) in the period leading up to the Solvay conference, in Leiden, Ithaca and Pasadena.[31] In Pasadena he also had the opportunity of discussing with Schrödinger the possibility that Schrödinger may also give a report at the conference, as in fact he did.[c] Schrödinger's wave mechanics had also made a great impression on Einstein, although he repeatedly expressed his unease to Lorentz at the use of wave functions on configuration space (calling it obscure,[33] harsh,[34] a mystery[35]), and again during the general discussion (p. 442).

One sees Lorentz's involvement with the recent developments also in his correspondence with Ehrenfest. In particular, Lorentz appears to have been struck by Dirac's contributions to quantum mechanics.[d] In June 1927, Lorentz invited Dirac to spend the following academic year in Leiden,[37] and asked Born and Heisenberg to include a discussion of Dirac's work in their report.[38] Finally, in late August, Lorentz decided that Dirac, and also Pauli, ought to be invited to the conference, for indeed:

> Since last year, quantum mechanics, which will be our topic, has developed with an unexpected rapidity, and some physicists who were formerly in the second tier have made extremely notable contributions. For this reason I would be very keen to invite also Mr Dirac of Cambridge and Mr Pauli of Copenhagen. . . . Their collaboration would be very

[a] Cf. Section 4.1.
[b] Note that Schrödinger (1926a) had written on 'Einstein's gas theory' in a paper that is an immediate precursor to his series of papers on quantisation.
[c] Lorentz was at Cornell from September to December 1926, then in Pasadena until March 1927.[32] On Schrödinger's American voyage, see Moore (1989, pp. 230–3).
[d] This correspondence includes for instance a 15-page commentary by Lorentz on Dirac (1927a).[36]

useful to us . . . I need not consult the scientific committee because Mr Dirac and Mr Pauli were both on a list that we had drawn up last year . . ..[39]

Lorentz invited Pauli on 5 September 1927 (Pauli 1979, pp. 408–9) and Dirac sometime before 13 September 1927.[40]

On the experimental side, some of the main achievements of 1927 were the experiments on matter waves. While originally de Broglie was listed to give a report on light quanta, the work he presented was about both light quanta and material particles (indeed, electrons and photons!), and Lorentz asked him explicitly to include some discussion of the recent experiments speaking in favour of the notion of matter waves, specifically discussing Elsasser's (1925) proposals, and the experimental work of Dymond (1927) and of Davisson and Germer (1927).[41] Thus, in the final programme of the conference, we find three reports on the foundations of a new mechanics, by de Broglie, Heisenberg (together with Born) and Schrödinger.

The talks given by Bragg and Compton, instead, reflect at least in part the initial orientation of the conference. Here is how Compton presents the division of labour (p. 301):

> Professor W. L. Bragg has just discussed a whole series of radiation phenomena in which the electromagnetic theory is confirmed. . . . I have been left the task of pleading the opposing cause to that of the electromagnetic theory of radiation, seen from the experimental viewpoint.

Bragg focusses in particular on the technique of X-ray analysis, as the 'most direct way of analysing atomic and molecular structure' (p. 260), in the development of which, as he had mentioned to Lorentz, he had been especially interested.[42] This includes in particular the investigation of the electronic charge distribution. At Lorentz's request, he had also included a discussion of the refraction of X-rays (Section 8 of his report), which is directly relevant to the discussion after Compton's report.[43] As described by Lorentz in June 1927, Bragg was to report 'on phenomena that still somehow allow a classical description'.[44] A few more aspects of Bragg's report are of immediate relevance for the rest of the conference, especially to the discussion of Schrödinger's interpretation of the wave function in terms of an electric charge density (pp. 280, 285, Section 4.4), and so are some of the issues taken up further in the discussion (Hartree approximation, problems with waves in three dimensions), but it is fair to say that the report provides a rather distant background for what followed it.

Compton's report covers the topics of points *2* and *3* listed above. The explicit focus of his report is the three-way comparison between the photon hypothesis, the Bohr–Kramers–Slater (BKS) theory of radiation, and the classical theory of