6 From Röntgen to Marie Curie

Our next five remarkable physicists were born in the twenty-three years from 1845 to 1867. Two came from England, two from Germany and one from Poland.

Wilhelm Conrad Röntgen (1845–1923)

Wilhelm Conrad Röntgen, the discoverer of X-rays, was born on March 27, 1845 in Lennep im Bergischen, a small town in the part of the Rhineland which then belonged to Prussia. His father Friedrich Conrad Röntgen was a cloth manufacturer and textile merchant. The family of his mother Charlotte Constanze (née Frowein) were in the same line of business, and, although they too came from Lennep, her parents lived in the Netherlands. In 1848, when their son was three, the family moved to the town of Apeldoorn in Holland, about a hundred miles distant, and as a result they became Dutch citizens rather than Prussian. After elementary school, Wilhelm attended a nearby private boarding school until at the age of seventeen he entered the technical school in the provincial capital Utrecht. There he lived with one of the teachers, and later recalled that

> the father of this family was a fine scholar, a solid character and a really splendid man who understood superbly the task of guiding young persons along the correct path in life. The mother was a loving, cultured and kindly woman who provided the proper atmosphere for a full life, one of happiness and at the same time pleasant stimulation. There was no time for foolish and stupid things, but much for creative activities. Self-created amusements were offered at community celebrations, but otherwise diligent work was demanded in serious learning. That was a happy and equally rewarding time, and looking back on the years of my youth, I have to add that I also went horse-riding and ice-skating and generally busied myself in many wholesome outdoor activities.

The young man was aiming to enter the famous old University of Utrecht, but a problem arose, which was to cause him considerable

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difficulty. After an incident in which he refused to tell on another boy who was at fault, Röntgen was expelled from the technical school. He then went to another school where he was prepared for university entrance but failed to qualify. Even so, he attended lectures at the university for a short while, but, because he was not a matriculated student, he would not have been able to proceed to a degree. Röntgen then decided to try instead for a place at the Polytechnikum of Zürich (since 1911 part of the Eidgenössische Technische Hochschule, or ETH), which it was possible to enter by passing a special examination. However, when he was all ready to sit this he went down with an eye infection, but was admitted anyway.

'Röntgen was a tall, handsome youth who, with penetrating brown eyes, looked soberly at the world', wrote someone who knew him in Zürich:

> He had a well spread nose and a large mouth. He had thick black wavy hair, was clean shaven and always dressed well. His father supplied him with sufficient money for clothes and extravagant fun and good living. Usually his attire was a modest dark coat, grey trousers, a soft wing collar with a large bow cravat, and a gold watch chain dangling over his waistcoat. He was conservative and modest. Although he disliked blatant conviviality, he was fun-loving, a popular young man

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> in a city where students were not always as serious as its sober citizens. He often went riding along the lake-shore, but when opportunity presented itself he would hire a fancy two-horse carriage to ride in style through the city streets. He did not join one of the *Burschenschaften*, which went in for carousing and duelling, but enjoyed the company of other students from the Netherlands who had their own informal club.

In Zürich at that time there was a scholarly innkeeper named Johann Gottfried Ludwig who had been forced to leave his native Jena because of suspected revolutionary activities. He settled in Zürich, where he purchased an inn and married a Swiss girl, Elsabeth Gschwend. They had four children, Lina Barbara, Anna Bertha, Hans Otto and Maria Johanna. Röntgen was a regular customer of the inn and became attracted by Bertha, the second daughter of the innkeeper. She was a charming woman, tall and slender, with a healthy and wholesome attitude towards life. When she became ill and was hospitalized in a sanatorium he hired, on her thirtieth birthday, a carriage drawn by four perfectly matched horses and driven by a top-hatted coachman in splendid livery, and drove up to the sanatorium to present her with a huge bouquet of red roses. It was agreed that they would marry once his future was more secure.

Röntgen's studies were going well. He received his diploma as a mechanical engineer in 1868 and then moved over to physics, in which field he wrote his doctoral dissertation on thermodynamics, after taking a course from the great Rudolf Clausius. When this was accepted his parents came to Zürich to inspect his fiancée; they found her well-educated, of good family, intelligent, of good character and very agreeable. However, they felt that, although over thirty, she was not yet fully prepared for matrimony, so it was agreed that she would go to Apeldoorn to learn cooking and other domestic skills. At the same time Röntgen obtained the position of assistant to the physicist August Kundt, from whom he learnt the importance of taking the utmost care in experimental work, often repeating an experiment over and over again until the results were absolutely certain. When Kundt moved to Würzburg he took his assistant with him. However, Röntgen found the laboratory facilities there disappointing, a regular complaint throughout his life.

At that time Friedrich Kohlrausch was one of the most eminent German physicists. Röntgen, in the course of some experiments on specific heat, found some errors in the published work of Kohlrausch and sent a report to the prestigious *Annalen der Physik und Chemie*. When this first scientific paper of his was accepted, he felt he could look forward to his future with some confidence, and therefore get married. The wedding took place in Apeldoorn at the beginning of 1872. A few months later Kundt announced that he was moving again, this time to Strasbourg, and asked Röntgen to come with him. This he was glad to do, because his prospects of advancement in Würzburg seemed poor; even the first step of becoming a Privatdozent was thwarted by his unsatisfactory school record.

After the Franco-Prussian war, Strasbourg (or Strassburg) lay in German hands, and the ancient university was being reopened with new and well-furnished buildings. For once he could not find fault with the equipment in the laboratory. His elderly parents moved to Strasbourg to join the young couple. In 1874 Röntgen himself was appointed Privatdozent. The following year he was offered a full professorship in physics at the Agricultural Academy in Holdenheim, close to Stuttgart. After some hesitation he accepted the post, but soon regretted doing so, because the experimental facilities were so inadequate. When Kundt became aware of the situation, he arranged for Röntgen to return to Strasbourg as associate professor of theoretical physics, at the age of thirty-four.

This second Strasbourg period was in many ways the most fruitful of his professional life. His experimental work made good progress and he published his results on a wide range of topics but particularly on the physical properties of crystals. Soon he was ready for a full professorship and in 1879 the offer of one came from the University of Giessen, some 30 miles north of Frankfurt, where he would be director of the institute of physics. A new building for the institute had been agreed; not only could Röntgen choose the equipment for this, but he also had a say in the choice of his own assistants. The Röntgens found the small town of Giessen congenial and were pleased when his parents did so too. In 1880 his mother died, and his father died four years later. In 1887 the Röntgens, realizing that they would never have children of their own, decided to adopt the daughter of Bertha's brother Hans, their six-year-old niece Josephine Bertha.

Two years later Röntgen made one of his most important discoveries when he demonstrated the correctness of a prediction of the Faraday–Maxwell theory of electromagnetism. This discovery, one of the foundations of the modern theory of electricity, made Röntgen famous internationally. By this time he had been at Giessen ten years and was forty-three years old. He began to receive offers from other universities. One was Utrecht, but, although Bertha liked the idea of returning to the Netherlands, he turned it down. Another was to return to Würzburg as professor of physics and director of the new institute of physics, where there was accommodation for the director in the form of a spacious nine-room apartment. He accepted the latter position without hesitation and took office on October 1, 1888.

At this age the bearded Röntgen was impressive in appearance. As a colleague wrote:

> He had a penetrating gaze and unassuming manner which gave him extraordinary character and dignity. His nature was amiable and always courteous, but his reticence and shyness amounted almost to diffidence when he received strangers. In later years his shyness acted as a wall; it protected him from selfish and curious persons, but it also kept many fine and sincere persons away. Occasionally Röntgen would appear distrustful, but actually he concealed a deep sympathy and understanding. After he was convinced of the sincerity of his caller he would extend a warm friendliness toward him. He had close friends among his colleagues at the university who remained close to him for the whole of his life.
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> Röntgen showed no patience with persons whose behaviour was actuated by selfish personal motives or was noticeably shaded by personal prejudices. His was an intellectual honesty which characterized not only his work but his attitudes as well. He believed that their attitudes interfered with the progress of science and were actually detrimental to the person. Many times he was gruff to people only concerned with their own importance and he was not apologetic for such behaviour. He detested those who would try to cover up superficial academic knowledge with dazzling but utterly meaningless theories.

Röntgen disliked lecturing, speaking in such a low voice that students at the back of the class could hardly hear him at all. As an examiner he was dreaded. Social activities took on a certain routine: four or five families from his group of close friends would gather for dinner at one or other home. Dinners were elegant, with fine white wines and red wines drawn from a cask. For recreation the Röntgens made use of a small log cabin they had bought some five miles from the city as a base for walks. Unfortunately, Bertha did not enjoy good health, and their adopted daughter was not strong either.

Röntgen was elected Rector of the University of Würzburg, for the customary year of office, after which he and his wife took an Italian tour,

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although normally they always took their summer holidays in the Swiss Alps. In June 1894, just before they left for Italy, Röntgen was conducting a series of experiments with cathode rays. Many other scientists were interested in these, so he was anxious to proceed as rapidly as his meticulous standards would permit. Cathode rays would not penetrate more than a few centimetres in the air but he discovered a new form of radiation, which was much more powerful. Helmholtz had predicted that, on the Maxwell theory, a sufficiently short-wave light-ray should go right through solid materials. He tested this out on various materials. Lead blocked the radiation entirely, but other metals let it through. However, what struck him most was that, when he held up his hand, the screen showed the bones of his hand, encased in darker shadows. He decided that, although the eye might be deceived, the photographic plate could not be, and took photographs of the phenomenon. As was his practice, he repeated the observation over and over again, until he was satisfied, and within a few weeks he was.

So far the work had been kept secret, but now Röntgen felt sufficiently confident to publish his results, albeit in just a small academic journal. The historic paper he wrote, entitled 'A new kind of ray', appeared in time for him to send out copies to many of the leading scientists in the field on New Year's Day 1896. There were sceptics, but Röntgen had a reputation for careful experimentation. The exciting news of his discovery produced a flood of messages of congratulation from all over the world. The potential for applications in medical diagnostics was immediately recognized; the university made him an honorary doctor of medicine, while the students put on a torchlight parade in his honour. The Kaiser, Wilhelm II, summoned him to Berlin, to give a demonstration, and decorated Röntgen with the Prussian Order of the Crown, Second Class. He declined an invitation to speak before the Reichstag. This was perhaps the first time that a scientific discovery had, almost overnight, caused such a sensation and received so much publicity, to Röntgen's horror. He returned to the scientific investigations that had occupied him before his great discovery. At first the X-ray pioneers saw no reason to protect themselves against the effect of the radiation, but before long some of them began to experience loss of hair and burns, particularly on the hands.

In 1900 Röntgen left Würzburg, with considerable reluctance, to become professor of physics and head of the institute of physics at the University of Munich. The next year, when Nobel prizes were awarded for the first time, he received the prize in physics 'for the discovery of the remarkable rays subsequently named after him'. Although he always called them X-rays, others called them Röntgen rays. In his will he left the prize money to the University of Würzburg to be used in the interests of science, but unfortunately the legacy became valueless together with the rest of Röntgen's personal fortune when the German economy collapsed after the First World War. The Prince Regent of Bavaria bestowed upon him the title of 'Geheimrat' in 1908 and soon afterwards the city council of Weilheim, where he owned a hunting lodge, made him an honorary citizen. His wife Bertha, whose health had been failing for some years, died in 1919; the following year he retired from his position at the university while retaining facilities in the laboratory of the physics institute. A staunch patriot, he was deeply depressed by the German defeat and its consequences. Röntgen died of rectal carcinoma at the age of seventy-seven on February 10, 1923, in his Munich apartment; his ashes were buried with those of his wife and parents. Röntgen was of the opinion that his discoveries and inventions belonged to humanity and that they should not in any way be hampered by patents, licences or contracts or controlled by any one group. His altruism made a very favourable impression on scientists both in Germany and abroad. A statue of him was erected on the Potsdam Bridge in Berlin.

Joseph John Thomson (1856–1940)

Manchester in the middle of the nineteenth century was a prosperous industrial town with an active cultural life. Many of the northern businessmen were devout nonconformists. Their faith often impelled them to live austere

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personal lives and frequently to initiate schemes of social amelioration and works of personal charity, often at considerable cost to themselves. The advancement of education, public health and science were the main areas which attracted these public-spirited men. One of the most important of these initiatives was Owens College, the predecessor of Manchester University, founded in 1851 by a wealthy bachelor who had been in the textile trade. Its aim was to provide an education modelled on the practices of the Scottish universities, rather than Oxford and Cambridge, and to be of use to young men who intended to enter commerce or industry. The courses were based on traditional subjects: Latin and Greek, mathematics, natural philosophy, English and history, chemistry, foreign languages and natural history. The degrees were those of the University of London, which imposed no residence requirement. There were no faculties of law, medicine or technology.

Joseph John Thomson, later known informally as J.J., was born on December 18, 1856. His father Joseph James Thomson managed a small business selling antiquarian books, occasionally acting as publisher as well. This prospered sufficiently to give him a reasonable living and a house with servants in the middle-class suburb of Cheetham Hill. The Thomsons had lived in Manchester for several generations but originally they came from lowland Scotland – hence the spelling of their name without the letter p. Joseph married Emma Swindells, who also came from Manchester. She has been described as small, with bright dark eyes brimming with kindness, and dark hair hanging in clusters of ringlets over her ears. They had one other child, Frederick, who was four years younger than J.J.

Although not much seems to be on record about the father, who died when J.J. was only sixteen, it is recalled that he was acquainted with some of the scientific and literary people of Manchester, many of whom would probably have patronised his bookshop. When J.J. was a boy he had been introduced to the famous Joule by his father, who had afterwards said 'some day you will be proud to say you have met that gentleman'. J.J. was a shy boy but determined and 'knew which way he was pointing'. When asked what he wanted to do when he grew up, he replied that he wanted to do original research, whereupon one of those present tapped him on the head and said 'don't be such a little prig, Joe'. By the age of fourteen he could be described as a 'rather pallid, bony youth with the air of a serious but happy student, unassuming and modest without diffidence, very approachable and friendly'.

J.J.'s father seems to have decided that his elder son's aptitude for mathematics indicated that engineering would be a more suitable choice of career for him than bookselling, perhaps hoping that the younger son would enter the business instead. Since J.J. had completed his secondary education by the age of fourteen, it was thought that Owens College would fill the gap until he was old enough to be apprenticed to a Manchester engineering firm. However, after the early death of his father there was no money to pay the premium for the apprenticeship; the family business was sold and his widow, with her two sons, moved to a smaller terraced house nearer Owens, where J.J. was in his second year. She could only just afford to keep him there.

After a difficult first twenty years, the college had started to flourish, despite having rough and overcrowded facilities. The range of lectures in engineering, mathematics and natural philosophy was impressive. There was probably nowhere outside Oxford and Cambridge that could match it in England, though Glasgow was perhaps its equal in Scotland. In effect J.J. went through university in three subjects while still a schoolboy. After he left, having thrived on the teaching it provided, the college authorities made a regulation raising the minimum age of admission.

To complete his education J.J. was determined to go to Cambridge, but his mother could not afford to send him there unless he won a scholarship. As there were no entrance scholarships for engineering or physics, the route had to be through mathematics. He succeeded on his second attempt at winning a scholarship to Trinity, the college with the highest reputation and the most difficult to enter as a scholar. There were several reasons why he chose Trinity. The first was his own self-confidence in his ability; he did not hesitate to test himself. The second was that a number of his teachers at Owens had come from the college. Thirdly, Trinity, as we know, was currently the college of Clerk Maxwell, the first Cavendish Professor, whose famous treatise on electricity and magnetism was a starting-point for much of J.J.'s early thoughts about research.

In the course of his long life J.J. never lived anywhere else but Manchester and Cambridge. Moreover, at Cambridge he was living either in Trinity, as undergraduate, college fellow, lecturer, young professor or head of the college, or nearby, and all these homes were within a few minutes walk of each other and of the Cavendish laboratory, which was then in the town centre. He liked Cambridge: the air, he said, seemed to favour him. Not once in that time could he recall a working day lost by sickness. His relations with

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his mother had always been close; she was a sweet-natured person, proud of her son without, apparently, understanding anything of his work. Up to her death in 1901, he regularly spent part of his summers with her, after his marriage as well as before, either in Manchester or at some seaside resort, usually with his younger brother Frederick, who worked for a firm of calico merchants in Manchester. A lifelong bachelor, Frederick admired his elder brother's success; after he retired early due to ill-health he spent the last three years of his life in Cambridge.

Mathematics was still (at Cambridge, at least) the usual approach to the study of physics, and the best students had to face the peculiar rigours of working for the mathematical Tripos. The examination was held in January in the unheated Senate House; during the midday break J.J. went to the barbershop for a shampoo. Having been coached, like Strutt, by the famous Routh, he was listed as second Wrangler, close behind Joseph Larmor, who spent his life in Cambridge at the adjacent St John's College. The two men became life-long friends, though there is little correspondence between them to show it, mainly because they lived so close and saw each other so often. In J.J.'s final year as an undergraduate Clerk Maxwell died, after years of poor health and periods of absence from the Cavendish. It was a matter of great regret to J.J. that they never met, but was able to acquire Maxwell's armchair, and kept it for the rest of his life in his study at home; much of his physics was done sitting in that chair.

After graduating J.J. stayed on at Trinity to try for a prize fellowship, which would provide him with seven years of leisure for research. His choice of subject for his fellowship thesis, on the transference of kinetic energy, followed on from the inspiring lectures on energy he heard at Owens College. Three years were allowed for the preparation of such a thesis, but, with great concentration and application, J.J. completed his within one year and with characteristic self-confidence submitted it, against the advice of his tutor. He was successful; the following year he won the Adams prize for a dissertation on the motion of vortex rings and became assistant lecturer in the college; in 1883 he became university lecturer as well.

In the three years between his fellowship election in 1881 and 1884, the crucial year of his early academic career, J.J. published a number of important papers on physics. These were both theoretical and to a lesser extent experimental, including – in 1883 – the first paper on the subject he was to pursue throughout his later life 'On the theory of electric discharge in gases', a new area of research at the Cavendish and one that was to lead to the discovery of the electron. They made his reputation in what was then the small world of professional mathematicians and physicists. In the first half of 1884, when still under thirty, he was elected a fellow of the Royal Society. Without that it is doubtful whether a few months later, when Rayleigh retired from the Cavendish chair, J.J. would have been appointed to succeed him. As it was the appointment took everyone by surprise. The fact that he should have put himself forward for the post at all was further proof of his sturdy self-assurance; only eight years previously he had arrived in Cambridge as a freshman.

There were nine electors for the chair and at least four of them, in the previous three years, had directly been involved in adjudicating J.J.'s work for the Trinity fellowship, the Adams prize or the fellowship of the Royal Society. In particular, the external elector was Sir William Thomson, no relation to J.J., who, as we have seen, could himself have taken the post on several occasions if he had so wished. With his commanding reputation and equally formidable manner of speech, it was probably his support that swayed the decision in J.J.'s favour. The electors took a bold decision and backed the original thinker of great promise rather than other candidates with more proven experience of teaching and experimental work, two of whom had actually taught J.J. in Manchester.

After the Cavendish laboratory had been started under Maxwell and consolidated under Rayleigh, J.J. was the right man to develop it further. In the 1880s physics generally was passing through a quiet period; there were no grand themes, but a lot of tidying up and improvement of measurements as well as a very necessary improvement in the methods of teaching and examining. The number of students at the Cavendish was small, and the organization of the laboratory informal. It took some time for J.J. to become established in the post, find promising lines of research and raise the money to enlarge and equip the laboratory. The professor personally conducted the administration, including, it seems, the book-keeping. J.J. wrote his correspondence standing up at a desk with a sloping top, in a neat and legible handwriting. It was the only thing about him that was neat, since he was noticeably casual in organizing his paperwork, his timetable and his dress. Conditions in the laboratory were described as somewhat chaotic.

One of the best-known Cambridge families of the time was that of Sir George Paget. He came up to Caius in the 1830s to read mathematics and, after distinguishing himself in the Tripos, switched to medicine because it would lead to a fellowship at Caius. He had progressed until he had become Regius Professor of physic, in which role he transformed the teaching of medicine in Cambridge. He married and had a family of ten children, of whom seven reached maturity. Among these were the twins Rose and Violet, who were born in 1856. Unlike her more extrovert sister, Rose grew up to be intellectual, precise and calmly organized. Although the twins were almost opposite in character, they remained devoted to each other all their lives.

Rose Paget, who had become a student at the Cavendish shortly after J.J. had become professor, had no formal qualification in physics at all, only an intellectual fascination with science, which had been fostered by her distinguished father, and a determined will. She and J.J. married in 1890; after his mother she was the only woman in his life and the centre of his affection for fifty years in a marriage of much warmth and mutual admiration. In the early years they first lived near the centre of Cambridge and then from 1899 in a large Victorian house with an acre of garden called Holmleigh, on the other side of the river Cam from the colleges. They had two children, a son and a daughter: the son, George Paget Thomson, was to become a physicist of distinction, who shared the Nobel prize in 1937 for an experimental demonstration of the wave nature of the electron.

By the early 1890s J.J. had come a long way from his Manchester roots. A star in the ascendant, he attracted the brightest students to the Cavendish. He had played himself in carefully at the laboratory and, while continuing the earlier lines of work and teaching of Rayleigh, had found himself a major field of research in the conduction of electricity through gases. Within a few years this was to lead him personally to his greatest discoveries and bring a world-wide reputation to the laboratory. The nature of cathode rays was then unknown. In 1897 J.J. succeeded in deflecting them by an electromagnetic field, thus showing that they consisted of negatively charged particles. He also measured the ratio of their charge to their mass and deduced that electrons were about two thousand times lighter than the hydrogen atom. These revolutionary discoveries were announced by J.J. on April 30, 1897, at a historic Friday evening discourse at the Royal Institution.

The growth of the Cavendish was also helped by a wise university regulation allowing graduate students of other universities to enter Cambridge as research students. In a photograph of the research students at the Cavendish taken in 1898, as many as nine out of sixteen were from outside Cambridge. At the same time, a timely change in the regulations of the Commissioners of the 1851 Exhibition allowed that well-endowed body to fund science-research scholarships for overseas students. The first to benefit from this was Ernest Rutherford; while still in New Zealand he had read everything J.J. had written and decided that this was the man under whom

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he wished to work. It was the start of a long and fruitful collaboration and friendship, further described in the profile of Rutherford.

It was the magnetic quality of J.J.'s greatness that drew so many of these brightest minds, and formed a seed-bed that was continually renewed as established members went off to professorships around the world (ninety-seven of them altogether, at fifty-five universities) and new students arrived. For more than twenty years his group of research workers in experimental physics was easily the most important in Britain, and probably in the world. It included a formidable list of scientists, both British and foreign, who in their turn were to make fundamental contributions to science; at least eight of them won Nobel prizes. Although so much was achieved at the Cavendish under J.J., it is striking what was not. It was Hertz who proved the existence of electromagnetic waves, Röntgen who discovered X-rays, Becquerel who discovered radioactivity, and the Curies who discovered radium, none of whom were directly influenced by J.J.

According to his son George Thomson: 'in all his theories J.J. liked to visualize, and for him the mathematics was always merely the language which described the physical and spatial concepts in his mind. He had no idea of mathematics dictating the theory.' He was not good at the physical handling of apparatus himself; he devised it in his mind and his personal assistant constructed it and got it working. To quote his son again: 'He had the physician's gift of diagnosis, and could often tell a research worker what was really the matter with an apparatus that a man had made and struggled with miserably for weeks.' His own apparatus was simply designed and constructed without unnecessary refinement. The phrase 'sealing wax and string' with which a later generation described the Cavendish apparatus of his day is not a great exaggeration; judged by modern standards there was something amateurish about it . . . yet this rather odd collection of glass and brass did in fact play a major part in producing the revolution in physicists' conceptions of the nature of matter and energy that was about to occur.

J.J.'s own mind, it was said, showed restless mental activity and originality. The subjects he pursued were for him the most exciting things in the world, and he communicated this excitement to researchers. Although most of the people in the Cavendish in his day were working on the conduction of electricity in gases, there was no attempt to direct research and quite a few were working on something else. Everyone at the Cavendish loved his characteristic smile, and felt a certain pleasure on hearing a footstep that could only be his. Niels Bohr described J.J. as 'an excellent man, incredibly clever and full of imagination . . . extremely friendly but it is very difficult to talk to him'. Rutherford's first impression of him is recorded in a letter he wrote to his fiancée: 'you ask me whether JJ is an old man. He is just fifty and looks quite young, small, rather straggling moustache, short, wears his hair (black) rather long, but has a clever-looking face, and a very fine forehead and a radiating smile, or grin as some call it when he is scoring off anyone.'

J.J. could be forceful and determined in getting what he wanted for his own work for the laboratory and for his students, and was always conscious that he possessed rare intellectual power, yet he was modest about his achievements. Throughout his written work he took careful account of what others had done. This showed particularly in the field of cathode rays, where much work had been done by German physicists. In the great upsurge of activity following Röntgen's discovery of X-rays there was a good deal of parallel activity taking place and no doubt J.J.'s discovery that the cathode-ray stream was made up of particles of a smaller order of magnitude than the atom, and which were universal constituents of matter, would have been postulated before long by others who were conducting very similar experiments. The fact is that he was the first to see the profound significance of these experiments and it took several years to convince others that he was right. Although J.J. had no gift for languages, he learned enough German, with the help of his wife who knew it well, to read the German scientific journals and kept closely abreast of work being done elsewhere, not only through the journals but also by direct correspondence. In later years he was out of sympathy with the new physics developed by Bohr, but by that time he was no longer Cavendish Professor and no harm was done. He continued to believe that atoms consisted of electrons embedded in a positively charged sphere, a model long superseded. J.J. was described as 'a curious link between the old and new physics. He opened the door to the new physics but never went through it himself. It was Rutherford who went through the door that he opened.'

The growth of J.J.'s intellect seems to have been almost complete by the time he left Manchester. What Cambridge did for him was to supply the mathematical knowledge, skill and discipline which enabled him to understand Maxwell's writings. These profoundly affected him and the resultant struggle to harmonize the view of the physical universe which he had formed at Manchester with that of Maxwell led him to the discovery of the electron. He was assisted in his labours by a comprehensive memory embracing a great variety of subjects from science to athletic records, although at times it was liable to fail him and he was known to repeat

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the same story to the same people in a matter of minutes. There were other instances, not uncommon in the laboratory, which were not capable of an easy explanation. A researcher would explain to J.J. what he believed was the theory behind the experimental results he was obtaining: J.J. would counter this by propounding quite a different view, and the argument would continue day after day and would finally cease, both sides being unconvinced. Then, perhaps a month later, J.J. would tell the researcher that he had found the explanation of the results they had discussed, and would give a detailed account of the very same theory as that which the researcher had propounded. The unconsciousness of its origin combined with the more perfected form was peculiarly trying. If generally this was dismissed as an instance of the vagaries of great minds, it did from time to time lead to difficulties and misunderstandings.

Being a man of very varied tastes and interests, often unexpectedly pronounced or unusual, Thomson was ready to talk to almost anyone about almost anything, and seemed to be bored by no subject except philosophy, which he once described as a subject where you spent your time trying to find a shadow in an absolutely dark room. He was one of the founders of the Society for Psychical Research and was also keenly interested in telepathy and water-divining.

The outbreak of the First World War in 1914 followed by his election to the presidency of the Royal Society brought J.J. more into public affairs. As British scientists made their contribution to the war effort, normal scientific research ground to a halt. However, the backwardness of Britain in applied science became all too evident and, as president of the Royal Society, J.J. led the efforts to persuade the government that something had to be done. Within the society itself he led the opposition to those who wanted fellows of German descent to be expelled. In 1918, when the war was over, J.J was appointed to the Mastership of his college, Trinity. At the same time he was persuaded to resign the Cavendish chair, and hence the direction of the laboratory, accepting in lieu a personal research chair with facilities in the Cavendish. He maintained his interest in physics, but no longer contributed to it himself. As Master of Trinity he was an effective chairman of college committees, took a keen interest in the students and particularly enjoyed watching their sporting activities, although he was never at all athletic himself.

He was most careless in his attire and appearance, and behaved as if it was a matter of no interest either to himself or to others. As a ready speaker with a remarkable command of English, he could, when occasion demanded, deal with complex, difficult or delicate situations with precision and tact. Travel as a recreation did not in itself appeal to him much, and in his prime he travelled little except to receive an honorary degree, a medal or a prize, or to deliver a prestigious course of lectures, for which he was quite prepared to cross the Atlantic. In later years J.J. played up his Manchester background, though he rarely revisited the city. He spoke with a noticeable Lancashire accent and liked regional dishes such as Lancashire hot-pot. His robust sense of humour came from the north: in a speech he remarked that there were two kinds of physicist in Cambridge, those who made discoveries and those who received the credit for them.

As for honours, apart from the Nobel prize in physics in 1906 for research into the conduction of electricity by gases, he received the principal awards of the Royal Society, in particular the Copley medal. He received a large number of honorary doctorates and was an honorary member of all the leading scientific academies. He was particularly proud of the Order of Merit. J.J. was knighted in 1908, but later declined the offer of a peerage, partly because he did not think himself wealthy enough to sustain the honour. In fact, he died a wealthy man, but this was through shrewdness in the management of his investments rather than through exploitation of any of his discoveries. He was always interested in commercial applications but did not seek to benefit from them personally. Unlike Lord Kelvin, he never took out any patents, though the cathode-ray oscilloscope and the television tube derive directly from his apparatus. In a broader sense the whole of today's electronic industry descends from his key discovery of the electron; no-one could have foreseen the vast range of practical applications a century later. He died at the age of eighty-three on August 30, 1940, in the Master's lodgings, after a progressive decline over the previous four years, and his ashes were buried in Westminster Abbey near to the graves of other great British scientists. There are portraits of J.J. in most of the institutions with which he was associated.

Max Planck (1858–1947)

Albert Einstein said of Max Planck 'Everything that emanated from his supremely great mind was as clear and beautiful as a great work of art; and one had the impression that it all came out so easily and effortlessly . . . for me personally he meant more than all the others I have met on life's journey.' The creator of quantum theory came from an old-established family of lawyers, public servants and scholars. One of his ancestors was a pastor in the south-German region of Swabia who later became a professor of

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theology at the Georgia Augusta and one of whose grandchildren became a jurist, the founder of the German civil code. He and Max Planck's father were cousins, the latter being also a distinguished jurist and professor of law first in Kiel and later in Munich. This ancestry of excellent, reliable, incorruptible, idealistic and generous men, devoted to the service of church and state, must be borne in mind if one is to understand the character of the great physicist.

Max Karl Ernst Ludwig Planck was born in Kiel on April 23, 1858, the fourth child of his parents. His mother, Emma Patzig of Greifswald, his father's second wife, came from a family of pastors. He grew up in a conservative, cultured family in prosperous Wilhelmine Germany. When he was nine the family moved to Munich, where he attended the renowned Maximilian Gymnasium. The mathematics teacher he found particularly inspiring, learning from him such fundamental ideas of physics as the principle of conservation of energy. His teachers did not rate him an outstanding student, rather they praised his personal qualities. When it came to choosing a profession, he considered philology but eventually decided on physics. He also became an excellent pianist and found in playing music deep enjoyment and recreation.

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After graduating from the gymnasium, Planck studied for three years at the University of Munich. There was no professor of theoretical physics at the university at the time, but there were lecturers who gave him a good foundation in mathematics and physics. It will be recalled that it was then the normal practice in Germany for students to spend their first two years at more than one university. The absence of any examination before the final one made this system possible. Its obvious advantage was that students had the opportunity to hear the great professors of their day. Planck migrated for a year to Berlin, where he heard Helmholtz and Kirchhoff. Helmholtz, he recalled, did not prepare his lectures properly; the students felt just as bored as he seemed to be himself. Kirchhoff's lectures were meticulously prepared, but his delivery was dry and monotonous.

Although Planck's doctoral thesis of 1879, on thermodynamics, was not particularly well received, he was not discouraged. He continued to study the subject in his *Habilitationschrift*, which qualified him to become Privatdozent in 1880, but found that he had been anticipated by Willard Gibbs. He tried to correspond with Rudolf Clausius on matters related to the second law of thermodynamics, but received no replies. However, Clausius' papers on entropy were a major influence on Planck, who later used the concept of entropy as a bridge into the realm of quantum theory. To make himself better known in the scientific world, Planck competed for a prize at the Georgia Augusta in 1887, on the concept of energy, but before he had completed his essay, for which he was awarded second prize, he accepted an associate professorship at the University of Kiel. After the death of Kirchhoff in 1889, the University of Berlin secured Planck for the chair of theoretical physics, at first as an associate professor but within three years as a full professor. He owed this rapid promotion largely to the support of Helmholtz. Planck's lecturing style was to read verbatim from one of his books; if you had a copy you could follow it line by line.

Meanwhile Planck's research into thermodynamics had led him to the inescapable conclusion that something new was needed; he called it the quantum of action. Matter, he decided, emits radiant energy only in discrete bursts; the quantum of energy grows larger as the wavelength decreases, but the product is constant. Planck had no doubts about the importance of his idea. He told his son that it was either complete nonsense or the greatest discovery since Newton. In public, naturally, he was much more modest, so much so that it was said later that he had not begun to realize its full implications himself. It is generally acknowledged that the year 1900 of Planck's discovery marks the beginning of a new epoch in physics, yet during the first years of the new century it did not make much of an impact. Planck himself returned to thermodynamics. Personally and scientifically he was thoroughly conservative and recoiled from his own findings, which clashed with the tenets of classical physics, and he tried hard to find ways of reconciling them.

Planck was very much a family man. His first marriage to Marie Merck, the daughter of a banker, ended in divorce, but he remained on good terms with her. Their four children lived with their mother until she died in 1909. He then married again, to a niece of hers, Marga von Hoesslin. The Plancks lived in Grunewald, an attractive new suburb at the edge of the pine forest west of Berlin. According to his disciple Lise Meitner, 'Planck loved happy, unaffected company, and his home was a focus for social gatherings. Advanced students were regularly invited to his home . . . if the invitation fell during the summer semester we played tag in the garden, in which Planck participated with almost childish ambition and great agility. It was almost impossible not to be caught by him.' Later she said that, while she had been swept along by Boltzmann's exuberance, she loved and trusted Planck for his depth of character. 'He had an unusually pure disposition and inner rectitude, which corresponded to his utter simplicity and lack of pretension . . . he was such a wonderful person that when he entered a room the atmosphere in the room got better.'

When the 'golden age' of physics began at the turn of the century, Berlin was central to its development, as Planck was to its success. Although he was not in the vanguard of those who accepted Einstein's ideas, in time Planck developed the greatest admiration for what Einstein had achieved. The Berlin Academy, mainly at the instigation of Haber, Nernst and Planck, created a special chair for Einstein, which allowed him to pursue his ideas unhampered by teaching and routine work. For many years Planck and Einstein met at regular intervals; their collaboration made Berlin, in the years preceding the First World War, the leading centre for theoretical physics in the world. A friendship that went far beyond the exchange of scientific ideas developed between them. They shared a fascination with the secrets of nature, similar philosophical convictions and a deep love of music. They often played chamber music together, Planck at the piano and Einstein on the violin.

Planck was a pianist of great technical ability, who could play at sight almost any piece of classical music. He also liked to improvize on a given theme, such as an old German folk-song; at one time he had thought of becoming a composer (he composed songs, conducted an orchestra and

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accompanied the famous violinist Joseph Joachim). One year a large harmonium, with numerous keys, built at the suggestion of Helmholtz and tuned harmonically, was delivered to the department of physics. Planck learned to play this complicated instrument and compared the just intonation with the normal equal temperament. Unexpectedly, he found that our ears prefer the latter.

When Boltzmann died in 1906, Planck was invited to succeed him in Vienna, but colleagues in Berlin persuaded him to stay. He served as Rector of the university for 1913/4; when the war began he was one of a number of prominent German signatories to the chauvinistic 'Manifesto of the 93' or 'appeal to the cultured peoples of the world'. Like others he soon regretted doing so, explaining that he had not read it when he signed it. Within the Berlin academy, of which he was an influential member, he succeeded in preventing the expulsion of members from enemy countries.

Planck was deeply rooted in the traditions of his family and nation, an ardent patriot, proud of the greatness of German history and typically Prussian in his attitude to the state. During the war years, however, a change came over him. It was not only the general suffering, the catastrophic end to the struggle which hurt his patriotic feelings deeply, but grievous personal loss. Three of the four children of his first marriage died during the war period. His eldest son Karl was killed in action on the western front in 1916. The two daughters, Emma and Margarete, were identical twins; Margarete died in childbirth; her sister took charge of the baby and then she too died in childbirth. The surviving children were brought up by their grandfather. Only one son, Erwin, of the first marriage remained, and a younger son, Hermann, of the second marriage. Erwin also fought in the war; he was taken prisoner by the French but survived.

In 1928 Planck, being seventy, retired from his university post, but continued in office as permanent secretary of the Berlin Academy and as president of the Kaiser Wilhelm Gesellschaft, the Society for the Advancement of Science. In the Wilhelmine period the prestige of chemistry in Germany was very high, so, when it was proposed that the society create a number of specialized research institutes, financed at first by German industry, later with increasing support from the state, it was decided that the first two should be for chemistry and for physical chemistry. The physics institute was not organized until after the First World War, when Einstein was appointed the first director. The Society fully intended that it should become a proper institute with a building including a laboratory, but at first it was no more than an office concerned with dispensing research grants.

The Rockefeller Foundation was prepared to help finance the building of a laboratory if the Germans assumed responsibility for its maintenance. This was a project close to Planck's heart and in 1938 he had the satisfaction of seeing the long drawn out negotiations concluded. However, by then the golden age of German science was over. We must go back over the previous decade to understand what had happened.

In 1929 the worldwide economic collapse was under way; in Germany unemployment began to soar. Reactionary groups in Germany never accepted the reality of the defeat of the imperial military machine and sought to exploit a historical fantasy in which an undefeated army was betrayed by a sinister alliance of socialists and Jews. The reactionary forces included not only remnants of the military, industrialists and large landowners, but also many conservative academics. They all detested the social-democratic government of the Weimar republic and were dedicated to its destruction, the generals and business magnates by overt action and the university mandarins by incessant and insidious propaganda. Against this background the Nazis were gaining more and more adherents, and there were demonstrations on the streets of Berlin, in which students were much involved. The summer of 1932 marked the beginning of the end for the Weimar republic: by January 1933 Hitler was Chancellor and soon effectively dictator. Many Germans wrongly believed that, having achieved power, Hitler would moderate some of the more extreme Nazi policies; they regarded Nazism as a passing phase and Hitler as a puppet in the hands of the Reichswehr and the great industrialists. One has to remember that even many highly educated Germans never took the Nazi movement seriously. When they began to realize its disastrous impact it was too late for any serious opposition.

The first three months of the Third Reich began with an attack on Jewish and left-wing intellectuals and members of the cultural elite, such as musicians, artists and authors. Jewish businesses were boycotted. Within Prussia all Jewish judges were dismissed. This action was followed by much more far-reaching legislation 'for the reconstitution of the professional civil service' to ensure loyalty to the new regime. Its purpose was to exclude from state and municipal service 'unreliable elements', socialists and other political opponents as well as Jews. 'Non-Aryan' included 'descended from non-Aryan, particularly Jewish, parents or grandparents. It suffices if one parent or grandparent is Jewish.' The rules made exceptions for those who had fought in the First World War but in practice the only effect was to delay their dismissals. Similar action was taken against socialists and communists, but in scientific circles it was the Jews who were most affected. The act also applied to Privatdozenten, who were stripped of their *venia legendi*. Four years later people with Jewish spouses were included.

The law applied to the teaching staffs of universities and technical institutes, since in Germany they are state employees. In 1933, as a consequence, approximately 1200 academics were dismissed, without notice. Of course the law also meant that many younger people who were hoping for academic positions were prevented from obtaining them, while older people had to decide what to do. Those who were not affected by the new law felt it useless to protest. Some even took advantage of the resulting vacancies to advance their careers. The students, many of whom were Nazi supporters, contributed by organizing the burning of books by Jewish authors. Ordinary people were astonished at the speed and intensity of it all; the course of events was so bizarre and irrational that they could not believe it was happening. Although anti-Semitism of a less-virulent form had existed in Germany before Hitler, not only under the empire but even under the Weimar republic, nothing like Nazi anti-Semitism had been seen before.

Planck's reputation as diplomat, patriot and conciliator, and his professional standing, meant that he was the man to whom the scientists looked for leadership. Universally respected for his absolute integrity and devotion to German science, Planck went to see Hitler in 1933, to plead for reason and restraint, emphasizing the enormous damage being done to science in Germany by the racist laws. Characteristically, Hitler worked himself into such a rage that Planck could do nothing but listen in silence and take his leave. Afterwards Heisenberg said he looked 'tortured . . . and tired'. Hitler had assured him, Planck said, that the government would do nothing further that could hurt science in Germany. Planck trusted that the violence and oppression would subside in time. 'Take a pleasant trip abroad and carry on some studies', he advised a worried colleague, 'and when you return the unpleasant features of our present government will have disappeared.' The logical process of German thinking inhibited resistance. 'If I protest', the reasoning went, 'I shall be removed from my post where I have influence, then I'll have none. So I had better be quiet and see what happens.'

The Prussian tradition of service to the state and allegiance to the government was deeply rooted in Planck. Whatever his personal feelings, he believed that it was his duty to work with the regime; he did not believe that public protest would achieve anything. Busts of Hitler were installed in the institute. Telegrams were sent to Hitler avowing pride in the 'national resurrection' which was taking place and thanking him for his 'benevolent

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protection of German science'. When Einstein, under pressure, resigned from the Berlin Academy, Planck wrote to thank him for doing so and hoped that they would remain friends. For the next ten years Planck, like other German scientists, omitted all reference to Einstein when relativity and quantum theory were under discussion, believing that it was more important to promote his work than to credit him with it, which might have led to political interference.

By 1938, far from relaxing, the Nazi persecution of the Jews had reached a new pitch of intensity. The admission of Jews to higher education was already very restricted; now it was forbidden. Thoroughly disillusioned, the eighty-year-old Planck resigned as secretary of the academy in 1938, after twenty-six years of service. He still enjoyed good health, due to the simplicity and regularity of his life and his custom of spending most of his holidays in the Bavarian Alps, usually at a small property he owned near Tegernsee. When he lectured it was usually on science and religion.

After the Second World War Planck was but a shadow of his former self. His house in Grunewald had been destroyed in one of the air raids on Berlin, and he had lost all his possessions. His son Erwin, the only surviving offspring of his first marriage, was marginally involved in the bungled July 1944 plot to assassinate Hitler led by Count von Stauffenberg and was executed by the Nazis. Towards the end of the conflict the Plancks took refuge on the estate of a friend on the west bank of the river Elbe, near Magdeburg. There they found themselves between the lines of the retreating Germans and advancing Allied armies; the battle raged around them for days. Eventually the American troops came and took him to safety in Göttingen, where he remained, leaving on only a few very special occasions. A great celebration was being prepared for his ninetieth birthday but a few months previously his health had begun to fail and he died from a stroke on October 4, 1947. Max Planck had received the Nobel prize for physics in 1919, for his discovery of energy quanta, and other honours too numerous to mention.

William Henry Bragg (1862–1942)

The early life of William Bragg, the founder of the science and art of X-ray crystallography, was tough and testing. He wrote about it in a short autobiography in 1927, not intended for publication, and as a result we have more information about these years, before he arrived in Australia, than we have for many other scientists of his period. Since his son was also an

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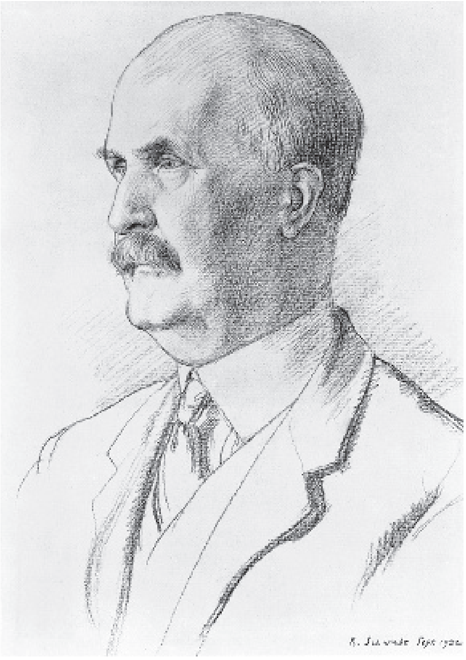

eminent physicist and his first name was also William, we must be careful to distinguish between them.

The Bragg family came from West Cumberland, the part of England that lies between the Lake District and the Solway Firth. William Henry Bragg was born on July 2, 1862 at a farmhouse called Stoneraise Place near the market town of Wigton. His mother, Mary Wood, was the daughter of the local vicar. He did not remember her well, for she died in 1869 at the age of thirty-six when he was barely seven years old. His father Robert John Bragg had taken up farming after retiring from the merchant marine. He lived on, but there is little about him in the autobiography. William, the first-born child, grew to manhood with hardly any parental love or guidance that he could recall. Instead his boyhood was dominated by an uncle, also named William Bragg, with whom he went to live after he had lost his mother. Uncle William was a pharmacist at Market Harborough in Leicestershire, a widower with no children of his own. His nephew recalled that 'there were no parties for children; we never went to other people's houses, and no children came to ours. I think my uncle was too particular. He used to lecture us terribly, talking by the hour, and I suspect he was not to be shaken in his opinions by anyone.'

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School offered some outlet from this regime. On the initiative of Uncle William the old grammar school at Market Harborough was reopened the same year as his nephew arrived. The master 'was an able man, I believe, . . . and I got on quickly enough'. In 1873, at the age of eleven, Bragg went up for the Oxford Junior Local Examinations at Leicester and was the youngest boy in the whole country to pass, despite failing church history and Greek. An aptitude for mathematics and modern languages rather than the subjects of the old classical syllabus was already becoming apparent.

The few organized school ball-games were 'a great delight' to him, and there were some happy times with his cousin Fanny, who also lived with Uncle William. Otherwise, whatever enjoyment, satisfaction and contentment the young Bragg found in life were discovered primarily within himself. He was already a solitary child: 'I liked peace and was content to be alone with books or jobs of any sort.' However, he was not without personal ambition; his tough childhood had made him self-reliant, quietly self-confident and self-content, these characteristics would sustain him for the rest of his life.

Uncle William would have liked his nephew to go to Shrewsbury, an old-established public school of good repute, but 'In 1875 my father came to Harborough and demanded me; he wanted to send me to school at King William's College on the Isle of Man, where his brother-in-law was a master. I think he became alarmed lest he should lose me altogether.' The few accounts of this college in the second half of the nineteenth century do not paint an attractive picture. The discipline was strict, the social and psychological pressure severe. Cruelty among the boys was widespread, engendered no doubt by the fearful beatings that the masters meted out to their pupils.

Bragg survived and even prospered in this environment by adhering strictly to the rules of the college, by applying himself diligently to his studies, by enjoying to the full the sporting, social and educational opportunities that the school increasingly provided, and by repressing almost totally the emotions he had already learnt to hide. Bragg found much satisfaction in his school work, especially the mathematics, where his school reports testify to his exceptional ability and achievements. In 1880 he won a school prize for mathematics, which took the form of Clerk Maxwell's two-volume treatise on electricity and magnetism. Outside the classroom, Bragg was first prefect and then captain of the school. He participated in many activities, especially the annual theatricals of the Histrionic Society. The ultimate academic goal for school and boys alike was to win a scholarship at one of the Oxford or Cambridge colleges. In 1880 Bragg won a minor scholarship to Trinity

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College, Cambridge. The following year he tried again in the hope of upgrading it to a foundation scholarship, but his academic work had stagnated and he did not succeed: 'The effective cause for my stagnation was the wave of religious experience that swept over the upper classes of the school during that year. The storm passed in time, sheer exhaustion, and the fortunate distraction of other things, work and play.'

Bragg went up to Cambridge in 1881. To begin with he was lonely: 'I had no companions', 'I could not afford, or thought I could not afford, to join the Union or the Boating Club.' His carefulness and reserve held him back. He was coached, like Strutt and J.J. Thomson before him, by the famous Routh, an indication of Bragg's own awareness of the Cambridge scene and of Routh's early appreciation of his abilities. In the college examinations of 1882 he won a prize and his minor scholarship was converted into a foundation scholarship, which brought him various small privileges. When he took the first part of the Tripos in 1884 he came out, to his great joy, as third Wrangler. For the second stage he specialized in physics, gaining some experience of experimental work. When he gained first-class honours in the examination at the beginning of 1885, he might have tried for a fellowship, but there happened to be strong competition that year. Instead he started experimental work in the Cavendish Laboratory and by the end of that year he knew Thomson pretty well. Although earlier he was 'much shut in myself, unventuresome, shy and ignorant', after graduation he 'found Cambridge a lovely place and Trinity something to be very proud to belong to'.

Walking along King's Parade to the Cavendish one morning, Bragg was joined by Thomson, who started to talk about the professorship of mathematical physics at the University of Adelaide in Australia, which had just been advertised; Horace Lamb, the incumbent, was moving to Owens College in Manchester. When Bragg enquired whether he might have a chance, Thomson said that he might. Bragg applied by telegraph, only just in time. In fact there was a strong field of 23 candidates; by far the ablest man was excluded 'on personal grounds' (not safe with the bottle). After the interviews, which were held in England, Lamb reported the conclusion to the Chancellor of Adelaide: 'yesterday the interviews were held and – with some slight hesitation between two of the candidates – we unanimously recommend Mr Bragg of Trinity College, Cambridge. It is evident that his mathematical abilities are of the highest and he has also worked at physics in the Cavendish Laboratory under my coadjutor in the appointment, who says his work is very good . . . as far as I can judge the only possible source of misgiving as to the propriety of our choice is Mr Bragg's youth, he is only 23.'

That evening at Market Harborough a telegram broke the exciting news that he had been chosen. Uncle William broke down and wept (Bragg's father had died shortly before). The position was a professorship, where he would be his own master, with a generous salary, and there was all the excitement of going to a new country. The colony of South Australia had been founded only in 1836, but Adelaide was already a fine city of some 30 000 inhabitants; and the university had already been in existence for ten years.

Soon after his arrival in Australia Bragg found time to explore the country to the east of Adelaide as far as Melbourne and Sydney before settling down to work. The problem in Australian universities during this period was neither shortage of money nor conservatism of thought but rather a shortage of students who wanted to study and who could afford to do so. The university capped the educational pyramid but the base of the pyramid was weak. Bragg found himself heavily overworked; the full extent of the demands on his time and physical stamina was something he had not foreseen. Consequently, although he followed new developments in science, he was not involved in research at all at this stage in his career.

One of the leading citizens of Adelaide at this time was Charles Todd, the government astronomer, postmaster-general and superintendent of telegraphs, famous throughout Australia as the architect and builder of the transcontinental telegraph line, which was one of the epic achievements of Australian history. It linked the eastern cities of the country through Adelaide with Darwin on the north coast and then by submarine cable with the outside world. It was after Todd's wife Alice that the town of Alice Springs was named. Bragg had met Gwendoline, one of the Todd daughters, several times at their home in the Adelaide observatory. When the family went on holiday to Tasmania, he accompanied them, proposed marriage to Gwendoline and was accepted.

Despite the heavy pressure of work at the university there were ample opportunities for recreation in Adelaide. Bragg performed in amateur dramatics, played tennis, golf and lacrosse, and took up the new craze of bicycling. Gwendoline was keen on painting and performed in Gilbert and Sullivan operettas; together they had a busy social life. In 1897 he took her on her first visit to England, and it was after their return that he started to think seriously about scientific research – it had never before entered my head, he once remarked. He was particularly interested in Marie Curie's

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work on the element radium, of which he was able to purchase a sample, and began experimenting with it. He sent his results to Rutherford, the great authority on radioactivity, and received an encouraging reply. Before long he was being asked whether he might be interested in moving closer to the mainstream of scientific research. Because Rutherford was leaving for Manchester, a possibility opened up at McGill University in Montréal, but nothing came of this.

After Bragg had been elected fellow of the Royal Society in 1907, he received and accepted an invitation to become professor of physics at the University of Leeds, not far from Rutherford at Manchester. So now life, work and interests in Adelaide had to be wound up. He had enjoyed success there, success in university teaching, in popular lectures, in sport, in adult education; he was a highly respected citizen, governor of the public library, museum and art gallery, a pillar of his parish church, on the council of the school of mines and prominent in the Australian Association for the Advancement of Science. The family said goodbye to Adelaide at the beginning of 1909. They now had two adolescent children, William Lawrence, the future physicist, his brother, Robert, and a toddler named Gwendoline like her mother. They soon began to regret what they had left behind in Australia, where they loved the life.

For Bragg himself there was a warm welcome by his new colleagues in Leeds although the students did not appreciate his lectures. He became engaged in a tiresome dispute with Charles Groves Barka, then professor at King's College, London. It boiled down to the old disagreement on the nature of light between the corpuscular theorists on the one hand and the undulatory theorists on the other. In research he continued to study radioactivity, especially the passage of alpha and beta particles and gamma rays through matter. In 1912 he invented the Bragg diffractometer for the measurement of X-ray wavelengths and with his son discovered the law of X-ray diffraction.

For Gwendoline initially the contrast between beautiful Adelaide and the dirty industrial city of Leeds, with its rows of poor little back-to-back houses, was quite painful, with only the wild open country to the north to provide relief. Before long, however, she had a house of her own, a pleasant square house with low-pitched slate roof and large garden, with carriage sweep and lawn. She employed two maids and a cook, and began to build up a social circle, including some of the successful manufacturers of the city, the brewers and the steel-makers, the makers of railway engines and of ready-made clothing. She threw herself into social work, together with the wives of such people.

For Bragg struggling at Leeds there was some compensation in the success of his eldest son Lawrence, who was doing brilliantly at Cambridge. Later a certain tension grew up between them. Unlike his father, Bragg junior held to the undulatory theory of light. Even after they had shared a Nobel prize in 1915, for their analysis of crystal structure by means of X-rays, this tension persisted, although it never seemed to disturb their mutual affection. They collaborated on a book, *X-rays and Crystal Structure*, published in 1915. When their research overlapped, Bragg senior never hesitated to give credit to 'his boy'. Bragg senior was always scrupulously fair in giving credit to his son's contributions to their joint work, yet it was assumed by others that the father was just showing parental generosity and that *he* was really the dominant contributor. Again, when his son first used a Fourier synthesis to calculate the electron density in a crystal in an important paper in 1929, he acknowledged that this work owed much to a suggestion put forward by his father much earlier, but later came to feel that the paper should have been a joint one.

In 1915 William Bragg moved from Leeds to London as Quain Professor of physics at University College and became involved in research on underwater sound propagation for the admiralty. After the war he tried to build up a research group at the college, but he did not care for the way the place was run. However, early in 1923 the death of the aged Sir James Dewar, the director of the Royal Institution, created an opportunity for him to move to somewhere more congenial. According to the then secretary of the Institution, Dewar had hoped that Rutherford would be his successor. 'So one day when Rutherford had come from Cambridge to give a lecture at the Royal Institution we interviewed him. He explained that he was too deeply committed at Cambridge to think of changing. "But", he said, "I know of a man who is as well fitted as I am to fill the billet." We eagerly asked the name of this man: "William Bragg", he replied. I supposed he meant young William Bragg [i.e. the son Lawrence]. "No", he answered, "I mean Sir William Bragg, professor of physics at University College, London; he is a great man of science and also a very great man".

When the invitation arrived, on May 7, 1923, William Bragg knew that he would be given the facilities he needed for his own research in the Davy–Faraday Laboratory. Moreover, he had always worked for an understanding between science and the other disciplines, and he would have plenty of scope to pursue this through the noble tradition of public lecturing. Already in 1920 he had given the Christmas Lectures intended for children on 'The World of Sound'. An excellent lecturer himself, he explained that, in his view, 'the value of a lecture is not to be measured by how much one manages to cram into an hour, how much important information has been referred to, or how completely it covers the ground. It is to be measured by how much a listener can tell his wife about it at breakfast the next morning . . .' He particularly felt that it was quite wrong to read a lecture: 'I think it is a dreadful thing to do, something quite out of keeping with everything a lecture should mean. When a man writes out a lecture he invariably writes it as if it were to be read, not heard. The ideas follow each other too fast. It is easy for the lecturer to deliver well-considered rounded phrases but the audience has to follow and to think.'

However, the Royal Institution was very run down, most of the scientific staff were past their best, and it would take energy and determination to restore it to its former glory. William Bragg set to work energetically, and within a year the place had been transformed. Rutherford as visiting professor was often in the laboratory. Gwendoline played her part by entertaining in the Upper Chambers. While they were at Leeds the Braggs had rented a country cottage in beautiful Wharfedale, above Bolton Abbey. Wharfedale was now too far away but they found a romantic old place called Watlands near Chiddingfold in Surrey, within easy reach of London, to provide a retreat from the official residence of the director.

William Bragg had been knighted in 1920; now a different honour arrived, the prestigious Copley medal of the Royal Society, and a stream of other scientific distinctions. Sadly, Gwendoline's health was giving cause for concern and she died in the autumn of 1929. Sir William was not yet seventy, but he tended to get very tired, although determined to carry on. He would walk to the Royal Society at Burlington House from the Royal Institution in Albemarle Street, just a few hundred yards, with his old slow countryman's walk, making several pauses on the way when he seemed to be taking an interest in some shop window. One evening, opening his study door, his younger daughter noticed how wearily he looked up from his papers: 'Daddy', she cried, 'need you work so hard?' He answered simply 'I must my dear; I am always afraid they'll find out how little I know.' In 1935 he was elected president of the Royal Society; he had to be persuaded that at seventy-three he was not too old for this.

Although Sir William was not attracted by politics – he declined an invitation to stand for Parliament – he made an influential radio broadcast, putting the case for what he called 'moral rearmament'. This phrase was taken over by the American evangelist Dr Frank Buchman, leader of the Oxford Group, but Sir William was no follower of his. When the Second

World War began, Sir William was involved in various kinds of committee work. He had always been keen on broadcasting about science; one of his last contributions was to a radio programme on 'The Problem of the Origin of Life'. A few days after that he took to his bed and on March 12, 1942 he died, at the age of seventy-nine. The memorial service was held in Westminster Abbey.

Lawrence Bragg has already been mentioned briefly; he was scarcely less distinguished than his father, with whom he shared a Nobel prize. He might well have had a profile of his own, but he had a much easier start in life than his father. His story begins in Adelaide, where he was born on March 31, 1890. At the age of eleven he started school there until four years later his father decided he was ready for university. At the University of South Australia he read mainly mathematics, graduating with first-class honours in 1908 at the age of eighteen. That was the year that the family returned to England, and it was to be fifty years before he saw the land of his birth again.

Following his father's example, Lawrence Bragg went up to Trinity College, Cambridge, to read mathematics, but moved to physics at the first opportunity. By 1914 he had been elected fellow and lecturer at Trinity. When the war came he joined up and was commissioned at once, on the strength of some previous military experience. He was soon sent to France where he helped to perfect the French technique of locating enemy guns acoustically. The award of the joint Nobel prize in 1915 came as he was setting up an acoustic-ranging station near the front line; his military service brought him decorations and promotion to the rank of major. His younger brother Robert also joined up but died in the ill-fated Gallipoli operation to try to obtain control of the Dardanelles.

As the war drew to a close, Lawrence Bragg was looking for a professorship. After returning briefly to Cambridge, he was appointed to succeed Rutherford at Manchester. At the age of twenty-nine he had no previous experience of teaching undergraduates, although he had a gift for lecturing. However, the students were mainly ex-servicemen who had no mercy on novices. Also, a junior staff member sent him anonymous letters accusing him, amongst others, of incompetence. However, in 1921 he was elected to the Royal Society and, during the same year, he married Alice Hopkinson, whom he had first met at Cambridge. Had she not been a native Mancunian he would have had misgivings about bringing a lively young wife to grimy Manchester and introducing her to his sober colleagues. However, she already knew the city well because her father had been a much-loved

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physician there. In all respects it was a successful marriage, with four children, namely two sons and two daughters.

By 1929 he was thinking of moving on. He sounded Rutherford out about the Cavendish chair, with no result, and was offered one at University College, London, which he turned down. Worried that he might find himself remaining in Manchester for the rest of his career, he suffered a nervous breakdown, but soon recovered. In 1935 he spent a term at Cornell University in the State of New York and ended the year by giving the Christmas lectures at the Royal Institution, on the subject of electricity. Then, in 1937, he was appointed director of the National Physical Laboratory, at Teddington, on the outskirts of London. He was just reconciling himself to a life of tedious committee work when, following the death of Rutherford, he was elected the next Cavendish Professor.

So Lawrence Bragg and family moved to Cambridge after all, and he ran the Cavendish from 1938 to 1945; for part of the time he was president of the Institute of Physics as well. Once the Second World War began his main preoccupation was to see what contribution he could make to the war effort, not just in Cambridge but nationally. He was knighted in 1941 and became known as Sir Lawrence, his father being Sir William. He had held a non-resident chair at the Royal Institution since 1938 and in 1953 he accepted the offer of the much more important post of resident professor. In spite of his father's efforts there were still serious financial problems at the institution and a need for further reform. Sir Lawrence set to work to put matters right, especially on the research side, and to continue the tradition of first-class public lectures. In 1966, when he retired at the age of seventy-six, he received the Copley medal from the Royal Society and was made a Companion of Honour. After retirement he continued to live in London most of the year, giving lectures at the Royal Institution and elsewhere. He died in hospital near his home in Waldringfield on July 1, 1971, at the age of eighty-one.

Marie Curie (1867–1934)

The name of Marie Curie is as well known to the general public as that of Charles Darwin, Albert Einstein or Louis Pasteur. She was born in Warsaw on November 7, 1867 and christened Maria. Her parents came from the numerous class of minor Polish landowners. Her father Władisław Skłodowski, a kindly, erudite man, who had studied at the University of St Petersburg, was a teacher of physics; her mother Bronisława (née Boguska) conducted a private school for daughters of upper-middle-class families.

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Their five children were Sofia, Józef, Bronisława, Helena, and finally Maria Salomea, the subject of this profile. By the time she was born her father was professor of mathematics and physics at a high school for boys. However, Poland was under Russian oppression and, under a policy of replacement of Polish officials by Russians, he lost his position and the apartment which went with it. Not without difficulty, he found another apartment where he could lodge boys of school age and give them tuition.

Her unfortunate father had made the mistake of investing his life savings in a business owned by his brother-in-law, which went bankrupt. From then on the family lived in a state of considerable poverty, but there were other troubles. Her eldest sister Sofia died of typhus. Her mother had developed symptoms of tuberculosis after her last pregnancy. She resigned her headship and spent a year 'taking the cure', first in the Austrian alps, then in the south of France, but the disease progressed and she died two years later. In the aftermath of the loss of her mother, Maria's health began to suffer; and she experienced some kind of nervous breakdown. At the age of fifteen, she was sent off for a year to some country relatives to recover, being forbidden to study, except that she was allowed to learn French.

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Under Russian subjugation, Poland was intellectually isolated. Conventional universities were not open to women. She joined a self-improvement society called the floating university. Maria's brother Józef was studying medicine; her two sisters were planning to go into teaching, while Maria herself started work as a governess. Her first such post was a failure but the second was less so. As well as educating the ten-year-old daughter of her employer, a wealthy lawyer, she started a school for peasant children and continued her own education by reading, with an inclination towards science. She had an affair with the son of the house; marriage was out of the question because of the difference in their stations in life. She returned to Warsaw and the floating university at the age of twenty. After a year in the capital working as a governess, she returned home to her father, who had reluctantly become director of a reformatory near Warsaw. Meanwhile her elder sister Bronisława, now married, urged Maria to join her in Paris. In 1891, after some delay, she set off to study at the Sorbonne at the age of twenty-four.

Marie, as she now called herself, spent the first few months of her new life staying with her sister and brother-in-law, who had set up a medical practice in the outer suburbs of Paris. Although she was too hard up to become involved in the gay social life of *fin-de-siècle* Paris, she then rented a garret apartment near the university like many other students. She attended lectures in the physical sciences, but at first she had difficulty with the language, also she lacked the basic mathematics. However, she persevered and graduated with high honours first in physics in 1893 and then in mathematics the next year. She spent the intervening long vacation back in Warsaw, where she was awarded a scholarship for outstanding students who wished to work abroad; characteristically she repaid the scholarship money as soon as she could.

In the spring of 1894 she met Pierre Curie at the home of a Polish physicist who was staying in Paris. Her future husband was responsible for the laboratory of the Ecole Municipale de Physique Industrielle et de Chimie, a new foundation where the lectures were combined with substantial experimental work. He was tall with auburn hair and sported a small pointed beard. 'He seemed to me very young, though he was at that time thirty-five years old', she recalled, 'I was struck by the open expression on his face and by the slight suggestion of detachment in his whole attitude. His speech, rather slow and deliberate, his simplicity and his smile, at once grave and youthful, inspired confidence.' The son of a homeopathic physician, he was as shy and introverted as she was. After their first meeting she

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noted that 'he expressed the desire to see me again and to continue our conversation of that evening on scientific and social subjects in which he and I were both interested and on which we seemed to have similar opinions'. He was dedicated, she soon learned, to a life entirely devoted to science and the rewards its purity has to offer. He presented her with a copy of an important paper he had written 'On Symmetry in Physical Phenomena: Symmetry of an Electric Field and of a Magnetic Field'. Pierre Curie was a physicist of the first rank, a pioneer in the investigation of the magnetic properties of various substances at various temperatures. He discovered the piezo-electric effect and showed that ferromagnetism reverts to paramagnetism above a certain temperature (the Curie point). Even in his lifetime, his discoveries had widespread application, and the fame of this underpaid, overworked scientist spread far beyond the borders of France, particularly to Britain.

Quite soon after their first meeting, Pierre broached to Marie the question of marriage. He suggested they might start living together, but she had been too strictly brought up to consider that. Then he found an apartment in the Latin Quarter that could be subdivided into two parts; she said no to that too. However, at least she agreed to his suggestion of a visit to his parents. He took her to their home in the attractive township of Sceaux, whose inhabitants had once served a fine Louis XIV château and its magnificent park, and which by this time was one of the southern suburbs of Paris. Dr Eugène Curie's serene, plant-covered cottage stood in the rue de Sablons, later to be renamed after his famous son. His wife Sophie-Claire (née Depouilly) bore two sons, Jacques in 1855 and Pierre in 1859. The radical politics and anticlericalism of the doctor, a former Communard, appealed to her. Later, when she desperately needed it, the understanding which developed between them was to be of great importance.

Marie and Pierre Curie were married at a civil ceremony in Sceaux town hall in 1895. Since Pierre was a freethinker, like his father, and Marie had given up her faith, they dispensed with a religious ceremony. Her married elder sister was already in Paris; her father and younger sister came over from Warsaw for the occasion. Among the wedding presents the couple received were two bicycles; in the years to come they took cycling holidays in Auvergne, the Cevennes and along the coast of Brittany.

The young couple had few distractions from their scientific work; a bicycle outing or a rare visit to the theatre were their only recreations. His parents and her elder sister and brother-in-law seemed to be their only social contacts. She became pregnant, with accompanying sickness, and in due course gave birth to a daughter, Irène. She felt lonely and homesick

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for Poland. After Pierre's mother had died of breast cancer in 1897, his father helped the young couple look after the baby. Marie was studying for the *agrégation*, the certificate which would permit her to teach in a secondary school for girls. She also helped Pierre prepare his teaching courses while filling in gaps in her scientific education. The Ecole de Physique et de Chimie agreed that she could start research alongside her husband, on how the magnetic properties of various tempered steels varied with their chemical composition.

After Röntgen had discovered X-rays in 1895, many scientists began to investigate their properties. When Marie needed a thesis topic in 1897, it would have been natural to have looked in that area. Instead she chose to work on the phenomenon of radioactivity, which had been discovered by Becquerel the previous year and had attracted much less general attention. So far uranium was the only radioactive element known; she set out to discover whether there were others. Quite soon she found that thorium had similar properties, unaware that the German physicist Erhard Schmidt had made the same discovery and had already published it. However, in the laboratory the Curies were encountering substances that were much more strongly radioactive than thorium; one they called polonium was 350 times as powerful. It was in their paper describing this discovery that the term radioactive was used for the first time.

The Curies were working with a natural ore called pitchblende, which consists mainly of uranium oxide. When they had removed all known radioactive substances from this material there was still something else left, and they decided to call it radium. They were determined to isolate it and find out whether it was a new chemical element. In this quest another scientist, named Gustave Bemont, was involved; the Curies acknowledged this but just what he contributed is not clear. Others helped in different ways, for example by lending them equipment. One of them remarked that it was the amiable and self-deprecating Pierre who was the ingenious one, while Marie provided the determination which kept the research going. She was more the chemist, he the physicist. They soon concluded that, rather than just the small quantities they had been using, they needed industrial quantities of pitchblende. The chief European source of this expensive ore was the St Joachimstal mine in Bohemia, then part of Austria-Hungary. The Curies realized that, once the recoverable uranium had been extracted at the mine, the massive first stage in their work would already have been carried out. With the help of a scientist at the University of Vienna they obtained samples, which confirmed that the unwanted residue contained

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what they needed, and they discovered where it was being dumped. The Austrian government was helpful and in due course a four-ton load of the material arrived in sacks in the yard of the school of physics.

To refine this further they needed a much greater working space than before. The best they could obtain was an abandoned shed once used by the school of medicine as a dissecting room: 'its glass roof did not afford complete shelter from the rain; the heat was suffocating in summer, and the bitter cold of winter was only a little lessened by the iron stove, except in its immediate vicinity. We had to use the adjoining yard for those of our chemical operations involving irritating gases; even then the gases often filled our shed.' However, the first stage involved heavy labour, as well as irritating and even dangerous gases, while the later stages were extremely delicate operations; the material they prepared was already showing visible signs of radioactivity.

At the turn of the century Pierre and Marie had been married for four years. Pierre's father Eugène had moved to be near them and help look after their daughter Irène, now two years old. Not having attended one of the Grandes Ecoles, Pierre was at a disadvantage when it came to appointments; moreover, he was unduly modest about his very considerable research achievements. After being passed over for the chairs of physical chemistry and of mineralogy at the Sorbonne, he was offered an attractive post at the University of Geneva, including a physics laboratory designed to his own specifications, and an official position there for Marie. At first they were tempted to accept. However, moving to Switzerland would have seriously dislocated their research, setting it back by months, if not years, at a time when they were becoming increasingly aware of competition to isolate radium and establish that it was a new element. Some commercial firms, with far greater facilities, were manufacturing radioactive material, so that impure radium became readily available. This increased the chances that someone else would beat the Curies to the object of their quest.

The question was resolved when a vacant chair was found at the Sorbonne as a possible counter to the Swiss offer. The mathematician Henri Poincaré had been impressed by the Curies' work and used his influence to ensure that Pierre was appointed. At the same time Marie was offered a part-time post teaching physics at an advanced ladies' college in Sèvres, so they decided to remain in Paris. These appointments eased their financial situation while committing them to additional teaching and other duties. However, although others enjoyed better research facilities than they did, no-one had greater determination. By March 28, 1902 they had refined just one tenth of a gram of radium chloride. Radium proved to be a million times as radioactive as uranium; its atomic weight came out at 225.93. As soon as the news spread around, the Curies found themselves famous, in Britain even more than in France. There was great excitement when Pierre lectured about their joint work at the Royal Institution and soon afterwards the Royal Society awarded him the Davy medal.

After Marie had completed her doctoral thesis, the oral examination was an emotional occasion. The crowd in the room where it was held included family and friends, some girls from the school where she taught and many supporters who burst into applause when, after she had disposed of a few questions, the presiding examiner announced that she was now doctor of physical science in the University of Paris and added the distinction *très honorable*. By chance Rutherford was in Paris at the time; he missed the examination but met the Curies for the first time at the celebration afterwards. As we shall see when we come to his profile, he resolved to provide a definite theory of radioactive phenomena, something they had not attempted to develop.

Unfortunately the Curies, who had been handling radioactive substances for years, without any precautions, were now experiencing health problems. Those around them were concerned at how ill they looked. Pierre's fingers were so painful that he could hardly write. Her hands were painful also. She became pregnant again but the outcome was a miscarriage. International recognition culminated in their being awarded the Nobel prize for physics in 1903 for their joint researches on the radiation phenomena discovered by Becquerel, with whom they shared the prize. Marie was the first woman to become a Nobel laureate in the sciences and remained the only one until her daughter Irène was so honoured in 1935. The Curies gave much of the prize money to good causes. Of course the floodgates of publicity now swung wide open, much to their dismay. The lofty idealism of her husband forbade him to court popularity, and the honours which now were offered him were either declined or accepted with some reluctance. In 1905, after an earlier attempt had been unsuccessful, Pierre was elected to the Paris Academy, at the age of forty-six. Ironically the state of his health was such that he could no longer undertake experimental work. In the same year Marie gave birth to their second daughter Eve (or Eva) Denise. Pierre gave his Nobel lecture in Stockholm on their joint work.

A few months later, on a rainy April day, a heavy wagon drawn by two carthorses was moving down the rue Dauphine near the Sorbonne when suddenly a man holding an umbrella who was crossing the wet street appeared to slip and fall under the wheels of the wagon. It was Pierre Curie, and he was fatally injured. Marie was distraught when the news was broken to her. Her sister Bronisława came from Warsaw to comfort her. Later Marie published his collected works, but first she was determined to complete the research on which they had been engaged. Rutherford and others were not convinced that polonium was an element, and there was even some doubt in the case of radium. More dogged effort was required in order to settle these questions. Rutherford wrote to his mother to tell her how 'wan and tired Marie looked and much older than her age. She works much too hard for her health. Altogether she was a very pathetic figure.' He sat next to her at the opera one evening and could see that she was far from well; halfway through the performance she left on his arm, completely worn out.

Within a month of the death of Pierre she was back in the laboratory, having been made assistant professor, the first woman in France to reach professorial rank. Within two years she had been appointed to the chair at the Sorbonne her husband had held. On a site near the Sorbonne, the Radium Institute was established, with one part devoted to pure research into the chemistry and physics of radioactivity, under her direction, and the other part to research on the application of radioactivity to the treatment of disease. She moved with her two daughters to the Curie family home at Sceaux, where the old doctor presided over the household and, assisted by a succession of governesses from Poland, provided companionship for the girls when their mother was out at work. The wealthy philanthropist Andrew Carnegie met her and was deeply impressed, especially by her attitude as a scientist on an equal footing with men. The result was the endowment of the Curies Foundation, which was available to fund her research and provide scholarships. She could now afford assistants in her scientific work. Several of these were women, who developed a fierce loyalty to her.

For some years Marie Curie had taken her daughters for holidays to a little place called l'Arcouest on the north coast of Brittany, sometimes called Sorbonne-plage, because a small group of Paris academics, with their families and friends, used to gather there regularly each summer. Eventually it became like a second home for the Curie family. Irène and Eve found happiness there that was denied them in Paris, since their mother was not so preoccupied with her work. Later on, however, the children were usually sent to stay with relatives. In 1911, for example, they went to Poland for the first time to stay with their Aunt Bronisława. In 1913 they went hiking in the Engadine in a party that included the Einsteins. According to Einstein, Marie was like a herring, meaning that she had little capacity for

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either joy or pain and that the main way she expressed her feelings was by grumbling.

Meanwhile Marie Curie was proposed for election to the Paris Academy. The permanent secretary, Gaston Darboux, wrote to the press explaining why he supported her candidature and specifying the practical advantages membership of the academy would bring her. She might have been the first woman to be elected to the Académie des Sciences, although one had just been elected to the literary Académie Française. However, there was a respectable rival candidate and, after a particularly close and tense election, he was successful. Deeply hurt, Marie never allowed her name to be put forward again. Much later she was elected to the Académie de Médicine, another section of the Institut de France, due to the success of radiotherapy in the treatment of tumours, although she was never directly involved in the medical applications herself.

When she was widowed she was thirty-eight years old, strikingly beautiful, some said it was the beauty of suffering. Her closest friends, outside the family, were the physicists Paul Langevin and Jean Perrin, the mathematician Emile Borel and their wives Henrietta Perrin and Marguerite Borel. Old Dr Curie died early in 1910, after being bedridden for a year. Following the death of her husband, Marie moved from central Paris to the suburb of Fontenay-aux-Roses, where there was a colony of scientists, including the Langevin family, who had moved there to get away from the bustle of central Paris. Paul Langevin was one of those who played a part in an educational cooperative that Marie organized, somewhat influenced by the thought of Rousseau. In 1905 he had succeeded the deceased Pierre Curie as professor at the Ecole de Physique et de Chimie. Four years later he became director of studies at the school and was also made full professor at the Collège de France, having previously held junior positions there.

Langevin had recently left his wife and taken an apartment in the city, closer to the Ecole de Physique et de Chimie, where he frequently had to work late at night. Marie Curie often visited him there. After having kept to sombre clothing following her husband's death, she now began to make herself look attractive again. Her relationship with him was the only one she was to have with a man who was not many years older than herself (in fact Langevin was five years her junior). Besides offering much to enrich her middle years, including a keen interest in politics, a love of literature and music, and other common interests, he was able to provide an intellectual bridge to the emerging new physics.

Marie Curie often naively misinterpreted what she believed to be other people's reactions to her actions. That she believed that she could have a love affair with Langevin in which only a few friends and colleagues would take any interest was a disastrous miscalculation. In the summer of 1910 at l'Arcouest, encouraged by the Perrins with whom she was sharing a house, Marie started to urge Langevin to seek a divorce. Soon Langevin's wife was openly threatening to murder her.

She had been invited to attend the first of a series of small and select conferences at which leading physicists met in Brussels to survey and discuss, under luxurious conditions, the status of some important field of physics. These were called Solvay conferences, after the wealthy Belgian industrial chemist Ernest Solvay who sponsored them. Marie Curie arrived in Brussels looking better in health, but very worried. The editor of a small magazine called *Le journal* happened to be the brother-in-law of Langevin's wife. The headline 'The Story of Love, Mme Curie and Professor Langevin' appeared in the issue of *Le journal* of November 14, 1911; by the next day every Parisian newspaper had the story and it was on its way to the tabloids in other countries. Although the story that they had eloped was pure invention, the affair rolled on day after day for the rest of the month. Back in Paris she threatened to sue; there was a partial apology, but the damage to her peace of mind was already severe.

Some letters Marie sent Langevin, locked up in his desk, had been purloined and were now in the possession of his estranged wife, who was seeking a legal separation. Adultery with Marie Curie was going to be alleged when the Langevin separation case came to court. The suspense was broken on November 23 when a magazine published long extracts from the letters. Gustave Téry, the journalist responsible, had been a contemporary of Langevin's at the Ecole Normale. He accused Langevin of being a cad and a scoundrel. The existence of the letters could not be denied, but they had been edited in such a way as to make them seem more sensational than they really were. The relationship was of long standing; had Pierre Curie been driven to suicide when he became aware of it?

Among her most loyal supporters at this difficult time were the Borels. Emile Borel was at this time scientific director at the Ecole Normale Supérieure; it was his *insouciante* wife the writer Marguerite who was most involved. When hostile crowds started to gather outside the Curie home in Sceaux, she arrived to take Marie Curie and the children off to the Ecole Normale Supérieure, where the situation could be discussed within the safety of the official apartment. The Minister of Public Instruction warned

Borel that he should not be sheltering her in his official residence. Borel's father-in-law, Paul Appell, dean of the faculty of science, hitherto one of Marie's staunch supporters, was also furious that the Borels had become involved; he and others thought that Marie should return to the land of her birth, as did some members of her own family.

Libel actions were very expensive and unlikely to succeed; duelling was both cheaper and quicker. At this late date duelling was a ritual performance, seldom resulting in serious injury let alone death. Several duels were fought over the Curie–Langevin affair, and Langevin himself decided that he must challenge the journalist. Paul Painlevé, the future Prime Minister, acted as one of his seconds. Langevin and Téry confronted each other with loaded pistols early on the morning of November 25, went through the ritual and then withdrew.

Only a few days later, a telegram arrived from Stockholm, to say that she had been awarded the Nobel prize in chemistry for the discovery of the elements radium and polonium. She was the first person ever to be awarded a Nobel prize in science twice, and this time the prize was not shared with anyone else. However, the immediate effect was to revive the debate in the press over the Curie–Langevin affair. There were those in the Sorbonne who thought her culpable, as did many of the general public. A senior member of the Nobel selection committee wrote to advise her not to come to Sweden to accept the prize. Determined to receive the Nobel medal in her own hands, she replied that she saw no connection between her scientific work and her private life.

In fact the turmoil was beginning to subside. The separation case was settled out of court without Marie Curie's name being mentioned. However, the strain of the elaborate Nobel ceremonies proved to be the last straw. On her return to Paris she became gravely ill. She was also deeply depressed; she later told her daughters that during this period she began to consider suicide. When she had recovered she moved house and started to live under her maiden name. Then she had a relapse and spent a month in an alpine sanatorium. Her whereabouts were kept secret as far as possible.

Marie Curie was already in contact with leading members of the suffragist movement in England, one of whom invited her over to stay. She spoke English quite well and, travelling incognito, she had a blessed relief from the unwelcome attention that pursued her in France. When she returned to Paris she felt strong enough to pick up the threads of her life again, although it was no longer possible that this could be shared with Langevin. She started to use her married name once more, to the great relief of her daughters. The new laboratory which had been promised her had just been finished. For six months she was on sick leave, after medical treatment. She left the house at Sceaux and moved into an apartment on the Ile St Louis. Since her health was no better, she also spent time at various alpine spas. Whether at this stage any or all of her suffering was due to radiation sickness is not certain; there was also a suspicion of tuberculosis.

In 1914, when the First World War began, the French government moved to Bordeaux for safety. Marie Curie took her precious store of radium, a large portion of the world's supply, to a bank there and then returned to Paris. On the eastern front her native land, as so often before, was being fought over by opposing armies. In the west the Germans had crossed the Belgian border, and already casualties were mounting. Soon she received a formal request from the Minister of War to equip operators for radiographic work. She organized more than 200 mobile X-ray units and, with her elder daughter, operated one herself. Most of her scientific friends were also involved in war work.

With some reluctance she agreed to write her autobiography and to visit America for the first time, to raise funds for her research. She took her daughters with her. Rather as she had feared, she was lionized incessantly and harassed by journalists, but thanks to American generosity her tour was a huge success financially. Soon radium treatment was being given at thousands of locations, although, among the medical staff concerned, many were reporting sickness. Radiation affects healthy cells as well as cancerous cells, but at first it was not realized how serious the consequences could be. Marie Curie herself was particularly slow to recognize the dangers. She suffered from cataracts, which can be an early symptom of radiation sickness; she had them removed by surgery, but went to great lengths to keep the operation secret. Those who met her for the first time were intimidated by the glacial expression, caused by the treatment, in such contrast to her gentle voice.

Despite her declining health, Marie Curie travelled widely, often in the company of her younger daughter Eve. Irène had been the favourite daughter until her marriage, but now Eve began to take her place. Marie had already built a holiday cottage in the north at l'Arcouest, for use in the summers, which she put in the name of Irène; now she built another at Cavalaire on the Mediterranean, for use in the winters, which she put in Eve's name. Early in 1932 she had a fall and recovered from a fractured wrist unusually slowly. At the end of the following year she was taken ill again, but made a good recovery and, not without difficulty, continued to attend scientific conferences. She made a will and sent for her sister Bronisława. She felt exhausted; tuberculosis was diagnosed; the doctors again recommended an alpine sanatorium. Once she was there the diagnosis was changed to pernicious anaemia, then usually fatal. She died in her sixty-sixth year on July 4, 1934 and was buried next to Pierre, in the cemetery at Sceaux. The cause of death was given as leukaemia, caused by prolonged exposure to high-energy radiation. The first of many biographies, written by her younger daughter Eve, was particularly influential in establishing her as a legendary figure, but it does not tell the whole story. For example, the degree of financial support she received in the early stages of her research is understated, and the Curie–Langevin affair is glossed over.