7 From Millikan to Einstein

Our next five remarkable physicists were born in the twelve years from 1868 to 1879. Two came from Germany and one from each of Austria, New Zealand and America.

Robert Millikan (1868–1953)

In America, individual physicists, such as Joseph Henry and Willard Gibbs, seem to have chosen to work in isolation, rather than develop a research school. Towards the end of the nineteenth century the situation began to change. The leading universities established something in the nature of a department of physics, with appropriate staff, and there was usually no division between experimental and theoretical physics. Our next subject was one of the key figures in this process. He wrote an autobiography consisting mainly of extracts from addresses he had given at various times, which was published two years before he died. What follows is largely based on that account. After his death a life-long friend and colleague made the following assessment: 'I do not think Millikan is a great physicist in the sense that we look upon Newton, Kelvin, Helmholtz or J.J. Thomson, that is as a man who has produced or will produce revolutionary ideas. His place is rather that of a great consolidator and experimenter, a man who is capable of gleaning by critical analysis from the suggestions of others those hypotheses which are most nearly correct, subjecting them to properly devised and carried out experimental verification and transforming them from the realm of hypothesis to the realm of exact proved fact.'

Robert Andrew Millikan's paternal grandfather was a typical American pioneer of Scottish descent who moved west from New England first to Ohio in 1825 and then on to Illinois in 1839, where he settled on the banks of the Rock river, not far from the present town of Sterling. He was one of those who helped runaway slaves to escape into Canada by the 'underground railroad'. Later he took his family yet further west, to the Upper Mississippi valley, near Prairie du Chien, Iowa. The future physicist was born on March 22, 1868, before this last move, but grew up in fertile prairie country by the great river. His parents were Silas Franklin Millikan, a Congregational

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

preacher, who married Mary Jane Andrews, formerly dean of women at a small college in Michigan.

The school education the boy received in rural Iowa was adequate except that there was next to no science teaching. Outside school he learned how to live in the practical self-sufficient way of the American pioneers. After leaving school he entered the first stage of the famous liberal arts college of Oberlin, which had been founded in part by a distant relative and was the *alma mater* of both his parents. The college reinforced the Christian values and goals he had acquired at home, which guided his whole life. Before he had been there long, he was asked to help teach elementary physics to other students. He was so good at this that he was appointed tutor in physics as soon as he graduated. At the same time he was employed as an instructor in the college gymnasium, having always been keen on sport.

Next Millikan moved to New York City as the sole graduate student in physics at Columbia University. At this time the study of physics in America was just beginning to develop, but, when Rutherford visited Columbia a few years later, he described the status of physical science there as 'miserable'. Millikan was taken in hand by an able young teacher from Serbia named Michael Pupin. After emigrating to America, Pupin had

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

gone back to Europe to take a doctorate under Helmholtz in Berlin and he had also worked under Kirchhoff in Heidelberg. Pupin was now working on an invention to improve long-distance telephony, which later brought him fame and fortune. He encouraged Millikan, who by then had obtained a Ph.D. for a thesis on optics, to go to Germany for post-doctoral work and lent him the money he needed to do so. Millikan began at Jena, where he became proficient in the German language. Then he made a bicycle tour, covering 3500 miles in all. This took him to Paris, where he heard Poincaré lecture, and to several places in Germany. He decided to base himself in Berlin, where he could work with Planck, Warburg, Neesen and Schwartz. He also spent a semester at Göttingen, where he took a course in thermodynamics from Voigt and another in geometry from Klein. He also saw something of Arnold Sommerfeld, then acting as Klein's assistant, but what he found most stimulating was the seminar led by the physical chemist Walter Nernst.

As he was about to leave the Georgia Augusta, Millikan received a cable from the physicist Albert Michelson of the new University of Chicago offering him an assistantship in his department. Millikan took the next train to London, then travelled on to New York and Chicago, arriving in time for the fall semester of 1896. He turned down the offer of a better-paid position from Oberlin because, as he told President William Rainey Harper, he wanted the opportunity to do research. The university was a new institution, strategically located both in time and in space to exercise a profound influence on the evolution of the American university. President Harper was a dynamic personality who had a definite programme for transforming the American collegiate system into a university system influenced in many respects by the German model. However, the British model was too strongly entrenched to be easily displaced.

To start with, at the University of Chicago about half of Millikan's time was occupied in writing badly needed textbooks and organizing courses. In 1900 he was sent to Paris by Harper to manage the university's exhibit at the World's Fair, which won a Grand prize. Harper was delighted by this success, which attracted much useful publicity. Two years later Millikan married Greta Irvin Blanchard, the daughter of a successful Chicago manufacturer; they spent most of their seven months' honeymoon in London and Paris, ending with a rapid tour of western Europe. While in England he was given a warm welcome by British physicists, notably J.J. Thomson. In Chicago he was promoted to assistant professor. The salary was not especially generous, but he was also receiving useful royalties from his highly successful textbooks, which was fortunate since he already had two sons to bring up and a third was on the way.

Throughout the twenty-five years they were together Michelson, a Polish *émigré*, always treated Millikan with the utmost courtesy and consideration. While Michelson pursued the experimental research which would make him the first American national to receive a Nobel prize, Millikan was left to look after the department's graduate students. With his family Millikan made another European tour, visiting Rutherford at Manchester on the eve of some of his greatest discoveries, and then went on to Berlin to revisit Planck and his research group.

In 1914 Millikan was elected to the National Academy of Sciences of Washington, at the age of forty-six, having been awarded the Academy's Comstock medal the year before. Four years earlier he had been promoted to full professor at the University of Chicago. Millikan was involved in the successful effort to develop a telephone repeater, which soon made it possible to communicate by telephone across the USA. This involved him in a major lawsuit over patent rights, but he said afterwards that he learned a great deal from the painstaking way the patent lawyers dealt with the case.

In the summer of 1916 Millikan made his first visit to the Pacific Coast, to lecture at the Berkeley campus of the University of California, and then went on to repeat his lectures at what was then the Throop College of Technology in Pasadena, later to become world-famous as the California Institute of Technology. Also in 1916 he was elected president of the American Physical Society. By this time the USA had entered the First World War and Millikan decided that he must go to Washington and devote himself full-time to the war effort. Submarine detection was the first priority; it was essential that the resources of American industry should be harnessed to the project, and for once competing firms could be persuaded to cooperate in the common cause. The new applications of physics were shared with the Allies and played an important part in the conduct of the war, especially in combatting the menace of the German submarines.

In its relation to the American state, the situation of American science has tended to be the result of war-time requirements. Thus President Lincoln first gave official recognition to science as an institution through the creation of the National Academy of Sciences to provide technological advice during the Civil War. The Academy was a semigovernmental body, the official adviser of the American government in scientific matters, but it was still a small body, had no permanent home and did not include engineering in its scope. The Royal Society of London was its model, rather than the

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

scientific academies of continental Europe, although the complementary role played by the Royal Institution was altogether missing.

In the First World War President Wilson, finding that an honorary academy of this type was ill-suited for providing the technical advice that modern war required, added a new operational arm, the National Research Council, which could draw on the up-to-date knowledge of the active core of the American scientific community. However, the need to plan for the future, when the war was over, was not lost sight of. The outcome of much discussion was a programme of National Research Fellowships in physics and chemistry, but initially not in mathematics and biology, open to Americans and Canadians under thirty-five years of age. Each such fellow was to be attached to some American university where he or she would undertake an approved research project, the necessary funding to come from the Rockefeller Foundation. A few years later the programme was extended to include the mathematical and biological sciences, but there was no intention of extending it to include non-American universities. Meanwhile efforts were being made to establish the National Research Council itself on a permanent basis, and it was decided to combine with the National Academy over a Washington headquarters. The Carnegie Corporation agreed to pay five million dollars towards this, provided that matching funds could be raised from other sources. Millikan was heavily involved in all the negotiations and fund-raising, which took him away from his department at the University of Chicago.

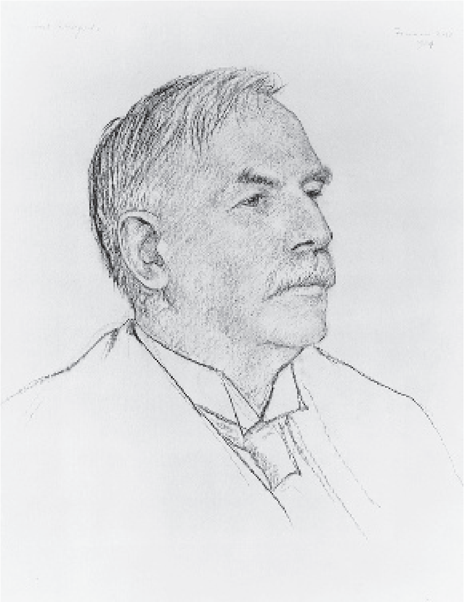
Millikan had already been to Pasadena once, as we know, and now he began making regular visits. The California Institute of Technology – known informally as Caltech – was still at an early stage of development, with only three permanent buildings of its own. However, it had the advantage that the Huntington Library was nearby, as was the Mount Wilson observatory; moreover, the Pasadena area was the most rapidly growing in the whole country. The institute had the status of a university, its graduate school one of the best in the USA, but it also had an undergraduate programme. In a great university like Chicago it is practically impossible to persuade the administration to break step and push one department out in front of the others, no matter how much the general interests might demand such discrimination. However, the powers-that-be at the institute were able and willing to do just that in the case of physics, so Millikan was persuaded to move there permanently and build it up. He said afterwards that his leaving the university which had given him his chance was the greatest service he could render it, since there was a need for new blood in Chicago.

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

Millikan had agreed with the trustees of the California Institute of Technology that he was to be chief executive officer and would concentrate on building the best department of physics he could. Before long the privilege of doing research at Caltech was so highly prized that no less than fifteen of the new National Research Fellows were working there, as well as other gifted young scientists, notably Robert Oppenheimer. Famous visitors came to lecture from all over the world, including Max Born, Albert Einstein, Werner Heisenberg and Erwin Schrödinger. In 1923 he was awarded the Nobel prize in physics 'for his work on the elementary charge of electricity and on the photo-electric effect'. After determining the first accurate value of the charge and hence of Planck's constant, Millikan turned his attention to the mysterious cosmic rays. He measured their intensities at great heights and great depths and observed their seasonal variations.

By this time Millikan was probably the best-known American scientist of his day. He wrote magazine articles popularizing the latest achievements in science and technology. In the face of growing attacks on modern science by religious fundamentalists, he organized a group of prominent businessmen, academics and religious leaders to sign a joint statement on the complementary role they believed science and religion played in the progress of humanity. The honours he received included membership of the Paris Academy and of the Royal Society of London. In politics he was a staunch Republican, strongly opposed to the New Deal and something of a racist. After being manoeuvred into retirement in 1946, he continued to give lectures, mainly on science and religion. He died in Pasadena on December 19, 1953 at the age of eighty-five.

There is no denying that Millikan had stormy days in his varied activities. His many vigorous debates on the nature and origin of cosmic rays were major events in the world of science in the 1930s. His determination to elevate the prestige of Caltech as rapidly as possible led to him being dubbed one of the great publicity agents in the field of education. He often differed vigorously from his colleagues on matters of politics, philosophy and religion. His administrative methods were hardly conventional and often confusing, yet his strong personal leadership always pulled things back into shape. A long-time associate of his said that 'the secret of his success lay to a large extent in the simple virtues instilled in his upbringing. He had a single-minded devotion to all that he was doing, and he put his work above his personal desires and aspirations. His combination of native good sense and intellectual honesty led him far both in science and in public life. In spite of his success and high public position, he always remained a simple man of true humility.'



Ernest Rutherford (Lord Rutherford) (1871–1937)

Einstein described Rutherford as one of the greatest experimental physicists of all time. In New Zealand he is rightly regarded as a national hero, held up as an example to all the aspiring young. Both his parents emigrated there as youngsters in the middle of the nineteenth century. His father, James Rutherford, had been a wheelwright working in the Scottish city of Perth. When he reached the South Island he tried his hand at farming and processing flax, cutting railway sleepers and constructing bridges. Although he was moderately successful in each of these enterprises, his family of a dozen children learned the value of hard work and thrift. The future physicist's mother, Martha Thompson, accompanied her own widowed mother to New Zealand from England and a few years later took over her mother's teaching post when she remarried. Martha was the dominant parent, who endeavoured to instil in her children an interest in literature and learning. She died in 1935 at the age of ninety-two. In their different ways both parents contributed to their son's characteristic traits of simplicity, directness, economy, energy, enthusiasm and respect for education.

Ernest Rutherford was born on August 30, 1871 at Brightwater, a settlement near the town of Nelson; when he was seven the family moved to Havelock, also near Nelson. Success in the local primary school won him a scholarship to Nelson College, which was rather like an English grammar

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

school. In his spare time the boy enjoyed tinkering with clocks and making models of the waterwheels his father used in his mills. By the age of ten he had read a scientific textbook, but otherwise there was not yet any sign of a special interest in science; he was expecting to become a farmer when he grew up. At Nelson College he excelled in nearly every subject, particularly mathematics, as well as becoming school captain or head boy. Another scholarship took him on to Canterbury College, in the city of Christchurch, which later became the University of Canterbury. At the conclusion of the standard three-year course he was awarded a mathematical scholarship that enabled him to remain for an extra year. He gained an M.A. in 1893, with double first-class honours in mathematics and mathematical physics and in physical science, and was encouraged to stay on at the college for yet another year to gain a B.Sc. He taught briefly at the local high school, during which time he became engaged to a fellow student at Canterbury College named Mary Newton, eldest daughter of the landlady of the house in which he was lodging. In a tiny basement workshop Rutherford began investigating the radio waves discovered by Hertz not long before. He devised a magnetometer that could detect radio signals over short distances and might be useful in lighthouse-to-shore communication. However, unknown to Rutherford, the American scientist Joseph Henry had already thought of this.

In 1895 Rutherford, as we know, was awarded a scholarship by the Commissioners of the Great Exhibition of 1851 and chose the Cavendish Laboratory because J.J. Thomson was the leading authority on electromagnetic phenomena. He brought his magnetometer with him to England and soon was able to show that he could receive radio signals from sources up to half a mile away. This demonstration impressed a number of Cambridge dons, Thomson included. Early in 1896, following the discovery of X-rays, Thomson asked Rutherford to join him in studying the effect of this radiation on electrical conduction in gases. Although Rutherford was anxious to earn enough to marry his fiancée in New Zealand, he could hardly turn down this opportunity.

While this work was in progress Rutherford was seriously considering his future prospects. Although the Thomsons went out of their way to be helpful, and Rutherford had been an academic and social success, he was conscious of the prevailing Cambridge snobbery towards those who had been undergraduates elsewhere, especially in the colonies. Seeing little chance of a Cambridge post, he started to look further afield. Without much hope of success, Rutherford applied for the professorship of physics at McGill University in Canada, where the authorities were looking for

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

someone to direct work in their well-equipped laboratory. Older men with far greater experience had also applied, but Thomson's emphatic testimonial 'I have never had a student with more enthusiasm or ability than Ernest Rutherford' persuaded them to appoint him.

Arriving in Montréal to a warm welcome in September 1898, Rutherford found perhaps the best laboratory in the western hemisphere (it was financed by a tobacco millionaire who considered smoking a disgusting habit) and a self-denying department chairman who soon voluntarily assumed some of Rutherford's administrative and teaching duties when he recognized his genius. In research Rutherford embarked on the field which was to occupy him for the next forty years, namely the study of radioactivity. After two years he felt sufficiently well established in Montréal to return to New Zealand in order to marry his fiancée Mary Newton after their five-year-long engagement and take her back with him to Canada. Their daughter and only child Eileen was born the following year; she was to die suddenly following childbirth at the age of twenty-nine.

Rutherford's nine years at McGill, dominated by the research which made him famous, were no less busy in other ways. He was in great demand as a speaker and travelled frequently to distant places to give a lecture or a course. Much of his time was consumed in writing *Radioactivity*, the first textbook on the subject and recognized as a classic as soon as it appeared in 1904. 'Rutherford's book has no rival as an authoritative exposition of what is known of the properties of radio-active bodies', wrote Lord Raleigh in a review, 'A very large share of that knowledge is due to the author himself. His amazing activity in that field has excited universal admiration. Scarcely a month had passed for several years without some important contribution from the pupils he has inspired, on this branch of science; and what is more wonderful still, there has been in all this vast mass of work scarcely a single conclusion which has since been shown to be ill-founded . . .' So rapidly was physics advancing, however, that, when Rutherford prepared a second edition the following year, it proved to be half as long again. No sooner was this finished than he embarked on the task of writing another book arising from the Silliman lectures he had delivered at Yale University. Friends urged him to limit his outside engagements, but he was often in London to deliver some prestige lecture and to keep in touch with what was happening.

Rutherford thoroughly enjoyed this recognition for, while not vain, he was fully aware of his own worth. The Royal Society elected him to the fellowship in 1903, at the early age of thirty-two, and awarded him the Rumford medal the following year. Various universities kept trying to

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

tempt him away from McGill, and the time arrived when Rutherford began looking for an opportunity to return to England, where he would be closer to the world's leading scientific centres. In 1907 Arthur Schuster offered to relinquish the Langworthy chair of physics at the University of Manchester on condition that Rutherford was invited to succeed him. This was agreed and Rutherford accepted. The following year he was awarded the Nobel prize, for his work on the decay of radioactive elements. Curiously it was a prize for chemistry rather than physics.

If the Cavendish, under Thomson, was the premier physics laboratory in England, then Manchester, under Rutherford, was easily the second. Schuster had built a fine structure less than a decade earlier and bequeathed to his successor a strong research department, including his invaluable young research assistant Hans Geiger. Rutherford's great and growing fame attracted to Manchester (and later to Cambridge) an extraordinarily talented research team who made profound contributions to physics and chemistry. One of them was the exceptionally able H.G.J. Moseley, whose death in action at Gallipoli in 1915 at the age of twenty-seven was such a great loss to science. It was Moseley, 'a born experimenter' according to Rutherford, who demonstrated the fundamental importance of the atomic number. Another Manchester colleague was Chaim Weizmann, better known for his promotion of the Zionist cause, who described Rutherford as being 'youthful, energetic, boisterous. He suggested anything but a scientist. He talked readily and vigorously on any subject under the sun, often without knowing anything about it . . . He was quite devoid of any political knowledge or feelings, being entirely taken up with his epoch-making scientific work. He was a kindly person but did not suffer fools gladly.'

In Rutherford's gift, as Langworthy Professor, there was a personally endowed readership in mathematical physics. He used this to bring Niels Bohr to Manchester for a period including the early years of the First World War. Although their personalities were very different, Bohr and Rutherford became close friends. In 1926 Bohr looked back on his Manchester days and described how he felt at the time:

> This effect [the large-angle scattering of alpha particles] though to all intents insignificant was disturbing to Rutherford, and he felt it difficult to reconcile with the general idea of atomic structure then favoured by the physicists. Indeed it was not the first, nor has it been the last, time that Rutherford's critical judgement and intuitive power have called forth a revolution in science by inducing him to throw

> himself with his unique energy into the study of a phenomenon, the importance of which would probably escape other investigators on account of the smallness and apparently spurious nature of the effect. This confidence in his judgement and our admiration for his powerful personality was the basis for the inspiration felt by all in his laboratory, and made us all try our best to deserve the kind and untiring interest he took in the work of everyone. However modest the result might be, an approving word from him was the greatest encouragement for which any of us could wish.

Rutherford remained at Manchester for fourteen fruitful years. When J.J. Thomson relinquished the Cavendish Professorship on his appointment to the Mastership of Trinity in 1921, no-one was surprised when Rutherford was elected as his successor. Increasingly beset by outside calls on his time, Rutherford had less and less opportunity for his own research and for keeping abreast of his students' work. Yet, with the tradition of enthusiasm for research that he had established earlier, his still frequent rounds to 'ginger up' his 'boys', the Cavendish Laboratory's output remained far more than just respectable. Usually half his students came from outside the United Kingdom, and after working in Cambridge they helped to spread his teaching throughout the world.

Rutherford was outspoken, outgoing and direct; swearing, he used to say, will make an experiment work better. He liked to keep his physics and his experiments simple and described his work in straightforward and precise language. He had a loud booming voice and it is said that, in the days when counting circuits tended to be sensitive to noise, his collaborators' equipment went wrong whenever he came near. He made decisions early and firmly, and once a matter was decided did not give it any further thought. He could be rude and even unreasonable on occasion, but, when he had cooled off, would put matters right with a handsome apology. One of his remarks, made at the British Association in September 1933, 'anyone who looked for a source of power in the transformation of atoms was talking mere moonshine', is often quoted; in private, however, he said he thought there might be something in it.

During most of his career, especially the Cambridge part, his wife Mary acted as his private secretary. As well as their Cambridge house, they had a rural retreat, first a cottage in Snowdonia and later an isolated country cottage near Chute in Hampshire. He was an enthusiastic motorist, one of the pioneers, and was also a keen golfer. The eminent physicist Sir James

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

Chadwick, who knew him well, has given some personal impressions of Rutherford at this stage in his life:

> The Rutherfords lived at Newnham Cottage, a low house in Queen's Road with a fine old garden, which belonged to Caius College. It was encircled by a wall of dirty *Cambridge brick*. One entered through a heavy door, and walked along a covered tiled way to the house itself. There was a very fine garden, in which Lady Rutherford took great pride. Rutherford's study was on the left, immediately after entering the house. Like the desk the room was littered with books and papers. For some years a niece of Lady Rutherford's lived with them and acted as his secretary and her companion.
>
> The Rutherfords occupied separate bedrooms, and there were no overt acts of affection between them. Yet they were devoted to one another. Lady Rutherford understood little or nothing of her husband's work, but she was very proud of the honours which showered upon him and reacted violently to any criticism. She treated him in ordinary matters as a child, still attempting to correct his faults when eating, for instance. 'Ern, you've dropped marmalade on your jacket.' When, rarely, Rutherford caught a cold or influenza she nursed him with loving care.'

From 1921, when he succeeded Thomson, until his death, Rutherford also held the chair of natural philosophy at the Royal Institution. In 1922 he received the Copley medal from the Royal Society. There were also numerous other public lectures to which great honour was attached, such as the presidential lecture to the British Association in 1923. Between 1925 and 1930 he was president of the Royal Society and subsequently he became chairman of the important advisory council which had been set up to allocate public money for the support of scientific and industrial research in the United Kingdom. That involved many public appearances, such as opening conferences and new laboratories, in addition to administrative and policy-making chores.

From 1933 Rutherford was president of the Academic Assistance Council and Chairman of its Executive Committee. This body, which sought to obtain positions and financial assistance for the displaced scholars, particularly Jews from Nazi Germany, raised a fund to provide maintenance for displaced university scholars, from whatever country. The Council also acted as a centre of information, putting individuals in touch with institutions that could best help them. The British government was sympathetic,

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

regarding it as in the public interest to 'try and secure for [the United Kingdom] prominent Jews who were being expelled from Germany and who had achieved distinction whether in pure science, applied science . . . music or art'. Many of the refugees brought intellectual riches to Britain. Of the 2600 rescued by the Academic Assistance Council and its successor body in the period before the war, twenty became Nobel laureates, fifty-four were elected Fellows of the Royal Society, thirty-four became Fellows of the British Academy and ten received knighthoods. Of the scientists, some were already famous but most were young and unknown when they arrived. Unlike Lindemann in Oxford, Rutherford made no special effort to encourage the physicists to come to Cambridge.

To continue with Chadwick's reminiscences:

> In appearance Rutherford was more like a successful business man or Dominion farmer than a scholar . . . when I knew him he was of massive build, had thinning hair, a moustache and a ruddy complexion. He wore loose, rather baggy clothes, except on formal occasions. A little under six feet in height, he was noticeable but by no means impressive . . . it seemed impossible for Rutherford to speak softly. His whisper could be heard all over the room, and in any company he dominated through the sheer volume and nature of his voice, which remained tinged with an antipodean flavour despite his many years in Canada and England. His laughter was equally formidable.
>
> He appeared to possess no fountain pen. He wrote slowly and laboriously with an old steel-nibbed pen, or more often with a short pencil. However with such a pencil he did arithmetic with surprising accuracy. Mumbling to himself he would use what appeared to be gross approximations to reduce multiplication or division to simple addition or subtraction, remembering to correct the final result by the necessary percentage. The answer he obtained was invariably within the overall accuracy of the experiment.
>
> Rutherford smoked interminably, usually a pipe and only occasionally a cigar or cigarette. His pipe tobacco was reduced to tinder dryness by being spread on a piece of newspaper in front of the fire or on a sheet of paper placed on top of a hot water radiator in his office or laboratory. When he lit his pipe it produced sparks and even flames, like a volcano. A result of this was that his waistcoat was peppered with small holes, and he often had to brush red hot grains of tobacco from the papers before him on his desk.

On October 15, 1937 Rutherford was suddenly taken ill at his Cambridge home and was operated on the next day for a strangulated hernia. Although at first the treatment he received seemed to be successful, the internal organs did not recover their functions and he died peacefully four days later, at the age of sixty-six. After his body had been cremated the ashes were buried in Westminster Abbey, just west of the tomb of Newton. In work that may be characterized as radioactivity at McGill, atomic physics at Manchester and nuclear physics at Cambridge, Rutherford, more than any other, formed the views later held concerning the nature of matter. As was to be expected, numerous scientific and other honours came to him. Dozens of universities awarded him honorary degrees and dozens of scientific societies conferred on him honorary memberships and other distinctions. In 1914 he was knighted; later he was awarded the Order of Merit and raised to the peerage, as Baron Rutherford of Nelson, the place in New Zealand from which he came. Lady Rutherford returned to live there after her husband's death, uncomfortable socially and demanding to the end, but the one love of his life and his most devoted admirer.

Lise Meitner (1878–1968)

Lise Meitner's name has become widely known for her part in the discovery of nuclear fission, which made nuclear power possible, as well as the atomic bomb. Among physicists she is particularly noteworthy as one of the early

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

pioneers in the study of radioactivity. Einstein described her as 'the German Madame Curie'; but, although most of her scientific work was done in Berlin, she came from Austria and retained her nationality, even after she became a Swedish citizen about eight years before her death. Lise Meitner was born on November 7, 1878 in Vienna, where she spent the first third of her life; she remained very much attached to the imperial city, never more splendid than in those last autumn days of its glory. Another third of her life was spent in Germany. When Austria was taken over by the Nazis she found refuge in Sweden, where she lived for twenty-two years. It was only at the age of eighty-one that she gave up scientific research and retired to England to live out the rest of her days in Cambridge.

Lise Meitner's father Philipp was a respected lawyer and keen chess player. His ancestors came from Moravia, now part of the Czech Republic; the family of her mother Hedwig (née Skovran) came from Russia. Being the third of eight children, she was used both to being ruled by her two older sisters and ruling over the four younger children. Although her parents were Jewish, her father was a freethinker and the Jewish religion played no part in her education. Indeed, all the children were baptized, and Lise Meitner grew up as a Protestant; in later years her views were very tolerant, although she would not accept atheism.

Lise Meitner said that she became a physicist because of a burning desire to understand the working of nature, a desire that appears to go back to her childhood. At the end of her school career she first had to pass the state examination in French, so that, if necessary, she would be able to support herself as a teacher; only then did she obtain permission to sit for the *Matura*, the school-leaving examination, equivalent to the German *Abitur*, that qualified her to enter the University of Vienna in 1901. For two years she worked intensively to prepare herself to pass this hurdle, coached by Arthur Szarvasy, later professor of physics in Brno. Her sisters used to tease her; she had only to walk across the room for them to predict that she would fail because she had interrupted her studies to do so. She was one of the four women who passed that year, out of fourteen candidates.

In her university days she encountered occasional rudeness on the part of the students (a female student was regarded as a freak) but also much encouragement from her teachers. In later years she often spoke particularly highly of the lectures of Boltzmann; it was probably he who inspired her with his vision of physics as a search for the ultimate truth, a vision she never lost. When she obtained her doctorate in physics in 1905 she was only the second woman in Vienna to have done so. She remained at the

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

university for another year or so, clearing up a question raised by Rayleigh. Thus encouraged to aim for a career in theoretical physics, she obtained her father's permission and promise of financial support for post-doctoral study in Berlin.

She had already made her first contact with the new subject of radioactivity, which was to become the chief topic of her life's work. In 1905 it was not known for sure whether certain rays were deflected in passing through matter; she designed and performed one of the first experiments in which some degree of deflection could be observed. She had met Planck briefly when he had visited Vienna in response to the invitation to be Boltzmann's successor and wanted to study under him. On arriving in Berlin in 1907, she arranged to attend his lectures. After he had invited her to his home, she recalled that 'even with my first visit I was very impressed by the refined modesty of the house and entire family. In Planck's lectures, however, I fought a certain feeling of disappointment at first . . . Boltzmann had been full of enthusiasm . . . he did not refrain from expressing his enthusiasm in a very personal way . . . Planck's lectures, with their extraordinary clarity, seemed at first somewhat impersonal, almost dry.' Although Planck, like so many of his colleagues, did not believe that women generally should be permitted to study at universities, he was prepared to make exceptions and Lise Meitner received his whole-hearted support. In her early days in Berlin she found cheerful, informal company and good music in the Grünewald house. She was often to seek Planck's advice in the years to come.

At first she had some difficulty in finding anywhere to carry out experimental work. Then she met the young chemist Otto Hahn, whose profile comes next. He was a frank and informal man of her own age from whom she felt that she could learn a great deal. He was looking for a physicist to help him with his own research into radioactivity. There was the difficulty that Hahn was to work at the chemical institute under the Nobel laureate Emil Fischer, who banned women from his laboratory (they might set fire to their hair); in any case, women were not allowed access to laboratories used by male students. However, an old carpenter's workshop was equipped for doing radiation measurements, and this was where Lise Meitner was permitted to work. Soon she and Hahn were collaborating in research on radioactive substances, Lise Meitner taking responsibility for the more physical aspects and Hahn being more concerned with the chemistry. In the years leading up to the First World War, they published a large number of papers on radioactivity, most of which are no longer of interest. To Hahn, the chemist, the discovery of new elements and the study of their chemical properties was the most exciting part of the work; Lise Meitner was more interested in understanding their radiations.

In 1908 Rutherford, as we know, was awarded the Nobel prize and, on the way back from Stockholm, the Rutherfords spent a few days in Berlin. While Rutherford had a valuable discussion with Hahn, Meitner was sent off to help Rutherford's wife Mary with her shopping. Although she and Hahn became close friends as well as colleagues, they never had a meal together except on formal occasions. She was very reserved, even shy, and had been brought up strictly.

In 1914 the outbreak of war caused their programme of research to be interrupted; Hahn was called up and Lise Meitner volunteered to serve as an X-ray nurse with the Austrian army. It was a harrowing time for her, working up to twenty hours a day with inadequate equipment and coping with large numbers of Polish soldiers with every kind of injury, without knowing their language. In the study of radioactive substances, measurements at fairly long intervals may be needed in order to let activities build up or allow unwanted ones to decay. Periodically she went back to Berlin on leave to make such measurements, and Hahn sometimes succeeded in synchronizing his leave with hers.

By then they were no longer working in the carpentry shed. The ban which kept her out of the chemical laboratories had been lifted in 1909, when women were at last admitted to academic studies in Germany. Hahn was offered a small independent department in the Kaiser Wilhelm Institute for chemistry, which was opened in 1912 on a (then) rural site in Berlin-Dahlem. Lise Meitner worked there with him for twenty-five years, first as a 'guest' and from 1918 as head of a department of physics. In her laboratory she maintained strict discipline, so that in a quarter of a century it never became contaminated with radioactivity, despite the large amounts of radio-elements that were handled in the same building. Although her students feared her strictness, they came to her with their personal problems even so, and later her warm, practical humanity was remembered with fondness.

Lise Meitner regularly attended the weekly colloquium at the University of Berlin, where new papers were discussed before an impressive bench of Berlin scientists. She was assistant to Max Planck from 1912 to 1915 and in 1922 received the *venia legendi*; the subject, cosmic physics, of her inaugural lecture was reported as cosmetic physics in the press. In 1926 she was made titular professor, but never gave any courses of lectures.

The discoveries of the neutron in 1932, the positron in 1933 and artificial radioactivity in 1934 caused a turmoil in the world of nuclear physics,

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

reflected in a number of short papers in which Lise Meitner and her collaborators tried to keep pace with the rapid new developments. After Hitler came to power, when 'non-Aryan' scientists lost their university posts, the scientists in the institutes of the Kaiser Wilhelm Gesellschaft were less vulnerable, being partly controlled by industrialists. Even so, the Nazis tried to enforce party loyalty by various forms of infiltration, and Hahn and Meitner had to be increasingly cautious in order to avoid open conflict and to avoid losing those of their staff who were partly Jewish or who refused to join the Nazi party. Although her *venia legendi* was rescinded in 1933 and she lost her external professorship at the university, this did not affect her position at the institute. People in her position were no longer allowed to give reports at scientific meetings; she stopped attending them. Her name was dropped from citations of papers of which she was a co-author.

The *Anschluss* (annexation) of Austria by Germany in March 1938 created serious problems for Lise Meitner: she was no longer a foreigner protected by her Austrian nationality and consequently became subject to the racial laws of Nazi Germany. As a person who was 'over 50 per cent non-Aryan' she could expect to be dismissed from her post and to suffer other penalties. Her honesty did not permit her to conceal her Jewish descent (as some people did), and her dismissal could only be a question of time. Her position looked even worse when her friend and colleague Max von Laue said that he had heard of an order, issued by Heinrich Himmler, head of the Gestapo, that no university teachers – whether Jewish or not – should in future be allowed to leave Germany without special permission. An attempt by the president of the Kaiser Wilhelm Gesellschaft to obtain a permit for her was unsuccessful. There appeared to be a very real risk that she might not only lose her position in Germany but also be prevented from seeking a new one abroad. She decided that she must leave without delay and arrangements were made by sympathizers in the Netherlands for her to escape to their country. On the day of her departure she had just an hour and a half in which to pack her most necessary belongings. In the laboratory no-one but Hahn knew that she was leaving Germany for good; he gave her a diamond ring to sell in case of need.

The Netherlands has a distinguished tradition in physics but at that time lacked good facilities for nuclear research, so Lise Meitner quickly moved on to Denmark, where for some weeks she enjoyed the hospitality of the Bohrs. The facilities for nuclear research in Copenhagen were excellent, and there were some young and active physicists at work. It was probably her wish not to compete with those younger people that led to her decision not to remain there but instead to accept an invitation to join Manne Siegbahn, head of the new Nobel Institute for Physics in Stockholm. In 1924 Siegbahn had been awarded the Nobel prize in physics for his research work in the field of X-ray spectroscopy; he and his pupils had created a Swedish tradition of precision physics.

It was shortly after her arrival in Sweden in 1938 that she made her most spectacular contribution to science. After she left Germany, Hahn and his assistant Strassmann had continued the research, as before, until they started discovering barium in the products of uranium bombardment. Hahn wrote to consult Lise Meitner for an explanation of what was happening in physical terms. His letter reached her before the discovery had been published, and thus she became the first scientist outside Germany to learn of this extraordinary phenomenon. It arrived during the Christmas vacation when she was visiting friends in a small Swedish village. In the party there was another refugee physicist, her nephew Otto Robert Frisch. Lise talked to him about Hahn's letter, but at first the young man did not believe that uranium atoms could split into two almost equal parts. He thought that Hahn and Strassmann must have made a mistake.

In order to talk the matter over at leisure, aunt and nephew took a long walk in the snow. Physical exercise, they thought, might clear their minds. Lise Meitner did most of the talking, urgently, convincingly. At last she persuaded Frisch that Hahn and Strassmann had made no mistake, that uranium atoms underwent fission, and that the energy released in the process was probably very great. Once they felt quite sure they hastened to Copenhagen to break the news to Niels Bohr. He listened eagerly to what they told him, exclaiming 'Oh, what idiots we have been. We could have foreseen it all. This is just as it must be.' He suggested an experiment whereby they might measure the energy released when uranium atoms split. Bohr was so engrossed in this extraordinary new phenomenon that he almost missed the ship which was about to take him to New York for a meeting of the American Physical Society. When he told the American physicists the news of the sensational discovery of nuclear fission, they said that his gaze, troubled and insecure, moved from person to person but stopped on no-one. In a state of great excitement, the experimental work was repeated by several research groups and confirmed. In Berlin Hahn was deeply worried: 'God cannot have intended this', he is reputed to have said.

The 1945 Nobel prize for physics went to the theoretician Wolfgang Pauli, although there were many who thought that Lise Meitner deserved it more. Bohr nominated Meitner and Frisch for the Nobel prize for physics in

1946 and for chemistry later, but to no avail. However, her work did not go unrecognized, since later she shared with Hahn the Max Planck medal of the Society of Physics, and the institute of nuclear research in Berlin was named the Hahn–Meitner Institute. Her relationship with Otto Hahn remained close, but he became increasingly inclined to undervalue her contribution to their great discovery. Yet she had been the physicist member of the team for thirty years and Hahn had always deferred to her judgement when it was a question of physics. Later Strassmann commented that 'she was the intellectual leader of our team, and therefore she belonged to us – even if she was not present for the discovery of fission'. This close working relationship between the head of a scientific institute in Nazi Germany and an *émigrée* Jewish scientist was a tribute to Hahn's stability of character and personal loyalty. However, it was widely felt that, by encouraging her to leave Berlin when she did, he might have saved her life, but he had effectively blighted her scientific career.

Lise Meitner remained in Sweden for twenty-two years, during which a cyclotron was constructed in Siegbahn's institute, the first to be built on the mainland of Europe. The experience of Lise Meitner was invaluable for making the best use of this new atom-splitting machine and for training students in the required ancillary techniques. She acquired a good command of the Swedish language, built up a small research group of her own and published a number of short papers, mostly describing the properties of some new radioactive species formed with the help of the cyclotron. Inevitably she felt cut off at the Nobel Institute since Sweden, as a neutral country, was isolated during the war; she had few students and lacked the stimulus that Hahn had given her during her years in Berlin. She also felt that Siegbahn was more interested in his precision physics than in the comparatively crude measurements that were possible in the study of radioactive isotopes. Initially there seemed to be a chance that she could go to Britain, which she would have preferred, but at Oxford Lindemann had the reputation of being unsympathetic to women, while from Cambridge there was such a lukewarm response that she did not think it worth following up. In July 1939, just before the war began, she nevertheless accepted Lawrence Bragg's invitation to visit Cambridge and was pressed to remain on a three-year research contract, but she hesitated and, to her lasting regret, returned to Sweden. During the war she contributed to the Allied war effort by helping to provide information about nuclear research in Germany, but she was adamant that she would have nothing to do with the atomic bomb.

In 1946 she spent half the year in the USA as visiting professor at the Catholic University in Washington and was nominated as 'woman of the year' by the American press. In 1947 she retired from the Nobel Institute and accepted an offer from the Swedish atomic-energy committee to set up a small laboratory for her at the Royal Institute for Technology. Later she moved to a laboratory of the Royal Academy of Engineering Sciences, where an experimental nuclear reactor was being built deep down in a hall blasted out of the solid granite on which Stockholm stands. There she remained for the rest of her time in Sweden, first directing the work of a research assistant, later mainly engaged in reading, attending colloquia and discussing problems with other physicists. Her mind was still active when in 1960 she retired to Cambridge in order to be nearer her relatives, including her nephew Otto Robert Frisch, who by then held the Jacksonian chair of natural philosophy at the Cavendish.

In Cambridge, Lise Meitner led a quiet life, but she still travelled a good deal, to meet friends and give lectures, often about the rightful place of women and, in particular, of women scientists. In 1963 she went to Vienna to address a conference about 'fifty years of physics', a talk that was later published in English. She had always taken great pleasure in music, as did all her brothers and sisters (one sister became a concert pianist). In old age she still fondly recalled the weekly musical evenings at the home of Planck. She went to concerts as long as she could walk, and tried to follow contemporary trends in music, although loss of hearing made this difficult.

After an exhausting visit to the USA at the end of 1964, Lise Meitner suffered a heart attack, which caused her to spend some months in a nursing home, from which she returned to her flat much enfeebled. Yet her strength only failed slowly, and in 1967 she made a good recovery after a fall in which she broke her hip. After that accident she did not travel any more and gradually gave up all other activity. For the last two months she was in a nursing home in Cambridge, where her life slowly ebbed away. She died on October 27, 1968, a few days before her ninetieth birthday, having outlived all her brothers and sisters, and was buried in a country churchyard, where her youngest brother had been buried some years previously.

In spite of her close friendship with Planck and other great physicists, Lise Meitner never quite lost the shyness of her youth, but among her friends she could be lively and cheerful, and was an excellent story-teller. She was interested in almost everything; always ready to learn and ready to admit her ignorance of things outside her own field of study. Within that field, however, she moved with great assurance and was convinced of the power of the human mind to arrive at correct conclusions from the great laws of nature. The advance of knowledge was always her first concern and she felt the delight of every good scientist in an excellent piece of work whoever it was done by.

Otto Hahn (1879–1968)

The borderline between physics and chemistry is one that should not be drawn too definitely. The chemists Dalton and Lavoisier have been mentioned incidentally and would certainly have been given profiles if this had been a book on remarkable chemists. However, Marie Curie is one exception, and Otto Hahn, who figured prominently in the preceding profile, is another. They seem to me to be chemists whose lives were so bound up with those of physicists that it is only natural to profile them here.

Otto Hahn was born on March 8, 1879 in Frankfurt. His father, Heinrich Hahn, was a glazier by trade and came from the village of Gungersheim near Worms. The family derived from Rhenish peasant stock but, while some of its members were farmers, others had pursued professional careers, becoming either teachers or doctors. Heinrich settled in Frankfurt in 1866, where he met a young widow named Charlotte Stutzmann (née Giese), who belonged to a North German family of some distinction. They

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

were married in 1875 and had three children, their sons Heiner, Julius and Otto, besides Charlotte's son Karl from her former marriage. One of Otto Hahn's cousins, Friedrich Thimme, was a historian who became director of the *Landesbibliotek* in Hanover, and another, Heinz von Trubzschler, was a member of the German foreign service and later became ambassador in Dublin.

The construction boom in Frankfurt after the Prussian victory in the Franco-Prussian war provided an opportunity for small tradesmen to expand their businesses and Heinrich Hahn was among those able to do so, becoming a contractor with several employees. Even so, the family lived plainly with few luxuries. Karl attended the Goethe Gymnasium and specialized in classics, while the other sons, including Otto, went to the Klinger Realschule instead. In childhood his health was not good, but after the age of fifteen this ceased to be a problem. His brother Heiner went into the family business, as did Julius at first, before opening what became a successful art gallery. Otto was sent to a technical school since his father had wanted to become an architect himself and hoped that his son would enter the profession. However, the youth soon came to the conclusion that architecture did not suit him and instead he turned to science, especially chemistry.

On the advice of a friend, he went to the University of Marburg, a town not far from Frankfurt. The science courses did not strike him as very inspiring: the chemistry lectures were scholarly but not well presented, the physics dull and the mathematics too difficult, although in later years he regretted that he had not pursued these subjects further. Following German custom, he did not remain at Marburg but migrated to the University of Munich. Until then he had managed to avoid taking part in the regular activities of the student fraternities, such as drinking beer and picking quarrels, but was obliged, in the Easter of 1899, to fight another student who had insulted him in the street by calling him a sissy. Although it was not unknown for one of the contestants in a duel to be permanently disabled, Hahn received only a few scratches. He began work on his doctorate, while living an active social life as chief officer of a student fraternity, which involved much carousing and other traditional activities. Nevertheless, the thesis he wrote was accepted.

In most of Europe a period of military service was required of able-bodied young men, two years in Germany and three years in Austria-Hungary. However, those with sufficient education and social standing could offer themselves for just one year's training as officer cadets. Hahn did so, but, although he passed out successfully at the end of the year, he did not apply for a commission. Instead he returned to Marburg to work as an assistant demonstrator, planning to go into industry afterwards. For this a knowledge of foreign languages would be an advantage, so in 1904 he went to work at University College, London, under Sir William Ramsay, discoverer of the inert gases. Ramsay was impressed by the young German and advised him to continue research in radiochemistry, rather than go into industry. Hahn took his advice and gained a place at the University of Berlin, but, before taking this up, he arranged a six-month visit to Rutherford's laboratory at McGill. Hahn was delighted with the easy, informal and yet stimulating atmosphere he found there.

Hahn returned home to write up his research and found time to holiday in the Tyrol with his brother Julius before settling down to work in Berlin in October 1906. The first step was to report to Geheimrat Fischer at the institute of chemistry. After six months he was given the status of Privatdozent, on the strength of his published research. The next year Lise Meitner, as we know, came from Vienna to study theoretical physics under Planck. She too wished to do experimental work in the chemical institute and Fischer agreed that she could work with Hahn.

Hahn was a handsome man who took pleasure in the company of women, both as friends and as colleagues. When he was on an excursion to Stettin by steamship, he met Edith Junghans, the daughter of the chairman of the Stettin city council; soon they had become engaged. Hahn's professional position became more secure with the formation of a separate department for radioactive work, enabling them to get married in March 1913. When the First World War broke out the following year, Hahn, being a reservist, was called up at once; he was involved in action on the western front at an early stage and participated in the fraternization between the British and German troops which took place at Christmas 1914.

Shortly afterwards he was ordered to attend a meeting at army headquarters in Brussels, where he was told that poison gas was to be used to achieve a breakthrough. When Hahn protested that this would contravene the Hague Convention, he was told that the French had already started using gas; moreover, if the war could be ended quickly through the use of chemical weapons, many lives might in the end be saved. So Hahn took part in their development and was horrified later when he saw the results and realized that his own work was partly responsible. A decision had been taken to attempt to break through the Italian line with the support of a gas attack. Hahn was sent there in September 1917 to make the necessary preparations and the attack the next month was completely successful. Soon he was back on the western front, taking part in chemical operations throughout the spring and early summer of 1918. Finally he went to Danzig for experiments with a new type of chemical weapon.

After the end of the war there were disturbances and strikes in Berlin for some time, and at one stage Hahn found himself acting as a stoker in a power station. His wife Edith was expecting a baby, after nine years of marriage; their first and only child, Hanno, was born in April 1922. Conditions were still difficult in post-war Germany and financial problems, which became increasingly severe during the remainder of the year, reached a climax in the early part of 1923 when the currency lost all value. Although domestic life was by no means easy under hyperinflation, scientific work at the institute continued much as before.

By 1932 Hahn had been invited to lecture on radioactivity at Cornell University. He gave a review of what he and Lise Meitner had been doing, later published as a book: *Applied Radiochemistry*. The alarming news from Germany made him cut short his stay and return to Berlin, when he went at once to Planck with a proposal for an organized protest by German scientists against the persecution of Jewish scientists. Planck advised him that this would have no chance of success; it was already too late for protest: 'if today thirty professors get up and protest against the government's actions, by tomorrow there will be 150 individuals declaring their solidarity with Hitler, simply because they are after the jobs'. Although Hahn steadfastly refused to join the Nazi party and continued to occupy his post without molestation, as the weeks went by he became increasingly aware of the political constraints. When the student fraternity to which he belonged decided to exclude non-Aryans, Hahn promptly resigned, while keeping in touch with some of the individual members. More significantly, he resigned his lectureship at the University of Berlin, although as a member of the Berlin Academy he could still lecture there whenever he wished.

In 1933 Hahn was made interim director of the Kaiser Wilhelm Institute of physical chemistry until a loyal Nazi could be found to take over. He was persistently and openly contemptuous of the Nazis, but at the end of his few months of office he reported that 'he had done his best with the unpleasant and thankless task of cleansing the institute of non-party members'; one of them, as we know, was Lise Meitner. At this point the able Fritz Strassmann was brought into the research project. He had originally joined the institute in 1929 and by 1935 was already an experienced radiochemist. Since he wished to enter academic life, Hahn had urged him to apply to the university for admission to the academic staff, but when he was informed

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

that he must first join one of the Nazi organizations, he refused to proceed with the application. His attitude towards the new political masters of Germany was therefore much the same as Hahn's; they were to remain close associates and collaborators for the next ten years.

Five years later, as we also know, the experimental work reached a climax with the discovery of what proved to be nuclear fission. Once it had been established that huge amounts of energy were released by the fission process, the excitement grew intense. After celebrating his sixtieth birthday, Hahn went to the Scandinavian centres and to England to lecture on the discoveries. However, the impending conflict was sharpening official interest and obstacles began to be placed in the way of free publication. An office for nuclear research was established by the German war department as early as the summer of 1939, and leading nuclear scientists, including Hahn, were drawn into the national discussions.

Hahn's position during the war was in many ways typical. He had always been a loyal German. Although he felt that he owed no loyalty to the Nazis, who could be held responsible for starting the war, he nevertheless recognized that the whole German nation was involved. His presence at high-level meetings and the cooperation of his institute were bound to be regarded as essential. The most useful thing they could do was to characterize the fission products and to study relative yields, a programme that was in fact a continuation of Hahn and Strassmann's personal research and therefore quite acceptable to them.

Five years later the war in Europe was coming to an end. The bombing offensive against Berlin intensified. Hahn's institute was destroyed and the staff were moved to the small town of Tailfingen in southwest Germany. The Hahns' son Hanno joined his parents to convalesce after losing an arm on the eastern front. The details of what happened after the area was occupied by the Allied forces will be told in the profile of Heisenberg, who was more closely involved with the German nuclear project. Suffice it to say here that Hahn was taken to England in 1945, with nine other leading German nuclear scientists, and interned.

Soon afterwards the first atomic bomb was exploded over Hiroshima, and then a second dropped on Nagasaki, killing altogether more than a hundred thousand people. Hahn felt partly responsible for the Japanese casualties and contemplated suicide. Then a letter arrived from Planck saying that he wished to retire as president of the Kaiser Wilhelm Gesellschaft and that Hahn was being proposed to succeed him. Hahn was duly appointed; soon afterwards he was awarded the 1944 Nobel prize in chemistry for the discovery of nuclear fission. Lise Meitner was not included, but Hahn gave ten per cent of the prize money to Strassmann.

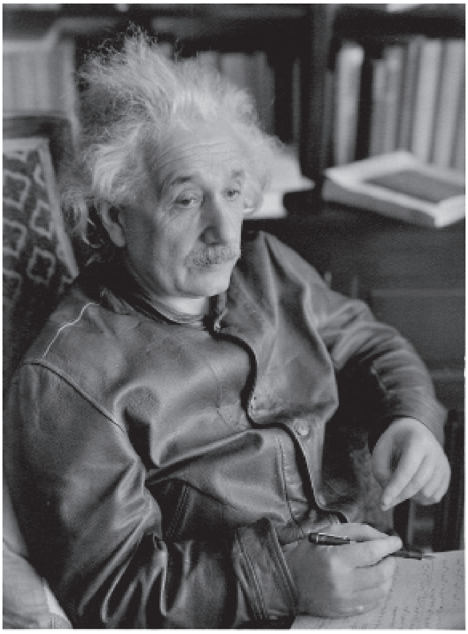
The internees returned to Germany in January 1946 and were resettled in Göttingen, where the Kaiser Wilhelm Gesellschaft was restarted, under Hahn's presidency, and renamed the Max Planck Gesellschaft. At first it mainly operated in the British zone of occupation, one of four. Göttingen was close to the border with the Russian zone; Hahn went to bed each night wondering whether he might be kidnapped and wake up in Russia. Rumours kept circulating that the Germans had also constructed atomic bombs; Heisenberg and Hahn vehemently denied this, saying 'at no time did Germany have any atomic bombs or installations for the manufacture of atomic bombs'.

Hahn was now almost sixty-seven, a respected figure in the new Germany. This rather unassuming scientist, who had spent most of his life in the laboratory, spent the next few years helping to rebuild German science after the war. He wrote two autobiographical books, giving a somewhat biased account of the Nazi period and of the post-war years when many of those who, thanks to political opportunism or conviction, had flourished during the Nazi regime still held important positions and were using their influence to the detriment of their anti-Nazi colleagues. With other German scientists, he presented to the West German government a statement that they would not cooperate in the development of nuclear weapons.

Hahn was awarded various honorary degrees, lectured in Germany and England, travelled in many other parts of Europe, but his declining years were clouded by misfortune. One evening as he opened the door of his house in Göttingen he was shot by a disgruntled inventor, who wished to draw attention to the neglect of his ideas by established scientists. He had hardly recovered from this incident when his wife Edith had a nervous breakdown. Then, in 1952, he was injured in a car accident; the following year he had a heart attack. His son and daughter-in-law were killed in a motor accident. Edith never recovered from the shock and remained an invalid for the rest of her life. Hahn himself had a fall getting out of a car, became progressively weaker and died in Göttingen on July 28, 1968, at the age of eighty-nine. His wife survived him by no more than a fortnight.

Albert Einstein (1879–1955)

Einstein realized that each of the separate fields of physics could devour a short working life without having satisfied the hunger for deeper knowledge, but he had an unmatched ability to scent out the paths that led to the depths



and to disregard everything else, all the many things that clutter the mind and divert it from the essential. This ability to grasp precisely the particular simple physical situation that could throw light on questions of general principle characterized much of his thinking.

Albert Einstein was born in the peaceful German town of Ulm, in the state of Württemberg, on March 14, 1879. He was the only son of Hermann and Pauline (née Koch); both sides of the family were from Swabia. His father Hermann was a kind, inoffensive but somewhat ineffectual person; his mother the more dominant parent. His father's brother, who lived with the family, was a trained electrical engineer; father and uncle together ran a business designing and manufacturing electrical apparatus, such as dynamos. Not long after Albert was born the family moved to Munich, and a year after that a sister Maria (known as Maja) was born. There were no other children.

The future physicist grew up in suburban Munich. Although the family was Jewish, he attended a Catholic primary school before proceeding to the Leopold Gymnasium, a conventional school of good repute. His scientific interests were awakened early by a small magnetic compass his father gave him when he was about four; by the algebra he learned from his uncle; and by the books he read, mostly popular science works of the day.

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

A textbook on Euclidean geometry that he studied at the age of twelve made a deep impression. We have an account of his childhood from his son Hans Albert:

> He was a very well-behaved child. He was shy, lonely and withdrawn from the world even then. He was even considered backward by his teachers. He told me that his teachers reported to his father that he was mentally slow, unsociable and adrift forever in his foolish dreams. Very early Einstein set himself the task of establishing himself as an entirely separate entity, influenced as little as possible by other people. In school he did not revolt, he simply ignored authority. His parents, although Jewish, were largely indifferent to religion. Einstein, while still a schoolboy, deliberately emphasized his Jewish origin and went through a period of religious fervour which he later described as his 'first attempt to liberate myself from purely personal links'. At the age of twelve he finally freed himself from conventional religious belief, although he retained a firm belief in some rather undefined 'cosmic religion', which was entirely suprapersonal. When asked about this, later on in his life, he used to say that although he did not think there was a God who was interested in people he thought, like Spinoza, that there might be one who created the universe.

As a child Einstein was echolalic, repeating to himself what he heard in order to make sure that he had heard it correctly. He did not learn to speak before he was three and did not speak fluently until he was seven. Later in life he was a confusing lecturer, giving specific examples followed by seemingly unrelated general principles. Sometimes he would lose his train of thought while writing on the blackboard. A few minutes later he would emerge as from a trance and go on to something different. He explained that 'thoughts do not come in any verbal formulation. I rarely think in words at all. A thought comes and I try to explain it in words afterwards'. He did poorly at school, where so much teaching is verbal rather than visual; he is believed to have been dyslexic. He was also a loner: 'I'm not much with people', he would say. The mature Einstein impressed everyone who met him by his gentleness and wisdom, but, as one of his biographers remarks, 'he has never really needed human contacts; he deliberately freed himself more and more from all emotional dependence in order to become entirely self-sufficient'.

When the family business failed in 1894 after an over-ambitious attempt to compete with much stronger firms, the rest of the family moved from Munich to Pavia in Lombardy, leaving the fifteen-year-old Einstein in the care of distant relatives. The intention was to allow him to continue his education, but he felt abandoned. He found the authoritarian Leopold Gymnasium, with its emphasis on classics, increasingly unbearable. He became ill and before long left, officially on medical grounds, but perhaps partly to avoid liability for military service, and joined the family in Pavia. One of his first actions was to renounce his German citizenship, thereby becoming stateless. After spending most of a year enjoying life in Italy, he resumed his education, but the family business was again failing and he could expect no financial support from his parents. An aunt in Genoa gave him a monthly allowance to see him through school and university, but after that he would need to support himself.

Einstein's aim was to enter the Polytechnikum (ETH) in Zürich, but to do so he had to pass the entrance examination. After one unsuccessful attempt, due to a poor performance in non-scientific subjects, he was advised to complete his school education first. Accordingly, he spent a year at the liberal gymnasium in the Swiss town of Aarau, where the regime was influenced by Pestalozzi. His teachers thought him lazy and were unimpressed, but he gained the certificate needed for university entrance. By the time he was admitted to the Polytechnikum his main interests centred on theoretical physics rather than mathematics. His mathematical abilities were not exceptional; he was slow and made mistakes. The professors of mathematics, Hurwitz and Minkowski, were outstanding, but Einstein had not yet fully realized the creative value of mathematics in physical research. Later he attributed his failure to learn from them as due to his lack of mathematical instinct. He avoided normal classes and spent most of his time studying the classics of physics, especially the works of Clerk Maxwell. Einstein was impressed both by the successes and by the failures of the old physics and was attracted to what he later called the 'revolutionary' ideas of Maxwell's field theory of electromagnetism. His study of the writings of the nineteenth-century masters received a new impetus from Ernst Mach's *Science of Mechanics*.

After graduation Einstein became a Swiss citizen; this again made him liable for military service, but he was rejected on medical grounds. For two years he applied for schoolteaching posts but was unable to obtain regular employment. While supporting himself by occasional tutoring and substitute teaching, he published several scientific papers. Then, in 1902, he was appointed an examiner at the Swiss patent office in Berne. The seven years Einstein spent there, examining applications for patents in electrotechnology, were the years in which he laid the foundations of large parts of twentieth-century physics. He liked the fact that his official work, which occupied only part of the day, was entirely separate from his scientific work, so that he could pursue this freely and independently, and he often recommended this arrangement to others later on.

In 1905 Einstein received his doctorate from the University of Zürich with a dissertation entitled *Eine neue Bestimmung der Moleküldimensionen*, which contained the germ of his later theory of Brownian motion. At this stage in his life he was about five and a half feet tall, with regular features, warm brown eyes, a mass of jet-black hair and a slightly raffish moustache. In 1903, against strong opposition from his mother (his father had died the previous year), Einstein married Mileva Marić, a Serbian woman, a fellow physics student from the Polytechnikum, more or less his contemporary academically although five years senior in age. Their two sons were born in Switzerland, Hans Albert in 1904 and Eduard in 1910. A previous child, Lieserl, was born at the home of Mileva's parents and given for adoption; there is no trace of her afterwards. Hans Albert emigrated to the USA before the Second World War and became professor of hydraulic engineering at the University of California; for various reasons he felt bitter towards his father. Eduard was a gifted child; as a young man his resemblance to his father was said to be 'almost frightening'. He suffered from paranoid schizophrenia, and after he had been institutionalized his father had nothing more to do with him.

Einstein never publicly acknowledged any contributions by his wife to his work; neither did she make any such claim. Yet some of his letters at the beginning of the twentieth century refer to her role in the development of 'our papers'; for example, in one of them he wrote 'How happy and proud I will be when both of us together will have brought our work on relative motion to a successful end'. Whatever this may mean, the consensus among his biographers seems to be that she gave up scientific work to devote herself to raising a family, while he did the opposite.

All biographers agree that he had a passion for music, as a way of experiencing and expressing emotion that is impersonal. Einstein was an enthusiastic violinist; Mozart, Bach and Schubert were his favourite composers. When he was world-famous as a physicist he is reported to have said that music was as important to him as physics: 'it is a way for me to be independent of people'; on another occasion he described it as the most important thing in his life. Photographs of him playing with Born, Ehrenfest, Hadamard, Hurwitz or Planck show a different Einstein from the more familiar images.

Einstein started his scientific work at the beginning of the twentieth century. The closing decades of the nineteenth century were the period when the long-established goal of physical theory – the explanation of all natural phenomena in terms of mechanics – came under serious scrutiny and was directly challenged. Mechanistic explanation had achieved many successes, particularly in the theory of heat and in various aspects of optics and electromagnetism; but even the successful mechanistic theory of heat had its serious failures and unresolved paradoxes, and physicists had not been able to provide a really satisfactory mechanical foundation for electromagnetic theory. It was a time of startling experimental discoveries, but the problems which drew Einstein's attention and forced him to produce the boldly original ideas of a new physics had developed gradually and involved the very foundations of the subject.

In 1905, one marvellous year, Einstein produced three masterly papers on three different subjects, which revolutionized the way scientists regarded space, time and matter. These papers dealt with the nature of Brownian motion, the quantum nature of electromagnetic radiation and the special theory of relativity. Einstein considered the second paper, on the quantum of light, or photon, as the most important, and it was for this that he was to be awarded the Nobel prize, but it was relativity that caught the popular imagination. It was not a new idea. Poincaré had already considered relativity from a mathematical point of view, in which the speed of light was regarded as an absolute constant. Of course, the idea of treating time as a fourth dimension has a long history; it had already been suggested by d'Alembert in the eighteenth century. The structure for the space-time continuum known as Minkowski space was developed by Minkowski only after he had moved to Göttingen; at the Polytechnikum he lectured on analytical mechanics. While Einstein was by no means alone in thinking about relativity, notably Langevin had been thinking on similar lines, it was only he who understood its revolutionary implications and worked out its consequences. Significantly, his original paper on the subject contained no references and very little mathematics.

Although Planck strongly influenced Einstein, it was more Henrik Antoon Lorentz who was his scientific father-figure. From his student days Lorentz had been a disciple of Clerk Maxwell, one of the few people in the Netherlands who understood the theory of electromagnetism. He was

https://doi.org/10.1017/CBO9780511535345.009 Published online by Cambridge University Press

also an admirer of the work of Fresnel and of Hertz. He loved mathematics and was invited by the University of Utrecht to become professor in the subject, but preferred physics. Before long a new chair was created at Leiden, his *alma mater*, and at the beginning of 1878 he returned there as professor of theoretical physics, although he was not yet twenty-five. Three years later, when he was twenty-seven years old, Lorentz was elected to the Royal Academy of Sciences at Amsterdam. Amongst many other honours he received the Nobel prize for physics in 1902. When Lorentz died in 1928, at the age of seventy-four, Einstein represented the Berlin Academy at his funeral and said 'I stand at the grave of the greatest and noblest man of our times. His genius was the torch which lighted the way from the teachings of Clerk Maxwell to the achievements of contemporary physics . . . his life was ordered like a work of art down to the smallest detail. His never failing kindness and magnanimity and his sense of justice, coupled with an intuitive understanding of people and things, made him a leader in any sphere he entered. Everyone followed him gladly, for they felt that he never set out to dominate but always simply to be of use. His work and his example will live on as an inspiration and guide to future generations.'

It took a few years for Einstein's research to receive recognition. When he submitted the relativity paper to support his application to become Privatdozent at the University of Berne, it was rejected, although he was invited to give some lectures. His academic career did not really get started until three years later, when he was appointed associate professor at Zürich University; two years after that he became full professor at the German University in Prague and then returned to Zürich as full professor at the ETH, as the former Polytechnikum had become, the following year. Finally, in the spring of 1914, Einstein was persuaded to move to Berlin as a professor of the Berlin Academy, free to lecture at the university or not as he chose, and as first director of the Kaiser Wilhelm Institute of physics. He had mixed feelings about the move, partly because he disliked the Prussian life-style and partly because in physics he felt that he would be expected to produce one brilliant idea after another. As it turned out, however, he found the atmosphere in the German capital quite stimulating, although he missed the freedom of Switzerland, and he greatly appreciated having Planck, Nernst and, later, Schrödinger and von Laue as his colleagues. In the First World War Einstein refused to join in the widespread support of the German cause by German intellectuals and did what he could to preserve a rational international outlook and to urge an immediate end to the war.

However, while Einstein's scientific work was flourishing, his private life was not. His marriage had been under strain for some years. He was physically attractive to women and had a number of affairs. His wife Mileva and their two sons followed him to Berlin, but before long they returned to Zürich, which remained Mileva's home for the rest of her life. Legal separation and finally divorce followed soon after the end of the war. Earlier, when Einstein became ill and was bedridden for some months, he was nursed back to health by his cousin and childhood friend Elsa Löwenthal, a widow with two daughters; when the divorce came through, in which violence towards Mileva and adultery with Elsa were cited, they married. She was three years older than he was, more maternal and protective towards him than Mileva had been, and totally ignorant of science. The film actor Chaplin, who knew her later, described her as 'a square-framed woman with abundant vitality; she frankly enjoyed being the wife of the great man and made no effort to hide the fact; her enthusiasm was endearing'. Einstein gradually lost interest in her.

Meanwhile Einstein had been developing the general theory of relativity, the kind of theory which the mathematician Riemann may have been seeking in vain, wherein gravitational forces arise from the geometry of space-time. For the necessary mathematics Einstein turned for assistance to Tullio Levi-Cività, an Italian geometer of the old school; later the theory was recast in a more modern fashion by Hermann Weyl. A new scientific theory needs to be tested by experiment, and an opportunity for this came in 1919 when the deviation of light passing near the sun, as predicted by the general theory of relativity, was observed during the solar eclipse. Already famous among scientists, Einstein now became a celebrity to the general public. The publicity, even notoriety, which ensued changed the pattern of his life. He crossed the Atlantic for the first time and was lionized to an embarrassing extent. He spent three months in Leiden and then went on a grand tour of China, Japan, Israel and Spain. In 1921 he was awarded the Nobel prize in physics, for his 1905 paper on light quanta; the prize money he received went to his former wife Mileva, as part of the divorce settlement.

As usual the Nobel prize, to which he attached little importance, was followed by a whole cornucopia of other honours. He was now able to put the prestige of his name behind the causes he believed in and he did this, frequently naively, always bravely, but trying not to misuse the status his scientific reputation had given him. The two movements he backed most vigorously in the 1920s were pacifism and Zionism, particularly the creation of the Hebrew University in Jerusalem. He also took an active part for a few years in the work of the Committee on Intellectual Cooperation of the League of Nations.

Einstein's chief outdoor recreation was sailing a dinghy on the numerous lakes formed by the river Havel around Berlin. He was very skilful at manipulating the little boat, enjoying the gliding motion and the quiet mind-soothing scenery. He could be seen almost every day out sailing, but he had no mooring for his boat. As the date of his fiftieth birthday approached, the municipality conceived the plan of giving its most distinguished citizen a birthday present: a house beside the lakes, which would give him perfect quiet and direct access to the water. Unfortunately the project became so entangled in politics that Einstein rejected the idea and simply built a lakeside house for himself. It was there that he began meditating on the final goal of his scientific life, the discovery of one unifying theory that would bring together the hitherto separate phenomena of gravitation and the electromagnetic field. With characteristic concentration and obstinacy, he advanced numerous ideas on this subject during the rest of his life, but none of them commanded widespread acceptance.

After the end of the war it had been the policy of the organizing committee of the Solvay conferences to exclude Germans, but this restriction was lifted for the fifth conference in 1927, the last time that Lorentz was in the chair. Much of Einstein's scientific work after the end of the war had been concerned with quantum mechanics, so he took the opportunity to present an extended critique of Bohr's ideas, with which he did not agree. There was a vigorous discussion after which most of the participants departed believing that the positivist Copenhagen view had prevailed, but Einstein and his followers were not convinced. The controversy continued for years; even today there are problems with quantum theory, although it works so remarkably well in practice.

In Germany Einstein became increasingly the target of the anti-Semitic extreme right. He was viciously attacked in speeches and articles, even his life was threatened. Despite this treatment, he remained based in Berlin, declining many offers of positions elsewhere. He still went regularly to the Netherlands to see Lorentz. In 1931 he spent some time in Oxford as Rhodes Memorial Lecturer, staying at Christ Church, where he accepted a five-year research fellowship, with no duties attached, the only condition being one of residence. Although in the end he did not take this up, he returned to Oxford in 1933 as Herbert Spencer Lecturer. He also visited the California Institute of Technology for three successive winters.

By this time the Nazis had seized power in Germany and the attacks on him were intensifying. His papers on relativity were publicly burned before the Berlin State Opera House and all his property was confiscated. When resigning from the Bavarian Academy he wrote 'To the best of my knowledge the learned societies of Germany have stood by passively and silently while substantial numbers of scholars, students and academically trained professionals have been deprived of employment and livelihood. I do not want to belong to a society which behaves in such a manner, even if it does so under compulsion.' He had been considering an arrangement that would have enabled him to divide his time between the Berlin Academy and the Institute for Advanced Study in Princeton. Such a compromise was clearly no longer viable and so he simply resigned from the Berlin Academy and moved to Princeton. With Einstein on the faculty, the institute was in a strong position to attract other leading scientists. Fortunately most of Einstein's scientific correspondence had been saved and brought to America by diplomatic bag. Having automatically become a German citizen again when he was appointed to the Berlin Academy, he relinquished this just before the Nazis could deprive him of it. Many other Jewish scientists were also leaving Germany; some stayed behind and, ironically, a few of them tended to blame Einstein for what befell them.

So Princeton became Einstein's home for the remaining twenty-two years of his life. He described it as 'a wonderful piece of earth and at the same time an exceedingly amusing ceremonial backwater of tiny spindle-shanked demigods'. His *Heldenzeit* lasted a good twenty years, but well before he left Europe his great days were over. He was noticeably aged; scientifically the Princeton years were much less fruitful than what came before. Although he thought the chances of success were small, he continued to seek a unified field theory and became increasingly isolated from the mainstream of physical research. Princetonians respected his desire for solitude. On one occasion he said that really his only friend in Princeton was Kurt Gödel, the mathematical logician, who used to call for him every morning at 11 o'clock so that, whatever the weather, they could walk together to Fuld Hall. He continued 'I do not socialize because social encounters would distract me from my work and I really only live for that, and it would shorten even further my very limited lifespan. I do not have any close friends here as I had in my youth or later in Berlin with whom I could talk and unburden myself. That may be due to my age. I often have the feeling that God has forgotten me here. Also my standard of decent behaviour has risen as I grew older: I cannot be sociable with people whose fame has gone to their heads.'

During the 1930s Einstein renounced his former pacifist stand, since he became convinced that the menace to civilization embodied in Hitler's regime could only be put down by force. He never returned to Europe, in fact the only time he left America was in 1935 as part of the process of becoming an American citizen. He did not participate in the American efforts that eventually produced the nuclear reactor and the atomic bomb. After the bomb had been used and the war ended, he devoted his energies to the attempt to achieve a world government and to abolish war once and for all. He also spoke out against repression, arguing that intellectuals must be prepared to risk everything to preserve freedom of expression. Nonetheless, despite his concern for world problems and his willingness to use whatever influence he had towards alleviating them, his ultimate loyalty was to science. As he said once with a sigh to an assistant during a discussion of political activities: 'yes, time has to be divided this way between politics and our equations. But our equations are much more important to me because politics is for the present but an equation like that is something for eternity.'

After 1936, when his second wife Elsa died, Einstein was looked after by his sister Maja, his stepdaughter Margot and his secretary-housekeeper Helen Dukas. Maja had come to live with her brother in 1939; she suffered a stroke in 1946, after which she was bedridden, and died in 1951. Einstein had retired from the Institute for Advanced Study in 1945 and was living almost like a recluse, trying to avoid the endless stream of people who wanted to see him about something, or just to see him. He suffered much harassment by press photographers; no other scientist has become so well known to the public in appearance. He was generally quite a merry person, with a strong sense of humour and a loud laugh; on one occasion he put out his tongue to express his annoyance and that photograph has been reproduced endlessly. Around Princeton he could often be seen at the local cinema – he was particularly fond of Western films. Although he kept a wardrobe of seven identical suits to wear on formal occasions, his ordinary dress was casual, he favoured sweatshirts, leather jackets and sandals. He never learnt to drive a car, but used to sail a dinghy on Lake Carnegie. Otherwise he stayed peacefully at home in number 112 Mercer Street, a colonial-style house no different from others in the neighbourhood.

For many years Einstein experienced recurrent health problems, including anaemia and digestive attacks, and he also suffered from an enlarged heart. He was drafting a speech on the tensions between Israel and Egypt when he became ill and died a few days later, on April 18, 1955, in his seventy-sixth year; the immediate cause was a haemorrhage after a large aneurysm of the abdominal aorta burst. One of his last acts was to sign a plea, initiated by Bertrand Russell, for the renunciation of nuclear weapons and the abolition of war. He left his brain for use in research, his body for cremation, which was carried out privately, and all his scientific and other papers to the Weizmann Institute in Jerusalem; this did not prevent historians having difficulty in obtaining access to study this material and permission to publish in scholarly works.

Einstein never identified with any particular country, living and working in many different places, and, although he had quite a few individual collaborators, he never set out to create a research school in any sense. In his own words: 'I have never belonged wholeheartedly to any country or state, to my circle of friends, or even to my own family. These ties have always been accompanied by a vague aloofness, and the wish to withdraw into myself increases with the years. Such isolation is sometimes bitter, but I do not regret being cut off from the understanding and sympathy of other men. I lose something by it, to be sure, but I am compensated for it by being rendered independent of the customs, opinions and prejudices of others, and am not tempted to rest my peace of mind upon such shifting foundations.'