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Elected FRS 1945

By Sabine Lee

Department of Modern History, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK

Born into an assimilated Jewish family in Berlin in the early twentieth century, Rudolf Peierls studied theoretical physics with many of the greatest minds within the physics community, including Sommerfeld, Heisenberg, Pauli and Bohr. His Jewish background made a career in Germany all but impossible, and Rudolf Peierls and his Russian-born wife, Genia, settled in the UK, where Peierls took up a professorship in mathematical physics at Birmingham in 1937. Peierls's discovery, together with his Birmingham colleague Otto Frisch, of the theoretical feasibility of an atomic weapon based on a self-sustaining nuclear chain reaction was instrumental in the setting up of the UK government committee studying the possibility of manufacturing nuclear weapons. Peierls continued to contribute to the British and later to the British–American–Canadian effort to produce an atomic bomb, and he became group leader of the implosion group at Los Alamos. After the war Peierls returned to the UK and he built a world-class school of theoretical physics at Birmingham before moving on to Oxford in 1963. Like many of his colleagues who had contributed to the development of nuclear weapons, Peierls devoted much of his time and energy to the control of these weapons, to nuclear disarmament and to the promotion of greater understanding between East and West, most notably through his activities within the framework of the Pugwash Movement.

Early years

The date 5 June 2007 marks the centenary of Rudolf Peierls's birth. He was born as the third child of Heinrich and Elisabeth Peierls (*née* Weigert) into a non-religious Jewish family in Berlin. Brought up in a materially comfortable position, Rudolf grew up in an environment not atypical of assimilated Jews in early twentieth-century Berlin. His father (1867–1945), who had joined the Allgemeine Elektrizitätsgesellschaft (AEG) in 1888, had worked his way up to

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become director of the factory in Berlin-Oberschöneweide, in succession to Erich Rathenau. Eventually Heinrich Peierls became a member of the managing board (1908) and later a member of the supervisory board (1929). Heinrich's first wife, Elisabeth, died of Hodgkin's disease in 1921, and Heinrich soon remarried. His non-Jewish second wife, Else (*née* Hermann) was the daughter of a famous actor and the sister-in-law of the playwright Ludwig Fulda, which added a stronger cultural dimension to the Peierls household.

From a young age Rudolf was interested in science and engineering. He was a bright child, who found school work easy and was keen to probe further into areas that interested him most: the sciences. His childhood friends remember many an occasion when he would leave their play in order to 'think', only to return once he had solved whatever problem puzzled him at the time. Rudolf's original idea had been to follow an engineering career, but his family, doubting his practical abilities, persuaded Rudolf to settle for physics instead. Bowing to parental pressure, he enrolled for a course in experimental physics at Berlin University. He was soon to discover that first-year students were prevented from taking any practical courses because of overcrowding, and thus he became a theoretician almost by default. This accidental choice was to be a decisive career move, as Rudolf firmly established himself in the theoretical field in subsequent years.

Berlin, Munich and Zurich, 1926–32

While a student at Berlin, Rudolf Peierls encountered some of the leading figures in scientific research—Max Planck ForMemRS, Walther Nernst (ForMemRS 1932) and Walther Bothe to name but a few—but the real inspiration came with his move to Munich in the autumn of 1926, when he became a student at Arnold Sommerfeld's institute. Unlike Planck at Berlin, whose research genius did not find expression in his teaching, Sommerfeld deservedly had the reputation of being a superb communicator and a great teacher. His lectures were a model of clarity. It is no coincidence that the list of his students and assistants includes virtually everybody who made his name in (quantum) physics in years to come: Pauli, Heisenberg, Bethe, Peierls, von Laue, Kossel, Ewald, Lenz, Herzfeld, Wentzel, Heitler, Houston, Eckart, Rubinowicz, Pauling, Laporte, Brillouin, Condon, Fröhlich, London, Landé and many others.

Being introduced to quantum mechanics in such an inspiring manner and being confronted by Sommerfeld with the topical question of the electron theory of metals proved to be important for Peierls's short-term, medium-term and long-term physics career. As significant was his acquaintance with Hans Bethe (ForMemRS 1957), a fellow student one year his senior. They shared an interest in and a passion for physics that resulted in a lifelong friendship that went far beyond the research-related acquaintance.

Peierls's years at Munich, the autumn of 1926 until the spring of 1928, were a time of rapid personal and scientific development. Basic ideas of quantum mechanics had already been worked out by de Broglie, Schrödinger, Heisenberg, Pauli and Dirac, but new formalism had not been tested widely on the problems that had defeated the old quantum theory of Bohr and Sommerfeld. This was the context of Peierls's first seminar paper at Munich. In early 1927, P. A. M. Dirac (FRS 1930) and P. Jordan, independently but concurrently (Dirac 1927; Jordan 1927), had proposed a theory for the description of measurements in quantum mechanics, which was to become known as transformation theory. Peierls was to report on the papers of

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Dirac and Jordan to Sommerfeld's seminar. This was a difficult first assignment, but one that provided a useful learning experience.

When Arnold Sommerfeld went on a world tour in 1928, Peierls continued his studies in Leipzig to work with one of Sommerfeld's most promising former students, Werner Heisenberg (ForMemRS 1955), who had been appointed to the chair there in 1927. The move to Leipzig allowed Peierls to witness a completely different style of mathematical physics. Sommerfeld's approach to theoretical physics was best summarized in his own words: 'If you want to be a physicist, you must do three things—first, study mathematics, second, study more mathematics, and third, do the same' (Kevles 1995, p. 200). In contrast, Werner Heisenberg relied more heavily on his brilliant intuition.

Prompted by Heisenberg, in the summer of 1928 Peierls began the research project that would lead to his first published paper, an examination of the theory of galvanomagnetic effects (1)*, a study of the anomalous or positive Hall effect. As long ago as 1879, E. H. Hall had tried to determine whether the force experienced by a current-carrying wire in a magnetic field was exerted on the whole wire or whether it was exerted only on what would later be called the moving electrons in the wire (Hall 1879). Hall suspected the latter.

The phenomenon of the Hall effect is largely analogous to the deflection of cathode rays in a magnetic field. In some metals, however, it produces a positive sign as though the current were carried by positive carriers. An explanation of this paradox was impossible as long as electrons were visualized as moving freely in the metal. Bloch's theory of conductivity explained that conductivity was caused by jumps of the electrons from atom to atom where their energy could be less than the maximum potential barrier between atoms. There was no classical analogue for the process and, as pointed out in Peierls's paper, with the new understanding it no longer represented force-free motion. Peierls showed that electrons could give an anomalous sign of the Hall coefficient in a regular lattice (2), when he explained the positive Hall effect in terms of a concept of holes.

In the spring of 1929, Peierls once again moved universities as a result of a mentor's absence. Heisenberg had accepted an invitation to lecture in the USA, Japan, China and India, and Peierls decided to move on to Zurich to work with yet another Sommerfeld pupil, Wolfgang Pauli (ForMemRS 1953). He quickly settled down to the work that would, in the summer of 1929, earn him a PhD at Leipzig: a study of thermal conductivity in crystals with its recognition of the importance of the so-called 'Umklapp-process' at low temperatures (3, 4).

In the autumn of 1929, Peierls took up Pauli's offer to become his assistant in succession to Felix Bloch. At about the same time, the young Russian theoretician Lev Landau (ForMemRS 1960) visited Pauli's institute. Landau had come on a Soviet government scholarship. Despite the brevity of his initial visit, Landau and Peierls initiated a deep and lasting friendship as well as an intense working relationship that was to result in several important (and controversial) publications in the following years. Peierls was immediately impressed with the depth of Landau's knowledge and with his striking intuition. Half a year younger than Peierls, Landau already had what his German friend judged to be a 'very mature understanding of physics'. During Landau's first stay at Zurich, in 1929, the most vigorously debated subject was quantum electrodynamics. Before his 'European tour', Landau had completed some work on the diamagnetism of metals by using quantum mechanics. At Zurich, however,

* Numbers in this form refer to the bibliography at the end of the text.

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he moved on to a collaborative study with Rudolf Peierls. The two investigated the limitations imposed on the measurability of physical quantities in the relativistic quantum region. Landau and Peierls looked at light quanta (photons) in space, and wrote a wave equation for photons not unlike Schrödinger's equation for electrons. From this they derived sequences of equations for different numbers of photons; however, as the two would recognize later, the results were not only complicated but physically nonsensical.

The main attraction of the summer of 1930 for Rudolf Peierls and a number of younger as well as more established Western and Soviet physicists was the 7th All Union Conference at Odessa. For many Westerners it was the first exposure to the Soviet Union, and for many Soviet scientists it was a rare opportunity to encounter non-Soviet scientists.

At the conference, and during a subsequent boat trip across the Black Sea, Rudolf Peierls met many of Lev Landau's Leningrad colleagues, a close-knit community of exceptionally gifted young men (and one young woman) not unlike the community that Rudolf had known in Sommerfeld's institute. They were known as the 'Jazz Band', a group formed around George Gamow (Jonny), Dmitry Ivanenko (Dymus) and Landau (Dau), also called the 'three musketeers'; Genia Kannegiser and Matvei Bronstein (Abbot) also played an active role. For Rudolf Peierls by far the most important new acquaintance of the summer of 1930 was the only female member of the Jazz Band: Eugenia (Genia) Nikolaevna Kannegiser. As Peierls recalled later, she 'seemed to know everybody, and was known to everybody' ((29), p. 63), and throughout the meeting and during the travels thereafter, Rudi and Genia got to know each other better. With their German and Russian backgrounds, neither of them could converse in the other's mother tongue and the only common language spoken sufficiently well by both to communicate reasonably comfortably was English. After six months of intense correspondence by letter (Lee 2007, vol. 1, ch. 2), Rudolf Peierls travelled to Leningrad again in March 1931, and during his brief stay—much to the dismay of his surprised family—married Genia.

At first sight the two were an unlikely couple. Among the reminiscences compiled by friends for Genia's 70th birthday (Peierls 1978) was one contribution from Denys and Helen Wilkinson that contemplated defining 'a genia' as a unit of 'loudness, big-heartedness, self-confidence, loving concern, bossiness, generosity, stubbornness, unbreakable English, compassion, bad verse, fantasy, hypnotic gaze and irresistible kindness', and it concluded that whatever the final verdict, Genia stood for something 'larger than life: the milli-genia should be perfectly adequate for normal purposes'. In contrast, Rudolf was unassuming and modest, quiet, and often even shy. However, he was no less determined than his wife, and the two complemented each other in many important aspects. The marriage lasted for 55 years until Genia's death in 1986. The intense affection of their early long-distance relationship remained strong throughout their married life. Genia was not 'merely' the professor's wife, she herself was the initiator of many of the not strictly speaking scientific aspects of departmental life, ranging from entertainment to housing, from student counselling to health and safety advice.

One of the topics hotly debated at Odessa had been the unresolved question of infinite self-energy of electrons, a topic that Peierls and Landau (who continued his 'European tour' after the Odessa conference) decided to revisit. They felt that Heisenberg's uncertainty relations for non-relativistic quantum mechanics needed extension in the relativistic field. In particular, they discussed the issue of measurability of momenta and accuracy of measurements of the intensity of electric and magnetic fields. Much of the Landau–Peierls work was done during

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various stays in Copenhagen, most notably their visit in February and March 1931. Niels Bohr ForMemRS, however, did not agree with their key conclusions, in particular the conclusion that it was impossible to measure electromagnetic fields accurately. Apparently, Bohr was so upset about the publication of the paper that he did not want to be acknowledged in it (see Pais 1991, pp. 359–361).

Despite Pauli's well-recorded aversion to solid state physics, Peierls's next research topic again was within this field. For his habilitation—the qualification necessary to teach independently at tertiary level in Germany and Switzerland—he investigated the question of electrical resistance at small temperatures. He completed this research speedily and gained his *venia legendi*, his tertiary teaching qualification in October of that year.

Rome, Cambridge, Manchester and Birmingham, 1932–39

Peierls spent the academic year 1932/33 as a Rockefeller fellow in Rome and Cambridge. In Rome he renewed his acquaintance with Enrico Fermi (ForMemRS 1950) and found himself deeply impressed with the latter's abilities as a researcher and academic tutor. Peierls's main research interest still concerned the theory of electrons in metals, and in particular diamagnetic metals. Landau had developed a theory of diamagnetism of free electrons (Landau 1930), but it was not clear how this theory needed to be modified in view of the presence of atoms in metals. While in Rome, Peierls completed two papers that discussed the general state of the electron band, deriving a general expression for weak fields (5) and considering strong fields and low temperatures (6). With this work, Peierls could explain the mysterious magnetic properties of bismuth, which showed much greater diamagnetism than any other substance.

Despite the difficult job situation for young scientists in Europe, Peierls turned down an offer from Hamburg to take up the assistantship at Otto Stern's institute, a position that Pauli had held some years previously. Living under Mussolini's regime in Italy had given Rudolf and Genia a taste of fascism, and of course Genia had already had experience of living under Stalin's totalitarian regime, albeit at a time when its worst excesses had not become apparent. Hence, both were sceptical about the wisdom of returning to Germany at a time when National Socialism was becoming an ever stronger force. They were therefore relieved when Peierls was offered a post at the institute of W.L. (later Sir Lawrence) Bragg FRS in Manchester, an offer with the added bonus that the Peierls couple were, once again, united with their close friend Hans Bethe.

Bethe and Peierls would often refer to the Manchester year as one of the most enjoyable and productive in their respective careers. They would recall with some satisfaction the anecdote of one of their great collaborative feats, their attempt to develop a theory of the deuteron photo-effect in 1933. In a conversation with James (later Sir James) Chadwick FRS in Cambridge, the latter had challenged the two friends to develop a theory of this phenomenon. On the train back from Cambridge to Manchester, a journey of about four hours, doubtless after intense conversations and with the help of numerous backs of envelopes, they succeeded in developing a consistent theoretical approach.

The subjective impression of productivity is amply supported by the written evidence in the form of publications. The time in Manchester was among the most prolific period of Peierls's career. He still worked on aspects of the electron theory of metals, publishing a significant

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number of papers (8–10, 13). However, in addition to this, he continued his work on Dirac's hole theory (12, 17).

The Manchester period also marked the beginning of Peierls's more intense interest in nuclear physics. It was a time of fruitful collaboration between Bethe and Peierls, and in February 1934, together with Hans Bethe, Rudolf Peierls published his first paper dealing with something other than solid state or quantum dynamics (7), quickly followed by several other joint papers on questions of nuclear physics (11, 14, 15, 16).

In 1935 Peierls accepted a position at the Mond Laboratory, the laboratory for magnetism and low-temperature physics that had been built for P. Kapitza FRS. After Kapitza's detention in Russia in 1934, which prevented him from returning to Cambridge, the Royal Society was persuaded by Rutherford to use the earmarked unclaimed salary for the establishment of two fellowships, one of which was offered to Peierls.

The two years at Cambridge were, again, a productive period for Peierls, partly inspired by old and new colleagues at Cambridge, partly continuing earlier collaborations. Among the papers based on his Cambridge contacts was one on supraconductors (18), which showed traces of Peierls's collaboration with David Shoenberg (FRS 1953) (Hoddeson & Hoch 1981), and a statistical mechanics paper (19), which was inspired by work of Ralph (later Sir Ralph) Fowler FRS (Fowler 1935).

Another paper originating at Cambridge was his now famous paper on the Ising model (20). The advent of quantum theory had sparked renewed interest in Ising's model (Ising 1925) for ferromagnetism. Heisenberg had replaced Ising's model with one based on exchange forces (Heisenberg 1928), and Bloch had extended the theory (Bloch 1933). Ising's model had solved the problem only for the one-dimensional case, and Peierls expanded the model to two dimensions by giving an elementary proof that in two dimensions the Ising model showed ferromagnetism; he concluded that the same held *a fortiori* also for the three-dimensional model.

In 1937 Peierls was offered his first permanent position, a professorship in mathematical physics at Birmingham University. This appointment was the first move to a university that could not be considered as being 'at the heart of theoretical physics'. Berlin, Munich, Leipzig, Zurich, Rome and Cambridge, and also Manchester with Rutherford's legacy and Bragg's—and, later, Blackett's—presence, could be regarded as such. Birmingham could not look back on a strong history of theoretical physics research comparable with any of these places, and in fact the chair of applied mathematics was only being created at the time of Peierls's arrival. Initially he was the only theoretician among the physicists. Few people would have predicted that within just over a decade this department of applied mathematics would become one of the foremost centres of theoretical physics teaching and research, not just in England but in Europe and arguably across the globe. This was largely due to the effort of its first professor: Rudolf Peierls.

Peierls continued to engage in cutting-edge research. His continued interest in nuclear physics was evident from the fact that he paid several visits to Niels Bohr in Copenhagen between 1937 and 1939, and discussion topics at the time were invariably linked to nuclear physics. Again, it was the compound nucleus that occupied the two scientists and their colleague George Placzek, who was working with Bohr in Copenhagen at the time. In the collision of a slow neutron with a nucleus, the resulting compound system has resonance levels that can be narrower than their spacing. At higher neutron energies, the width of the resonance increases and spacing decreases, leading to an overlap. In this region of overlapping resonances, two different ideas of expressing Bohr's compound nucleus formation, the Breit–

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Wigner formula on the one hand and detailed balancing on the other, gave conflicting answers. Bohr, Peierls and Placzek eventually arrived at an understanding of the problem and its solution. By the summer of 1938 the challenge of solving the physics problem had been superseded by the challenge of writing up the solution. Bohr was notorious for labouring over the formulation of his research results, often leading to unwelcome and unnecessary delays in their publication. In that respect the fate of the Bohr–Placzek–Peierls calculations was not unusual. In contrast with Bohr's intention of presenting a broad qualitative argument, Placzek and Peierls wanted a more mathematically rigorous exposition. When Bohr came to Birmingham to receive an honorary degree in June 1939, a short note to *Nature* was written to present the core arguments (21). The full paper had not been finalized by the beginning of the war and work had to be abandoned until afterwards. However, as a result of the numerous drafts that had been prepared and circulated to others for comment, the results of the proposed publication were already widely known and were being used in the scientific literature. Not surprisingly, therefore, the paper gained considerable fame as being the most frequently cited unpublished paper! (Several drafts of the paper survive and some more or less complete versions have been published; see (30), p. 49, note 86, and p. 50, notes 87–89.)

While Rudolf Peierls was establishing himself in his first permanent post in the UK in the late 1930s, he and Genia were reminded frequently that their position was a fortunate one indeed. Many of Rudolf's close friends and colleagues, who had been forced to leave Nazi Germany, struggled to find suitable positions. But even more disconcertingly, both Rudolf's and Genia's families in Germany and Russia were facing uncertain futures. By 1938 Rudolf's siblings had left Germany to settle in the USA and England, respectively. However, his father and stepmother found it difficult to face emigration, although the conditions for Jews worsened by the day in Germany. Finally, in early 1939, Heinrich and Else Peierls got the necessary permissions from Germany and the UK and emigrated to England. In 1940 they continued their journey to the USA, where they settled in New Jersey near Rudolf Peierls's sister Annie.

The war years, 1939–45

When war broke out in 1939, Rudolf Peierls had lived outside Germany for about a decade, and he had spent more than half of this time in England. He felt gratitude towards the country that had provided him with a safe home at the time when his country of birth had failed to do so, and by the late 1930s it was clear that Rudolf and Genia Peierls had no intention of returning to Germany. In May 1938, therefore, Rudolf Peierls applied for naturalization, but he also felt the need actively to end his association with the country that Germany had become under Hitler, rather than terminating it by default once the process of his naturalization had been completed. This proved technically impossible, because some of the documents needed for an application to end his status as member of the German nation were also required for his naturalization, which of course took precedence.

The war turned Rudolf and Genia Peierls into enemy aliens. Soon tribunals were set up to classify this group of residents. Being classified as 'category one' meant that the couple in practice had to endure very few restrictions to their everyday life. What concerned Rudolf Peierls more than these relatively insignificant limitations of his private life were those placed on him with regard to civil defence and to his work and research. The former were lifted when his naturalization was approved in February 1940, but engaging in war work was still not as

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easy as for native British citizens. This was felt most acutely in the work that Peierls did together with his Austrian-born colleague at Birmingham, Otto Frisch (FRS 1948). The latter, together with his aunt Lise Meitner (ForMemRS 1955), had developed a qualitative theoretical explanation of the nuclear fission process that had been discovered by Otto Hahn (ForMemRS 1957) and Fritz Strassmann in 1938. Using Frisch's knowledge about the fission process and Peierls's theoretical understanding of the nucleus, the two physicists turned to some fundamental questions of this process, and in particular they considered the critical mass of uranium-235, the uranium isotope that was believed to be the most promising candidate for fissionable material that would allow a self-sustaining nuclear chain reaction. Frisch and Peierls calculated that a chain reaction was not only theoretically possible but also practically feasible. In a memorandum they suggested that the amount of fissionable material (^{235}U) needed for an atomic bomb based on these principles of a self-sustaining chain reaction was far less than previously assumed and that a sphere of metallic ^{235}U of a radius of about 2.1 cm could be sufficient to be explosive, an amount that corresponded to less than 1 kg of ^{235}U (32). Both scientists were immediately aware of the potential implications of their finding, and communicated them to the Head of the Physics Department, Mark (later Sir Mark) Oliphant FRS. The recognition of the theoretical possibility of producing a nuclear weapon led to the creation of a government committee, the so-called MAUD Committee, to investigate further the feasibility of a uranium-based weapon. When the committee met for the first time in April 1940, Peierls and Frisch, as only recently naturalized and enemy alien respectively, found themselves excluded from the work, a fact that met with misapprehension and caused consternation among the two scientists. Eventually, the folly of 'trying to keep the scientists' own ideas secret from them' was recognized by the committee. Frisch and Peierls became members of the technical subcommittee and remained deeply involved in the developments leading to the production of nuclear weapons.

After months of research spread across various academic and research institutes, the MAUD Committee, in its final reports in June and July 1941, endorsed the Frisch–Peierls memorandum in concluding that the atomic bomb was feasible, although very costly (MAUD Committee 1941). The continuation of the project required theoretical physicists of the highest calibre, and among the people recruited by Peierls into the project was Klaus Fuchs, a German refugee who had to flee Nazi Germany because of his left-wing views. Peierls encouraged Fuchs to join him in his work at Birmingham, a step with fateful consequences, because Fuchs eventually passed atomic secrets to the Soviet Union.

After his initial preoccupation with the calculation of the critical mass of ^{235}U, Peierls became increasingly involved in the complex problem of isotope separation. Many of his papers between 1940 and 1942 discussed the more or less promising avenues on the way to an efficient separation process (see, for example, (22–28) and numerous papers on the Simon plant, an early diffusion plant concept). By the autumn of 1941, the nuclear programme, now codenamed Tube Alloys, under the chairmanship of Wallace (later Sir Wallace) Akers (FRS 1952), had received government backing, and the key technical subcommittee including Chadwick, Hans Halban, Peierls and Franz (later Sir Francis) Simon FRS had been set up.

In August 1943, at the Quebec Conference, the official nuclear relationship between Britain and the USA was agreed on for the duration of the war, with the American President Roosevelt trading nuclear cooperation with the British for Churchill's agreement for a cross-channel invasion of Europe during 1944. Soon after the signing of the Quebec Agreement, Chadwick,

Simon, Oliphant and Peierls arrived in Washington as part of a fact-finding mission about the British role within an Anglo-American project, and by the end of this visit in the autumn of 1943 it had become clear that the key figures of the British effort would join their American colleagues in the USA.

Peierls had significant roles in the Manhattan Project, first by working on the complex issues involved in the ^{235}U isotope separation process, and second, after his move to the Los Alamos plant in 1944, as head of the hydrodynamics group, also referred to as the implosion dynamics section.

Rudolf Peierls was deeply concerned about the consequences of the development and use of nuclear weapons from the moment he realized the feasibility of a fission bomb. His memorandum with Otto Frisch had contained a rather unusual 'non-scientific' section in which the use of a potential weapon was considered. Despite his realization of the destructive power of the weapon, Peierls believed that it was necessary for Britain and America to produce it, at first in case Germany should develop a nuclear bomb and later, after Germany's surrender, because he reasoned that its use could shorten the war in the Pacific and thereby save lives. As Peierls would later put it himself, his work on nuclear weapons ceased in 1945, but his concern with the weapon he had helped create did not. He became a keen supporter of nuclear disarmament and devoted much time and energy to the campaign against nuclear weapons, not because he felt guilty about the role he had played in their development but because he was convinced of the danger of an irresponsible nuclear policy.

Birmingham, 1945–63

After the end of the war, Rudolf Peierls and his family returned to the UK, and although he had attractive offers from several universities, including Oxford, Manchester, London and Cambridge, he chose to remain at Birmingham. He had clear ideas of what he regarded as important for a prosperous theoretical physics community in the UK: a balanced flexible system that provided good training and high standards without prejudicing against students outside Oxford and Cambridge. Peierls had come to Birmingham in 1937 as the first professor of Mathematical Physics and had set himself the task of establishing a school devoted to both first-class research and first-class teaching. The war had put the effort on hold, but as soon as Peierls returned to Birmingham he re-engaged in the process and, virtually from scratch, he developed a school of mathematical physics, or theoretical physics as it would be called later, that was arguably the best in the country and could compete with any in Europe and with most others globally.

He succeeded where many others failed because he had a clear vision and a determined devotion to his subject and to the people he engaged with. In the postwar decades he regarded teaching as his main responsibility. Although he enjoyed his research and recognized its importance as a contribution to a discipline that was undergoing exciting developments, increasingly this research was being done in collaboration with research students and younger research staff and thereby became virtually indistinguishable from teaching.

His enthusiasm for teaching and building up a viable team found expression in time and energy devoted to securing funding for young scholars and finding the best possible people to perform the increasingly complex research. Within a few years he had built a reputation for his institute, that of being an ideal training ground—a reputation that helped in achieving both

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the above aims—but it also enabled Peierls to work within a group of a critical mass that would always be certain of being supplied with the best of talent from within Britain and from abroad.

Peierls's commitment to his students and research fellows did not end with the completion of their stay at Birmingham. Much thought and letter-writing went into the task of securing future positions and exchange opportunities. In this, the prospects of the individual scientists were as important as the future of his own institute at Birmingham. Collaboration with the USA throughout the war and close contact with many friends and colleagues across the Atlantic had sharpened Peierls's awareness of the role reversal that had occurred with regard to academic physics. As early as September 1945, he expressed, in a letter to Raymond Priestley, the Vice Chancellor of Birmingham University, that 'American universities [had] matured a great deal and contact with this country [was] now less important to them, and more important to us'. The consequence of this, in Peierls's view, had to be regular academic exchanges that would allow the UK to benefit from scientific achievements of colleagues in the USA. And his attempts to put Birmingham firmly on the academic map in theoretical physics meant that he was keen to secure a sizeable fraction of the exchange for this institution.

A supplementary ingredient that could not be found in any other institute was what some would later term the 'Genia factor'. Genia Peierls was an enthusiastic supporter of her husband's endeavours to attract the best young scientists to Birmingham, a place that—with post-war rationing, shortage of housing and generally meagre facilities—was not the most appealing location. Her hands-on efforts, which ranged from provision of short-term and long-term accommodation to general advice, from organizing social gatherings to job advice for spouse and general counselling, had a significant impact on the cohesion of the growing 'Peierls school' (Peierls 1978).

Although Peierls ceased his involvement in weapons production as such, his expertise was enlisted in consultancy work for the Atomic Energy Research Establishment (AERE) at Harwell. Among the friends and colleagues from the Manhattan Project who were on the staff at Harwell was Klaus Fuchs. His arrest in 1950 on charges of passing secret information to the Soviet Union was a severe blow to the British scientific community as a whole, and it was a particularly traumatic experience for Peierls and his family. Fuchs had been a close friend of the Peierlses; he had lodged with them when he first came to Birmingham, and he had collaborated closely with Rudolf, who had not only hired him in his department at Birmingham but had also been instrumental in securing his appointment at Los Alamos.

Rudolf Peierls never shied away from expressing his views in public. He did so regardless of the effect this would have on is own position. He defended civil liberties in the aftermath of the Fuchs affair in his memorandum 'Lesson of the Fuchs Case' (Lee 2007, vol. 2, ch. 6), although his close association with Fuchs had made him a prime target of suspicion. He was never secretive about his friendships with people from Communist countries and of Communist persuasion; he argued for the re-establishment of scientific exchange with the Soviet Union and its satellites. He rejected the idea of oppressing the voices of dissenters by arguing that this totalitarian measure would bring security at the expense of values that any democracy had to fight to retain. In the aftermath of the arrest of Fuchs, Peierls's overt expression of these views led some to question his reliability, especially in view of the fact that he had access to sensitive and secret information in connection with the UK nuclear programme. However, at that time, as on many other occasions during the subsequent decades, it was

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recognized by people in authority that the views may have been uncomfortable at times but at no point did they undermine the security and values of democracy in the UK, and at all times Peierls proved loyal to the national interest of the UK.

Rudolf Peierls regarded international exchange as one of the most significant prerequisites for securing first-class research in the UK. Since his Munich days he had been establishing contacts with colleagues all over the world, and his work at Los Alamos had added more depth and breadth to his international links. First and foremost within the postwar collaborative network in and out of Birmingham was the link to Cornell, where Hans Bethe had settled in the mid-1930s. Perhaps the most influential of the exchanges orchestrated by Bethe and Peierls was based on the recommendation of Hans Bethe to Freeman Dyson (FRS 1952), in early 1949, to spend some time at Peierls's institute. Rudolf Peierls and Robert Oppenheimer (ForMemRS 1962), at that time director of the Institute of Advanced Studies at Princeton, where Dyson, the rising star of theoretical physics at the time, was based, arranged a flexible fellowship. Dyson was based at Birmingham but it was agreed that he was at liberty to spend time at Princeton regularly as long as it fitted in with departmental requirements at Birmingham. This resulted in Birmingham's being in direct contact with the development of quantum field theory, which at the time was worked on by Julian Schwinger, Sin-Itiro Tomonaga, Richard Feynman (ForMemRS 1965) and Dyson. The arrangement demonstrated two essential ingredients that promoted the success of the Peierls School at Birmingham: first, Peierls was excellent at spotting talent, and second, he was flexible enough to make Birmingham an attractive option for scholars to choose his institute despite stiff competition from Cambridge, Oxford, Liverpool, Manchester, Bristol and other universities. Others similarly made the journey across the Atlantic; the exchange went both ways with, among others, Nina Byers, Elliott Lieb, Jim Langer, Gerry Brown, Richard Dalitz (FRS 1960), Edwin Salpeter (ForMemRS 1993), Claude Bloch and Stanley Mandelstam (FRS 1962) moving between the USA and Birmingham.

Another example of Peierls's spotting talent and being slightly unconventional in securing it for Birmingham was the recruitment of Gerry Brown, a young American scientist who would spend almost a decade at Peierls's department and made significant contributions to its functioning, to research, teaching and administration. Brown had studied at Wisconsin and Yale, where he obtained an MS and a PhD. A short-lived membership of the Communist Party, from which he was eventually expelled, put his academic career in the USA at risk, despite his outstanding doctoral work with Gregory Breit. Various enquiries to universities in England led to the now famous threepenny folded airmail return from Rudi Peierls saying, 'Come ahead' (Brown 2002, p. 6). In February 1950 Gerry Brown arrived as a political refugee from pre-McCarthy anti-Communist America; in 1960 he left to take up his appointment as full Professor of Theoretical Physics at Niels Bohr's Nordic Institute for Theoretical Physics (NORDITA).

Although not many of Peierls's students arrived as refugees in the same way as Gerry Brown did, many left to take up distinguished positions. The Birmingham department itself was seen as an exceptional training ground for young scientists well beyond the UK. Many of those who came to Birmingham as students, graduates or research fellows in the 1950s later filled lectureships and professorships around the globe: Dyson, Dalitz, Samuel (later Sir Samuel) Edwards (FRS 1966), Brown, Byers, Brian Flowers (FRS 1961), Mandelstam, John Bell (FRS 1972), Paul Matthews (FRS 1963), Denys (later Sir Denys) Wilkinson (FRS 1956), Lieb and Langer, to name but a few.

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The rising numbers of staff and students and their exceptionally high standard caused some logistic and administrative problems, too. As accommodation within the Physics Department was notoriously limited, huts had to be employed to overcome the shortage of space, and on one occasion Peierls had to ask for permission to add a trailer to overcome the departmental space crisis.

If Rudolf Peierls felt strongly on an issue, he was prepared to make his views known, irrespective of whether this would cause difficulties for himself. One such example was the political rat race that his friend Robert Oppenheimer found himself facing in the 1950s. In 1953 Oppenheimer had been suspended from the Atomic Energy Commission, on which he had served as Chairman of its General Advisory Committee between 1947 and 1952. Concerns had been expressed about his loyalty and reliability, and his security clearance had been withdrawn. Oppenheimer appealed against this decision, and between April and June 1954 hearings were held to determine whether his clearance should be restored. The commission decided against a restoration. However, Oppenheimer continued to speak out on nuclear physics issues, and although he was never officially rehabilitated, in 1963 he received the Enrico Fermi Award, a US government presidential award honouring scientists of international stature for their lifetime achievement in the development, use or production of energy. This served as a measure of reconciliation for what many perceived to be a grave injustice done to Oppenheimer.

Peierls spoke out tirelessly in support of Oppenheimer, and his many letters to ‘Oppie’ are evidence of the deeply felt indignation at the attacks launched against his friend. Peierls himself had his share of ‘security troubles’. His contacts with left-wing colleagues, his friendship with people of Communist persuasion, his marriage to a Russian, his close friendship with Klaus Fuchs—all led to his being viewed with a degree of suspicion by many. When he applied for a visa to attend a conference in the USA, his application met with a long delay, as did his paperwork in connection with his sabbatical at Princeton in early 1952.

In 1957 Peierls, who at the time was acting as a consultant for the AERE at Harwell, had his security clearance revoked at the request of the American authorities. Disappointed with the action of the Harwell authorities over this matter, Peierls resigned from his consultancy. Even before this episode, Peierls had been challenged by William (later Lord) Penney FRS, then on the board of the UK Atomic Energy Authority, about his contact with Russian colleagues and in particular his intention of participating in a conference in Moscow. In a letter in 1956 Peierls expressed his conviction of the sanctity of the ‘freedom of scientific enquiry, the freedom of exchange of scientific information, and of objective discussion with any scientist, regardless of person, nationality, or position as long as these do not interfere with his approach to scientific fact or argument’, a principle that was subject only to ‘the overriding requirement of national security’.

The more liberal flow of information from Russia brought the West into contact with Landau’s work, and his views on renormalized quantum electrodynamics were discussed widely among Peierls and some of his colleagues. The contacts with Landau facilitated the first English edition of Landau & Lifshitz’s seminal *Course of theoretical physics*, a set of textbooks that had previously been available only in Russian and was to become one of the standard works of teaching and reference for generations of physicists to come (Landau & Lifshitz 1976–81). Peierls clearly valued the fact that the restrictions to scientific exchange with Russian colleagues and friends were slowly lifted, and he attempted to encourage an understanding in the West of the work done by Russian physicists. He asked Niels Bohr to use

his reputation and standing in Russia to help Lev Landau travel to the West, and it was doubtless on his recommendation that Birmingham University invited him to accept an honorary degree in 1958.

By the 1960s, Peierls's impact through teaching and collaboration with younger colleagues outweighed the contributions he made independently. In addition, his focus was shifting to political work and publications in the area of arms control. Having been offered the Wykeham Chair of Physics in 1961, Rudolf Peierls, after lengthy negotiations, decided to accept in early 1962 and took up his appointment in the autumn of 1963. When asked about the reasons for his decision to move from Birmingham to Oxford, he would later refer to the need for change after a quarter of a century at the same university. However, it was more than simply the desire for change: Peierls liked the challenge. After successfully building a school of theoretical physics at Birmingham, he wanted to achieve something similar in Oxford.

Oxford, 1963–74

If Peierls's role as a senior academic in the UK had already undergone some changes towards the end of his time at Birmingham, this change became even more pronounced during the last decade of his university career, at Oxford. He became more concerned with university administration, teaching reform and, increasingly frequently, work for nuclear disarmament.

Evidently, Peierls's research had undergone a gradual change, which had already been visible in his final years at Birmingham and accelerated during his time at Oxford. He had been among the outstanding figures of the last generation of universalists in physics, and unlike many of his colleagues of his generation he refused to choose one narrow field as a focal point of his attention and instead tried to keep his interests broad. The increasingly rapid pace of developments in subject areas such as particle physics made it difficult to keep up with the trends in the discipline for anybody keen on dividing his attention between different specializations. In addition, Peierls felt that his age was beginning to make itself shown by the speed with which he was capable of picking up and using other people's ideas and concepts.

A recurring nuisance for the Peierls family, and above all for Rudolf Peierls himself, were the continued attempts of some to link him to Soviet espionage circles. As a German-born Jew with a Russian wife and numerous friends in the Soviet Union and Communist contacts elsewhere, as a close friend of Klaus Fuchs's, and as a nuclear scientist with access to classified information relating to atomic weapons, Peierls (and his wife) had been subjects of suspicion throughout the Cold War. He had been under investigation by the Security Service from 1938, when he had re-entered the UK after a visit to Russia, and naturally remained so throughout the war and beyond, until his file was closed in 1953. This exhaustive investigation over 15 years uncovered no evidence of any wrongdoing by Peierls; quite the contrary. In 1948, after espionage suspicion had first fallen on Fuchs, and Peierls was closely scrutinized, an MI5 officer minuted, 'not only have we nothing against him, but [that] he is a man of very good sense' (National Archives, Public Record Office, KV2/1658). Further investigations in the early 1950s in the aftermath of Fuchs's arrest and conviction led to the categorical conclusion that 'there is no substantial doubt about the loyalty of Prof. Peierls' (National Archives, Public Record Office, KV2/1662). The award in 1968 of a knighthood must have brought some satisfaction to Rudolf Peierls, not least because it was a tangible sign of the official recognition of his loyalty to his adopted home country.

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Retirement

Rudolf and Genia Peierls had always enjoyed leading a nomadic existence, and during their Oxford years, both before and during retirement, they continued travelling large parts of the world. Three of their four children had settled in other continents, and this provided extra incentive to travel abroad. In the 12 years between Rudolf Peierls's retirement from his chair at Oxford in 1974 and Genia's death in 1986, the two rejoiced in the opportunities provided by the more flexible work arrangements that Peierls's semi-retirement made possible and the opportunities that the plentiful invitations to far-flung places brought. The travel schedule was truly astounding, with regular visits to the University of Washington, Seattle, where Peierls took up a part-time appointment that resulted in his visiting Seattle between February and May each year until his retirement in 1977, at the age of 70 years. Other places visited between 1974 and 1996 included Sydney, Los Angeles, Vancouver, Princeton, Oregon, Mexico, Pisa, Coimbra, Copenhagen, Finland, Russia, Italy, Stanford, Japan, Virginia, Toronto, Japan, India, Greece and Ljubljana.

Rudolf Peierls had always tried to keep in touch with his Russian friends, colleagues and in-laws, and his additional time for travel and leisure facilitated this. Often Peierls provided the 'semi-Western' angle on biographical material concerning Russian colleagues, or he liaised between Western and Russian colleagues in other history of science projects or even human rights issues. He and Genia had planned on visiting Moscow and Leningrad in the autumn of 1986, a visit eagerly awaited by both in view of the changes brought about by the advent of Mikhail Gorbachev. However, Genia had been unwell and had undergone surgery to have a benign brain tumour removed in 1985, an operation that had given temporary relief. She spent a comfortable year, and Rudolf and Genia spent a 'glorious' holiday in Greece in June 1986. But amid preparations for their Russian trip, Genia's condition deteriorated, and she died on 26 October 1986.

Around the time of Genia's final illness, Peierls's autobiography was published: *Bird of passage* (29) was the fitting title of a book that was endearing to many of his numerous friends.

Genia had been the warm-hearted centre of much of the social life around Peierls's institute at Birmingham and to some extent also at Oxford. She had made other people's problems her own, and had been keen to contribute to their solutions. Some people may have been irritated by her occasionally unwanted concern or interference, but everybody acknowledged that her heart had been in the right place.

This unsentimental approach to life was also visible in Genia's advice about how to deal with a partner's death:

> In our consciousness there are rings like in a tree. After the death of a partner it is important to develop new rings. At first any recollection of the past is painful, because every experience, every place is always linked to the picture of the partner. One ought to travel, find new occupations, new impressions. Then, after a while one will have recollections which are no longer painful.

Rudi Peierls took Genia's advice. He continued leading a nomadic lifestyle and an active social life, spending time with many old friends but also making new ones. In 1986 Peierls had received the Copley Medal, the highest award from the Royal Society, and the Rutherford Memorial Medal, which is associated with a lecture series to be delivered at selected centres in the British Commonwealth overseas. Initially, Rudolf and Genia had wanted to embark on the lecture tour together, but Genia's illness prevented them from doing so. The trip was post-

poned until the following year, and in November 1987 Peierls delivered his lectures in India, visiting Moscow and Leningrad en route. In the early years of their marriage, Rudolf, when travelling long distances by himself, would always send Genia detailed travelogues sharing his impressions and reactions to new places. Now, again travelling without a companion, he reverted to his habit of sending travelogues, this time to his children in the form of his 'Dear Everybody' circular letters. Peierls's journey to Russia in 1987, although of course filled with meetings of colleagues at the various scientific institutes, had a more personal note than many other trips, because of the emotional ties to the place.

Before his first extensive trip without Genia in the autumn of 1987, in June of the same year, Rudolf Peierls had celebrated his 80th birthday. The Theoretical Physics Department at Oxford marked this occasion with a symposium. The meeting was an impressive display of the breadth of physics tackled by Peierls on his own or by his students in collaboration with 'Prof', and it was an indication of the significance of the contribution of Peierls to our understanding of the world (Dalitz & Stinchcombe 1988).

Peierls's life was still a remarkably busy and active one well over a decade after embarking on 'retirement'. When Freeman Dyson commented that he and his wife were 'struck dumb with admiration' for his breathtaking travel schedule, Peierls dryly answered that he regarded this as the 'soft option as opposed to sitting on one's backside and doing more serious reading or thinking, which I find myself more and more reluctant to undertake—this kind of laziness grows with age.'

Whether others would agree with his own assessment that he was prone to laziness is debatable. Not only do his several hundred publications indicate the contrary, but also—and perhaps even more so—his willingness to devote his time and energy to causes he regarded as important.

In the early postwar years, Peierls joined many of his colleagues in political activities aimed at controlling the nuclear weapons they had made possible through wartime research. He was instrumental in setting up the Committee of Atomic Scientists, later called the British Association of Atomic Scientists in the UK, as a forum in which the responsible use of peaceful and nuclear energy was discussed and the control of nuclear weapons was debated. Later, he became increasingly involved in the Pugwash Movement, an initiative triggered by the Russell–Einstein manifesto of 1955, which had called on all scientists to work together to prevent nuclear war. Under its first president, Cecil Powell FRS, and secretary general, Joseph (later Sir Joseph) Rotblat (FRS 1995), the movement grew, with increasing numbers of scientists getting involved in the annual conferences and regular meetings and workshops. Peierls took an active part in the Pugwash Movement, serving on its continuing committee from 1963 to 1974 and as its chairman between 1969 and 1974. He had always given high priority to the Pugwash Conferences since attending his first such conference in Moscow in 1960; later, in retirement, he still tried to attend and contribute whenever possible. When he was awarded damages from a libel suit in the early 1970s, part of the money awarded to him was donated to the Pugwash Movement. Even in the last years of his life, when his health was declining and it was becoming increasingly difficult for him to engage in travel and writing, he kept up his determination to contribute to the nuclear debates; his last publication was devoted to these issues (31).

More locally, Rudolf Peierls had also become involved in the FREEZE movement, which had been publicly launched in 1985 as an organization mainly concerned with nuclear disarmament. (The organization had several changes of name, including Towards a Safer World

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(1988), Safer World Project (1989) and Saferworld (1991). For most of the time of Peierls's involvement (1985–89) it was known as FREEZE.) Peierls became a 'Patron' in 1985 and a director in 1986 until his resignation in 1989, and he chaired the local Oxford group, with many of the meetings taking place in his flat. In June 1989 it was decided that the local FREEZE group should not continue independent operations but should instead cooperate with the Oxford Research Group, a registered charity that conducted independent research into decision-making, accountability, intergovernmental mediation and other topics with special reference to nuclear weapons. In 1989 Peierls became a 'friend' of the Oxford Research Group.

During the last years of his life, Rudolf Peierls was troubled by a number of health problems and he suffered a deterioration of his eyesight, which restricted his reading and made correspondence more difficult. Despite all this, he continued to lead an active and independent life well into his eighties. In the summer of 1994, however, after suffering a combination of heart, lung and kidney problems, he decided to move into a residential home close to Oxford. Having been independent since leaving home well over 60 years earlier, Peierls nevertheless settled well into his new environment, one of the few residents at Oakenholt who would word-process circular letters to friends and family and read scientific papers in enlarged script on a computer screen! However, his health deteriorated further throughout 1995 and he died on 19 September 1995.

To adopt his wife Genia's well-rehearsed characterization of Rudolf, he was an intellectual tennis player, not a golfer. He needed partners in his research: in the early days these would be fellow students, then colleagues, or later his own more advanced students. He thrived on bouncing ideas off and receiving the return from others, and many of his important achievements occurred as a result of direct and intense contact with others. This was evident in his early collaboration with Hans Bethe, and then in his work with Placzek and Bohr; it was equally true for the Frisch–Peierls memorandum; and it remained true in his numerous collaborative efforts in cooperation with his graduate students and postdocs.

Not all efficient collaborators are enthusiastic or good teachers. Rudolf Peierls most certainly was. His own experiences as a student in the late 1920s, at a time of great excitement, stimulation and achievement in physics, were a key to his own passion for the subject as well as his approach to communicating it. His formative period as a scientist was in an environment with a belief in intellectual exchange as an essential ingredient of scientific progress. All his teachers, Sommerfeld in Munich, Heisenberg in Leipzig, Pauli in Zurich and Bohr in Copenhagen, in their distinct ways, created settings that would provide for a spirit of collaboration and communication.

When looking back at his own experiences as a student, Peierls fondly remembered the warm and friendly atmosphere of the Bohr Institute in Copenhagen. He commented that Bohr's keen interest in people turned the personal relations in his institute into a family-like atmosphere and in fact into an extension of the Bohr family, into which members of the institute were allowed to intrude at any time. The same could be said about the Peierls household in Birmingham and later in Oxford. What impressed his numerous students and junior colleagues about the 'Peierls experience' was the way in which departmental affairs were allowed to be extended into the 'Peierls family'. There was no boundary between home and other portions of Rudolf Peierls's life, and to many students and postdoctoral workers the Peierls family became 'their family' for the time of their stay at Prof's institute and sometimes beyond.

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