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**The Historical Development
of
Quantum Theory**

VOLUME 1

Part 1

**The Quantum Theory of
Planck, Einstein, Bohr and Sommerfeld:
Its Foundation and the Rise of Its Difficulties
1900–1925**

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**The Historical Development
of
Quantum Theory**

Ô récompense après une pensée
Qu'un long regard sur le calme des dieux!
PAUL VALÉRY
Le Cimetière marin

I took pains to determine the flight of
crook-taloned birds, marking which were
of the right by nature, and which of the
left, and what were their ways of living,
each after his kind, and the enmities and
affections that were between them, and
how they consorted together.

AESCHYLUS
Prometheus Vincitus

Preface

Bertrand Russell quotes Callimachus, the Alexandrian poet, to say that ‘A big book is a big evil!’¹ Russell himself wrote some big books which had a large influence. As evils go, this book is a minor one. Nevertheless it calls for an explanation. The discovery and development of quantum theory in the twentieth century is an epic story and demands appropriate telling. This story cannot be told in the fullness of its glory without analyzing in some detail the multitude of problems which together came to constitute the fabric of quantum theory. Much more than the relativity theories, both special and general, which completed the edifice of classical mechanics, the quantum theory is unique in the history of science and the intellectual history of man: in its conceptions it made a complete break with the past and fashioned a new worldview about the structure of matter and radiation and many of the fundamental forces of nature.

My own intellectual development and choice of occupation, how I began to pursue the historical and conceptual development of modern physics, and how this work came to be written, are bound up with the story of my encounters with major quantum physicists and some literary figures. I shall briefly narrate it here. Since my early youth I had a number of heroes among physicists, mathematicians, philosophers and literary personalities, about whose lives and achievements I wanted to find out more. In my studies I had been greatly intrigued by the theories of modern physics, especially relativity and quantum theory, and had encountered the names of Planck, Einstein, Bohr, Born, Pauli, Heisenberg, Dirac and Schrödinger. Among all these personalities the name of Albert Einstein had a powerful attraction, and I read all about Einstein and his work—including his own scientific and general writings—that I could lay my hands on. In spring 1952 I wrote an essay with the pretentious title of ‘Albert Einstein’s Philosophy of Science and Life,’ which only youthful exuberance could allow. This essay won a small prize in a competition, but the real reward came from Einstein himself. He sent me a one-sentence letter which said:

112 Mercer Street
Princeton, N. J.
July 2nd, 1952

Dear Sir:

Apart from too unwarranted praise I find your characterization of my convictions and personal traits quite veracious and showing psychological understanding.

With kind greetings and wishes,
Sincerely yours,
Albert Einstein

¹ Bertrand Russell: *Wisdom of the West*, Crescent Books, Crown Publishers, Inc., New York, 1978, p. 5.

This kind letter inspired me for a long time and I hoped that one day I shall have occasion to meet some of the great quantum physicists in person, and that I shall pursue with them the question of how they had come upon their discoveries. It happened sooner than I had expected.

In the following I will mention the names of many famous physicists. I should at once state that I do not do so to express any easy familiarity with them. It was an enormous privilege and good fortune that I encountered them in the course of my work on the historical development of physics in the twentieth century, a privilege and fortune for which I am deeply grateful. Many of them became my 'sources.' I came to have great respect and, in a number of cases, affection for them; some of them began by being my heroes and became my good friends. Oscar Wilde says somewhere that: 'There are two tragedies in life: one is not to meet any of your heroes, the other is to meet them all.' In my case, I met most of them, and I have had the greatest pleasure.

Encounters with Quantum Physicists

In fall 1952 I received a fellowship, awarded by the German industrialist Oskar Henschel, with the help of which I could pursue advanced studies in almost any university of Western Europe that would accept me. My ambition was to go to Göttingen to study under Werner Heisenberg, whose name and work, after Einstein's, captivated me the most. But in mid-November 1952 I first went to Zurich to see Wolfgang Pauli. At the *Eidgenössische Technische Hochschule* (E.T.H.), at 35 *Gloriastrasse*, on Tuesday, 11 November, my first encounter was with Walter Thirring, who had just come down from Göttingen after a period of stay at the *Max-Planck-Institut für Physik und Astrophysik*, where Heisenberg was. Thirring told me that not much active work in physics was going on at Göttingen, and that Zurich was a better place to be. That afternoon I attended the theoretical physics seminar at the E.T.H., at which Robert Schafroth spoke about some work on superconductivity. In the lecture hall I sat in the back row next to a much older person and struck a conversation with him before the seminar began. He told me he was Otto Stern. I knew about the Stern-Gerlach experiment and was delighted to make the acquaintance of a prominent quantum physicist right away. Stern told me he was visiting Pauli. I told him that I had also come to see Pauli, but that I was rather awed by the prospect because I had heard about his terrible temper. Stern reassured me that Pauli was actually very kind. We agreed to meet the next day for lunch. Next morning, before meeting Pauli I saw Paul Scherrer, who was kind and charming. He also assured me that behind his gruff manner Pauli was really a friendly person, and he offered to take me to Pauli and make the introduction. Thus braced, I went in to see Pauli. He looked like the owner of a delicatessen, who consumed his own wares more than was good for him, but his eyes had a spiritual radiance. He received me kindly enough and talked with me about my background and education, about

Zurich and the E.T.H., and told me what the various theoreticians were doing at the *Physikalisches Institut der E.T.H.* As he did so he kept bobbing his head up and down and rocking his body from side to side. He asked me what I wanted to do. I expressed my wish to work on some aspect of quantum theory, perhaps on a problem of quantum electrodynamics. I also mentioned that I wanted to learn about the development of quantum theory from various angles and that some day I hoped to write about it. Pauli laughed, at what probably seemed to him to be my audacity. He said the ‘creators’ of modern quantum theory were all still around and I could find things from them, ‘but you will have to learn an awful lot to be able to write about the development of quantum theory; it may seem easy but it is not.’ He said that since I had a fellowship and was provided for, I could work at his Institute if I so desired. However, he said, I should meet Heisenberg before deciding on Zurich as a place to study, but if I chose Göttingen he would still be glad to talk to me and ‘you can use me as a source.’ I told Pauli that I was going to Göttingen to see Heisenberg and would inform him how things developed, and took his leave.

Afterwards I had lunch with Stern in a bistro at *Limmat-Quai* near the railway station in Zurich. I reported to him about my meeting with Pauli. Stern told me that Pauli had himself witnessed the entire development of quantum theory and participated in it since 1920, that Pauli alone was really qualified to write about it, and that of all people he had the ‘moral right to do so.’ But Stern was not sure whether Pauli would actually ever do it.

That same evening, Wednesday, 12 November, I took the night train from Zurich to Göttingen; it was the express which travelled from Rome to Hamburg, Copenhagen and Stockholm. The train arrived in Göttingen at 4:30 A.M. It was still very dark, and I was the only passenger to alight on the platform. The porter took me to the waiting room with my luggage. I anxiously waited in the coffee shop, then at 8:30 I took a taxicab to the *Max-Planck-Institut für Physik, Böttingerstrasse 4*. I did not speak any German, but somehow I made it clear enough to the concierge that I wanted to see Professor Heisenberg. The concierge called Fräulein Giese, Heisenberg’s secretary, a kind and courteous young lady, who took me to meet Harry Lehmann, then Heisenberg’s assistant. He sat in a small office in which there was barely room for another chair. I had already informed Heisenberg about my arrival in Göttingen, and Lehmann knew I was coming. Lehmann spoke good English and he discussed my plans with me. He promised that he would soon arrange my meeting with Heisenberg. At about 9:30 A.M. a middle-aged, well-dressed gentleman looking like a prosperous haberdasher walked into Lehmann’s office. He and Lehmann talked to each other in German; the visitor gave a nod to me with a smile, shook hands with me and soon left, leaving behind a stack of papers for Lehmann. Lehmann told me that this was Professor Heisenberg and my appointment to see him was fixed for 10 o’clock the next morning, Friday, 14 November. I felt very happy that I had already been introduced to the famous Heisenberg without realizing it. Lehmann introduced me to several members of the Institute, and I spent the day with

them: Reimar Lüst, Sebastian von Hörner, Kurt Symanzik, the American physicist Richard Farrell, the Italian physicist Paolo Budini, and a few others. They were all much senior to me; I was over ten years younger than Symanzik, who was then the youngest member of the Institute. I found the German and foreign physicists I met at the Institute very congenial. I was invited to spend that night at the apartment of a member of the Institute, but I was full of anticipation about my meeting with Werner Heisenberg the next morning.

At the appointed time I presented myself at Heisenberg's office. Fräulein Giese immediately ushered me into his inner office, past a double door, the inner door made of foam rubber and cork as in a sound studio. It was an elegantly furnished, comfortable office, done in soft blue, with a large uncluttered executive desk and chair which Heisenberg used, a light beige sofa and easy chairs for visitors, and a huge vase of fresh cut flowers at the coffee table. Heisenberg received me warmly. He wore a medium-gray worsted suit and a striped blue-and-white tie, with a gold pin bearing the letter \hbar (which I later learned was a present from the members of the Theoretical Physics Seminar at Leipzig) stuck into the knot of his tie. He was gentle and soft-spoken. He spoke excellent English with a faint touch of German-Danish accent, a reminder of the fact that he had learned his English in Copenhagen, but it had been perfected over the years.

Heisenberg made me feel at home and welcome and we talked about many things: about science, literature and theatre, and about Göttingen, Munich and Copenhagen. He told me about the great tradition of Göttingen in mathematics and physics and about the cultural life of the city. Then, gently but inevitably, he asked me about my background, education, and the subjects I had studied and liked (though he had already received the transcripts of my academic record earlier). He also asked me about my plans, but in a tone that he earnestly wished to encourage me in any worthwhile pursuit. I told him what I had told Pauli: that I wanted to learn all about quantum theory and its historical and conceptual development, that I wanted to have the opportunity of talking to all the living pioneers, and that hopefully I would write about it some day. I could not fail to notice the contrast with Pauli: Pauli, corpulent, overbearing and forbidding; Heisenberg, gentle, urbane, civilized and, at fifty-two, in the best of health, with a rather round face and balding head. Heisenberg thought that this was a 'wonderful idea,' that quantum theory had 'introduced a new way of thinking about physical problems' and had 'produced new insights about the workings of nature.' 'It would be wonderful,' he said, 'to write about the historical development of quantum theory in a rigorous and detailed manner.' He explained to me that probably the best way to proceed was to learn about quantum physics by doing research problems. 'In this way,' he said, 'you would learn the theory from the inside. And you can build on your knowledge by studying the original papers and finding out about their scientific and human background, about how they came to be written. Work on actual research problems of today will help you master the subject more easily.' At the institute, he said, the main fields of

research were nuclear physics, elementary particle physics and quantum field theory. He told me that numerous theoreticians at the Institute were able to work with the S -matrix and were well versed in quantum field theory. He suggested that I should study Walter Heitler's book on quantum theory of radiation, Gregor Wentzel's book on quantum theory of fields, and Freeman Dyson's notes of lectures (delivered at Cornell University) on 'quantum electrodynamics,' a few copies of which were in circulation among the theoreticians at the *Max-Planck-Institut für Physik*. He advised me to study carefully the papers of Tomonaga, Schwinger, Feynman and Dyson on quantum electrodynamics. Heisenberg also assigned to me a research problem about which Paul Scherrer had written to him from Zurich: this was to construct a theory of neutron–deuteron scattering at 3.24 meV. Heisenberg said that I was welcome to work at the Institute, and he invited me to stay in the guest quarters at the Institute itself until I had found lodgings of my own. This was a most rewarding meeting and I felt full of admiration for Heisenberg and hopeful about my possibilities.

A desk was assigned to me in an office and I immediately became engaged in the tasks given to me. In addition, I attended courses given by Heisenberg, Carl Friedrich von Weizsäcker and Richard Becker at the University of Göttingen, as well as other courses in the institutes of mathematics and philosophy. I carried a full load of activities and enjoyed the challenging assignments.

There were regular seminars at the *Max-Planck-Institut für Physik*: Wednesday mornings on nuclear physics and Thursday afternoons on quantum field theory. On Thursdays there would be tea and cookies after the seminar. After the first Thursday seminar on field theory and tea, Heisenberg invited me to go for a walk with him. The Institute was situated at the edge of the city, and soon we were walking on a meadow close to the woods in the falling darkness. I took advantage of this opportunity to ask Heisenberg about the old days of quantum theory in the early 1920s when he became Sommerfeld's disciple. Heisenberg first told me about himself, about his growing up and schooling in Munich, about his interests as a youngster, and about the difficult economic and political times during and following the First World War. He then told me about his first encounter with Arnold Sommerfeld and how at the very beginning of his university studies he got into research. During the walk I interrupted him with many questions and he responded to them candidly. On my return to my room I wrote down an almost verbatim account of our conversation and gave it to Heisenberg the following Monday to check, add or subtract. The following Thursday he again asked me to take a walk, and then it became our custom to take a short or a long walk, depending on the time available to Heisenberg, on most Thursdays when he was in town and weather permitted. As I learned more about quantum theory from original papers, I was able to ask him more searching questions about the context in which the problems had arisen, the manner in which they were approached, and the human interactions at the time the work was done; I regularly wrote down my notes and had them edited by him. For me this process was wonderful and Heisenberg's company inspiring.

But I noticed that Heisenberg enjoyed it too. He was young enough to remember still all the details of everything that had happened and old enough to enjoy looking back at the exciting moments of the past and telling about them; I was the aspiring chronicler of these ideas and events.

I pursued the story of the period of the creation of quantum mechanics during at least a dozen encounters with Heisenberg. It had been the most thrilling period of his life, and he was full of memories, feelings and sentiment about it. He told me about his visit to Berlin to give a colloquium on quantum mechanics (on 26 April 1926) at the invitation of Planck and Einstein. It was a great day for Heisenberg to address the famous Berlin Colloquium with many illustrious physicists in the audience. After his talk and discussion in the colloquium he walked with Einstein to his house and they had their first conversation in which Einstein wanted to know how Heisenberg had come upon his fundamental idea leading to the discovery of quantum mechanics. That evening Heisenberg went to a party in his honour at the *Studentenhaus*. 'I was very happy,' he said. 'I played a Beethoven sonata on the piano for the students. I had come of age as a physicist!'²

My discussions with Heisenberg continued even after I left Göttingen in April 1955. I saw him over the years in Göttingen, Munich, Varenna, Lindau, Geneva, Trieste and Brussels, and our conversations were resumed without suffering from the intervening lapses of time. When we did not go for walks and talked in his office, I often recorded our conversations on tape. My last conversation with him—dealing with his latest views about the nature of elementary particles, and some questions I still wanted to discuss with him about Einstein, Born and Pauli—took place in his office on 25 February 1975. During the last year of his life he was very ill and died on 1 February 1976. The record of my edited notes and transcripts of taped conversations with him covered several hundred typed pages. He had read the first draft of Volume 2 of this work, dealing with the discovery of quantum mechanics, and approved it.

During my first semester at Göttingen there came three physicists whose visits were especially significant for me; Sin-Itiro Tomonaga from Japan, Aage Bohr from Copenhagen, and Max Born from Edinburgh. Tomonaga had been with Heisenberg in Leipzig many years previously. He was lean of build, delicate of health and features, friendly, charming and simple, and I found immediate contact with him. It had now become my custom to keep notes and tapes of conversations with major physicists.^{2a} I had the opportunity of renewing my

²The mathematician Salomon Bochner attended Heisenberg's colloquium in Berlin and was also present at his piano recital. Bochner confirmed Heisenberg's recollection to me.

^{2a}The records of my conversations and interviews with major quantum physicists will be deposited with the archives of the *Max-Planck-Gesellschaft zur Förderung des Wissenschaften* in West Berlin, Federal Republic of Germany. All first person accounts and references to conversations in the text and footnotes refer to my encounters with the quantum physicists in question, unless otherwise identified. Complete references to all quotations indicated as 'Conversations' and 'Interviews' will be provided when all references to them are collected together in the last volume of this work.

contact with Tomonaga many years later; in June 1960 I spent several days with him in Tokyo and pursued further the history of quantum electrodynamics. On the latter occasion I also had conversations with Hideki Yukawa in Kyoto. Aage Bohr was young and robust and full of confidence, but polite and friendly, and he gave a talk about the moments of inertia of nuclei; this work led to the line of investigations with Ben Mottelson that would win them the Nobel Prize in Physics in 1975. At that time, however, I found personal contact with Aage Bohr and, through him and Heisenberg, with Niels Bohr. These contacts were maintained in the following years.

Early in 1953 Max Born came for a visit to Göttingen. He was about to retire from the Tait Professorship of Natural Philosophy at Edinburgh, Scotland, and was looking for a place to live (close to Göttingen) in Germany, where he was to receive full pension as a former university professor. He stayed in a well-appointed guestroom in the *Akademische Burse*, where I also lived. I walked with Born every morning after breakfast to the Institute, and during two weekends we went on walking tours of Göttingen and its environs. Born showed me numerous houses and places connected with the names of great mathematicians and physicists and historic events, such as the house on *Wilhelm-Weber-Strasse* 29, where David Hilbert had lived, and the house in *Merkel Strasse* in which Max Planck had lived after the war. We made a tour of the *Hainberg*, went to *Café Rohn*, and walked to *Nikolausberg* and the *Bismarck Turm*. I had explored all these places before, but coloured with the many memories of an old-time resident of Göttingen, this sightseeing with Max Born had a special charm. During these two weeks with Born I had many discussions with him about the early days of quantum theory and relativity, his work on specific heats with von Kármán, his work on matrix mechanics, and his associations with Einstein, Hilbert, Minkowski, Felix Klein, Bohr, Franck, Pauli, Heisenberg, Hund, Jordan and Dirac, and numerous others. Born disliked Dirac's notation of *bra* and *ket* vehemently; I found it strange for a man who was such a keen mathematical formalist himself. He discussed almost everything quite calmly; he had a genuine feeling of happiness about his associations with Einstein, Hilbert and Minkowski, and much pride in the school of theoretical physics he had founded in Göttingen. He expressed a sense of intimidation in talking about Pauli, and a touch of resentment about the glory of the discovery of quantum mechanics which, in a large measure, had gone to Heisenberg. His spirit was soothed with regard to the latter in 1954, when he was awarded the Nobel Prize in Physics (which he shared with Walther Bothe) for his discovery of the statistical interpretation of the wave function. Born settled in Bad Pyrmont, where I visited him from time to time until 1968 and pursued with him the discussion about the historical development of modern physics, especially quantum theory.

In spring 1953 I went on a long trip to meet several quantum physicists and traditional philosophers with introductions from Heisenberg and von Weizsäcker: Niels Bohr in Copenhagen, Pascual Jordan in Hamburg, Friedrich Hund

in Frankfurt, Wolfgang Pauli in Zurich, Louis de Broglie in Paris, and the philosophers Karl Jaspers in Basle, Gabriel Marcel in Paris, Martin Heidegger in Freiburg-im-Breisgau, and the Catholic philosopher and theologian Romano Guardini in Munich. In Paris I also met the Indian physicists Homi Bhabha and S. N. Bose.³ I started a series of discussions with Jordan, Hund, Pauli and de Broglie that were to continue for many years to come.

Pascual Jordan treated me most kindly. He had the disadvantage of stuttering badly, but he was a warm-hearted person. He told me how he had pursued many threads of knowledge as a 'natural philosopher' and not just as a theoretical physicist. He had lively recollections of his work on matrix mechanics and quantum field theory, and he cherished pleasant memories of his associations with Heisenberg, Born, Pauli, Dirac, Wigner and Oskar Klein, although all of them had overshadowed him: in the fundamental papers on quantum mechanics and quantum field theory his name was always that of the second or the third author and the other partners had made bigger names for themselves for other, independent contributions, hence Jordan did not receive much credit even for what he did with them. In talking to him about matrix mechanics (the first work with Born, then with Born and Heisenberg) it soon became evident that Jordan had played a central role in its development; I also learned from others that as a formalist Jordan had been an equal of Pauli. I did not meet Jordan again until 1964, when I spent several days with him in Hamburg. From then on I kept fairly regular contact with him and learned many things from him about the development of quantum theory and the various personalities connected with it. In September 1972 he attended the Symposium on the Development of the Physicist's Conception of Nature in the Twentieth Century, which I had organized in honour of P. A. M. Dirac's seventieth birthday.⁴ In 1976 he read the first draft of Volume 3 of this work, dealing with the formulation of matrix mechanics and its modifications, and recommended me most graciously for the award of the *Humboldt-Preis* of the *Alexander von Humboldt-Stiftung* and the research grant of the *Alfred Krupp von Bohlen und Halbach-Stiftung*. From then until his death on 31 July 1980 we exchanged a number of letters; he had read the final version of Volume 3 and approved it.

From 1953 to 1976 I met Louis de Broglie in Paris on seven different occasions. Always punctual, kind and considerate, he told me many things about the background of his family, about his brother Maurice, about his work on wave mechanics and its reception by Langevin and Einstein, and about the first and fifth Solvay Conferences in Brussels that had meant so much to him; about

³I visited S. N. Bose many years later in Calcutta, India, on 30 August 1970. In 1974, after his death on 4 February, the Council of the Royal Society invited me to write his biographical memoir. (See J. Mehra: *Satyendra Nath Bose, Biographical Memoirs of Fellows of the Royal Society* 21, pp. 117–154, 1975.)

⁴See J. Mehra (Ed.): *The Physicist's Conception of Nature*, D. Reidel Publishing Company, Dordrecht, Holland/Boston, 1973.

the first Conference he had learned from his brother and its proceedings,⁵ while he had attended the fifth himself.⁶

In Göttingen I had the great privilege of knowing Otto Hahn. He was a likable, charming and kind man. Very often we walked together from the Institute complex (where he had his office as President of the *Max-Planck-Gesellschaft*) to the bus stop in *Weenderstrasse* opposite the *Rathaus*. Occasionally I had lunch with him in the Institute's cafeteria. He told me many stories about Rutherford, about his work with him, and about the years in Berlin. He recalled the months during which he was interned at Farm Hall near Cambridge, England, with a number of other German nuclear scientists after the war, and he gave me impressions of his various co-internees. He was one of the most unpretentious of men, warm and friendly, and oblivious of his great reputation as the man who had discovered nuclear fission.

Another quantum physicist whose acquaintance I made in Göttingen was Max von Laue. He came to the Institute from time to time, always riding his bicycle, with clips to hold the cuffs of his trousers from getting into the chain. He was very accessible, kind and rather old-worldly. I learned a lot from him about the early development of relativity theory, about his discovery of X-ray interference patterns in collaborations with Walter Friedrich and Paul Knipping, about his relations with Planck, Einstein, Pauli and Heisenberg, about the scientific community in Europe during the Second World War, and the internment of German nuclear scientists after the war at Farm Hall. Von Laue was always courteous and candid.

On numerous occasions I had discussions with C. F. von Weizsäcker about science, literature and philosophy. He was learned, brilliant and civilized. He spoke German and English eloquently and was a master of the speculative argument. His presence at the Thursday afternoon teas at the *Max-Planck-Institut für Physik* added much lustre to the spontaneous conversations that took place there. Once at tea he built a whole case on how much science (including navigation) and geography Columbus knew on the basis of his reported voyages. He had a scintillating mind, and his monologues could be captivating. He had a controversial reputation though: among the physicists he was regarded as a philosopher and among the philosophers as an atomic physicist. Often he was referred to as a 'quantum theologian,' indicating at once his capability as a physicist, philosopher and public speaker with a religious zeal. I had many conversations with him about his ideas, about Heisenberg, about Leipzig and Copenhagen (where he had studied with Heisenberg and Bohr, respectively), and about Aldous Huxley, Bertrand Russell and the Indian mystic and philosopher

⁵*La Théorie du Rayonnement et les Quanta, Rapports et Discussions de la Réunion tenue à Bruxelles, du 30 Octobre au 3 November 1911, Publiés par MM. P. Langevin et M. de Broglie, Gauthier-Villars, Paris, 1912.*

⁶*Electrons et Photons, Rapports et Discussions du Cinquième Conseil de Physique tenu à Bruxelles du 24 au 29 Octobre 1927, Gauthier-Villars, Paris, 1928.*

Sri Aurobindo. In the 1960s I visited him in Hamburg, and in 1972 he attended the Dirac Symposium at Trieste at my invitation, where he gave an extemporaneous lecture on physics and philosophy.⁷ Early in 1975 I had some very serious conversations with him about the activities of certain prominent German scientists during World War II (in Geneva, where my friend Charles Enz and I had invited him to give the Joseph Jauch Memorial Lecture). In recent years I have met him occasionally in Munich, a conversation with him always being a memorable experience.

In Göttingen I also made the acquaintance of the mathematicians Theodor Franz Eduard Kaluza and Carl Ludwig Siegel. Kaluza had made important contributions to geometry and general relativity, and Siegel had later become one of the world's leading mathematicians. Siegel told me many things of interest about the Göttingen tradition in mathematics, as did Richard Courant whom I met many years later in New York.

In my meetings with Niels Bohr in Copenhagen in 1953 and 1954 I explored the story of his relations with J. J. Thomson and Ernest Rutherford, his early work on the Bohr atom, but especially the period from 1922 to early 1930s, beginning with Pauli's arrival in Copenhagen up to the Bohr-Rosenfeld analysis of the field quantities in quantum electrodynamics. Bohr was patient and loved to reminisce; though it was not easy to comprehend him, it was always interesting to listen to him. One had to be very attentive, what with the soft Danish accent and his habit of swallowing not only words but entire phrases. Some of the most fascinating things were his remarks about the contributions of Pauli, Kramers, and Heisenberg. The young Heisenberg had been for Bohr like a messiah who had brought forth the solution of the quantum riddle and dispelled all doubts and gloom. I also discussed with Bohr his visits to Berlin in April 1920, when he first met Einstein in person, and to Leyden in December 1925 to attend the golden jubilee of Lorentz' doctorate, when he and Einstein gave their blessing to the hypothesis of electron spin put forward by Uhlenbeck and Goudsmit (and the following furor with Pauli). In 1954 I also met Oskar Klein in Copenhagen, but I did not see him again until 1968 in Trieste and again in 1974 at Leyden. I did not see Bohr again until summer 1959 when on Thursday, 25 June, he came to inaugurate the John Jay Hopkins Laboratory of Pure and Applied Science in San Diego, California.⁸ On that occasion I spent some time with him and he invited me to visit him in Copenhagen to talk further about the development of quantum theory from his perspective. 'And perhaps you will tell me what you have found out yourself in this very fascinating matter,' he said. It did not happen until June 1962. Then I was invited to attend the symposium of the

⁷ See C. F. von Weizsäcker, 'Physics and Philosophy,' in footnote 4, Chap. 40, pp. 736-746.

⁸ Niels Bohr gave an address on 'Science and Technology.' On this occasion I also made the acquaintance of Lothar Nordheim, who had worked with David Hilbert at Göttingen in the 1920s on the mathematical foundations of quantum mechanics. He told me a good deal about Hilbert and the young John von Neumann.

Nobel Prize Winners in Physics in Lindau at Lake Constance as an observer. Many laureates were present on that occasion: Edward Appleton, John Bardeen, Niels Bohr, Max Born, Walter Brattain, John Cockcroft, James Franck, Werner Heisenberg, George de Hevesy, Robert Hofstadter and Harold C. Urey. On this occasion I interviewed James Franck and had several discussions with Niels Bohr. I was able to cover numerous points that had interested me about Bohr's role in the development of quantum theory from 1922 to 1927: the formulation of the dispersion-theoretic approach, Bohr's discussions with Schrödinger in summer 1926 about the interpretation of the wave function, his discussions with Heisenberg in February 1927 about the uncertainty principle, the Como Conference in September 1927 and the Solvay Conference in Brussels in October 1927, and finally the rise of the interpretation of quantum mechanics and his discussions with Einstein at the fifth and sixth Solvay Conferences that were continued afterwards. Bohr talked with me kindly and patiently enough, but he was rather unhappy on this occasion in Lindau, for some tension had developed between him and Heisenberg. Somehow the subject had come up again of Heisenberg's meeting with Bohr in Copenhagen at the end of October 1941 when the question of the atomic bomb had been broached and the misunderstanding that had persisted between Bohr and Heisenberg ever since.^{8a} Even on this occasion over twenty years later Heisenberg was not able to dispel Bohr's doubts about his intentions in that conversation during World War II, and Bohr was quite aggravated. I had looked forward to seeing Bohr again in Copenhagen at Christmas that year, but he died on 18 November 1962.

In spring 1954 I had written to Hermann Weyl about the possibility of meeting him, especially if he would be in the vicinity of Göttingen sometime. He proposed that I come to the 7th International Congress of Mathematicians that was taking place that year in Amsterdam from 2 to 9 September. I thought that was a marvellous opportunity, and I had three meetings of two hours each with him. He told me about the old days in Göttingen and Zurich, about his relations with Hilbert, Klein, Born, Pauli and Schrödinger, about the work on matrix mechanics in Göttingen and wave mechanics in Zurich (where he was at the time), and his own work on general relativity, unified field theory, and quantum mechanics, as well as his lectures on group theory and quantum mechanics at Zurich. At one point he mentioned that there used to be a feeling that the *Eidgenössische Technische Hochschule* (E.T.H.) in Zurich was considered a first class waiting room ('*Wartesaal erster Klasse*'), where one received calls to go to Göttingen or Berlin; this had happened to Minkowski and then to Weyl himself, both of whom were called to Göttingen, and to Schrödinger, who went to Berlin,

^{8a}For an account of Heisenberg's visit to Copenhagen in October 1941 and the controversy surrounding it, see: Robert Jungk, *Brighter Than a Thousand Suns*, Harcourt Brace Jovanovich Inc., New York, 1958, Chap. 6, pp. 99–102; Elisabeth Heisenberg; *Das politische Leben eines Unpolitischen: Erinnerungen an Werner Heisenberg*, R. Piper & Co., Verlag, Munich, 1980, V. Kapitel, pp. 89–103.

but Hitler changed all that by dismissing Jewish professors and destroying the schools of mathematics and physics in Göttingen and Berlin.⁹

At the end of my fellowship in April 1955 I left Göttingen. I had learned much about the development of quantum physics, as well as about the relations among the quantum physicists through direct contacts with them. However, my stay at Göttingen had not been as successful as I could have wished. I had lived there as a gentleman-at-large with a handsome fellowship which permitted me a convenient life-style and travel. I had enjoyed the closeness to Heisenberg and the accessibility to other major physicists and mathematicians. I was bent upon finding all I could about the development of quantum physics in a hurry. However, I was too young, and not yet practiced enough in advanced mathematical techniques to take the fullest advantage of the possibilities of research at the frontiers of quantum field theory which the *Max-Planck-Institut für Physik* and several of its members offered.

In May 1955 I took the open competition for the United Kingdom Scientific Civil Service. I was selected as a Scientific Officer with the Department of Scientific and Industrial Research, now the Science Research Council, to begin my first job in August: research on problems of theoretical hydrodynamics and magnetohydrodynamics at a laboratory of D.S.I.R. Several wonderful encounters occurred that summer. C. P. Snow, as a Civil Service Commissioner, had interviewed me in the competition; soon we became very good friends, indeed friends for life. Snow had a profound admiration for the founders of quantum theory, especially Dirac, and he always continued to encourage me in my work on the historical development of quantum theory. In spring and summer 1955 I also met and had discussions with Aldous Huxley, Bertrand Russell, T. S. Eliot, E. M. Forster, Arthur Koestler, J. B. Priestley, Arnold Toynbee, and Hesketh Pearson (biographer of George Bernard Shaw, Oscar Wilde, and Sir Walter Scott). Of these the most important were meetings in summer 1955 and the following years with Bertrand Russell and Arnold Toynbee, and the meeting and continued friendship with Aldous Huxley. When Huxley learned about my interest in quantum theory and quantum physicists, he told me that quantum theory was the greatest revolution intellectually and scientifically that had happened in the twentieth century and the story of its development was worth writing about. Huxley himself was in contact with Pauli at that time about the influence of archetypal conceptions and the role of the subconscious in intellectual and scientific creativity, as well as the nature of mystical experience common to highest creativity in arts, sciences and religion. (Pauli had written an essay on this subject in a book published jointly with C. G. Jung.¹⁰) Huxley and I

⁹Hermann Weyl told me the following story. In the mid-1930s Hilbert was once seated next to the Prussian Minister of Education at a meeting. The Minister asked Hilbert: 'Herr Geheimrat, I hope the departure of the Jewish mathematicians has not seriously affected the activities of your institute?' Hilbert replied: 'No, Herr Minister, not at all. [Pause] It just doesn't exist anymore.'

¹⁰C. G. Jung and W. Pauli: *Natureerklärung und Psyche*. Herausgegeben von C. A. Meier, Rascher-Verlag, Zurich, 1952; C. G. Jung; *Synchronizität als ein Prinzip akausaler Zusammenhänge*; W. Pauli; *Der Einfluss archetypischer Vorstellungen auf die Bildung naturwissenschaftlicher Theorien bei Kepler*.