him. Thus, ironically, a recommendation from Einstein, which prima facie should have carried great weight, lost its value.

By 1927 nonrelativistic quantum mechanics could be considered complete, and the main lines of its interpretation, according to the so-called spirit of Copenhagen, had been formulated. Bohr gave a paper on it at the International Physics Conference at Como commemorating the Volta centenary. Einstein did not attend the conference because he did not want to visit fascist Italy, but a little later, when Bohr repeated the same ideas at a Solvay Council, he was opposed by Einstein. Bohr, who had been inspired by Einstein many times, worshipped him, and Einstein had given repeated expressions of admiration and affection for Bohr. Einstein’s refutation of Bohr’s dearest concepts hurt and troubled him. A long debate evolved, in which Bohr dismantled all Einstein’s objections, only to be faced with new ones, without being able to convince him. To the end of his life, Einstein, one of the major creators of quantum physics, remained skeptical about the Copenhagen interpretation, although he became more and more isolated in this view.

With the arrival of Nazism, Einstein finally emigrated from Germany, where he would undoubtedly have been killed, and after some periphrasis settled at the Institute for Advanced Study at Princeton, New Jersey. The flame of his genius was weakening, and Einstein, who for decades had seen further ahead than anyone else and who had introduced some of the most profound and fruitful ideas in physics, devoted himself to problems that seemed to have no solution and perhaps were wrongly posed. The guiding light of new physics that had come from Berne, Zurich, and Berlin did not continue from Princeton.

Nevertheless, Einstein was still destined to play an important role, albeit a paradoxical one for a pacifist: urging the United States to construct the atomic bomb. I call it paradoxical, but his position conformed to his principles in the circumstances of the Second World War. But this was more a political than a technical step; Einstein certainly was not up to date in the nuclear physics of the 1940s, nor did he contribute technically to the development of atomic energy. On April 18, 1955, his life ended quietly in Princeton at age seventy-six.

He said of himself, “God is inexorable in offering His gifts. He only gave me the stubbornness of a mule. No! He also gave me a keen sense of smell.”

Chapter 6

Sir Ernest and Lord Rutherford of Nelson

Through the works of Planck and Einstein we have described the state of theoretical physics up to and beyond the First World War. But we left experimental physics at around 1907, when Ernest Rutherford left Canada and returned to England as a professor at the University of Manchester. From then until the First World War experimental research progressed rapidly, with Rutherford as the dominant figure. In this chapter we will deal with his work and other experimental discoveries of that period.

Back to England

The chair of Physics at Manchester, one of the main provincial English universities, had become vacant because Sir Arthur Schuster (1851–1934), a fine spectroscopist, had decided to retire from the position on the condition that Rutherford succeed him. Despite his German origins, Schuster was completely anglicized. He had inherited a fortune and had spent some of it equipping his department with an excellent laboratory. Although Rutherford’s field of study was far from Schuster’s, Sir Arthur felt he could not find a better successor, and he did his utmost to persuade Rutherford to accept.

He had arranged an endowment for the institute and had also financed a fellowship for a theoretical physicist, which later benefited H. Bateman, G. C. Darwin (the naturalist’s grandson), and Niels Bohr. Schuster also had a German assistant, Hans Geiger (1882–1945), who came under Rutherford’s supervision, and later became a first-rate nuclear physicist. Geiger always remained in close contact with Rutherford and, after returning to his native Germany, he contributed to the blossoming of nuclear studies in his own country. His name is familiar to all who have dealt with radioactive substances, and have thus probably used his invention, the Geiger counter, one of the most useful instruments for detecting radioactivity. Also among the
staff at Manchester was a technician, W. Kay, who helped Rutherford throughout his sojourn there.

Manchester, however, had little radium, less than 20 milligrams, and Rutherford needed radium, which, at the time was produced almost uniquely by the Joachimsthal mines in Austria (now Czechoslovakia). The Vienna Academy of Sciences loaned 350 milligrams of radium bromide to Ramsay, at University College, London. It was meant for both Ramsay and Rutherford, but there was friction between the two scientists and they did not want to share the supply. Fortunately, Rutherford managed to obtain 350 milligrams more for himself as a loan from the Vienna Academy of Sciences, and thus the problem was solved. The radium from Vienna remained in Rutherford’s hands during the First World War. At the end of the war the English government wanted to confiscate it as enemy property, but Rutherford insisted that the radium should be purchased and paid for as if it were a normal sale. With the proceeds he was able to help the impoverished Vienna Institute and its director Professor Stefan Meyer, who had been ruined by the war. This just and generous act profoundly moved Austrian scientists.

Having settled in Manchester and having obtained the necessary radium, Rutherford launched into research again. At first he reinvestigated old themes of research. Using spectroscopic methods, he obtained a definitive confirmation that the alpha particle was ionized helium. He did this with the help of T. Royds, another recipient of the 1851 exhibition scholarship (see Figure 6.1).

**New Light on Alpha Particles**

In 1908 Rutherford received the Nobel Prize in Chemistry. In his acceptance speech, “The Chemical Nature of the Alpha Particles from Radioactive Substances,” he reported the counting of single alpha particles using the scintillation method. That is, he counted atoms one by one, looking through a low powered microscope at the flashes in zinc sulfide caused by the arrival of alpha particles. Geiger participated actively in this work, which was rather tedious and required them to spend long hours in absolute darkness.

If the reader wants to see scintillations, all he has to do is to look at the figures on a luminous watch dial with a magnifying glass. This must be done when the observer has been in the dark for some time, such as when he first wakes up in the dark. By counting atoms, Rutherford and Geiger had a means of determining Avogadro’s number, the charge of the electron, and other universal constants that could also be found by entirely different experiments, for instance, by studying the blackbody radiation. The numbers derived from both methods corresponded very well, and these experiments convinced even the most skeptical physicists of the real existence of atoms, overthrowing the most obstinate, conservative rearguard.

![Figure 6.1 Rutherford and Royds' apparatus for demonstrating the nature of alpha particles. The needle A contains radon whose alpha particles emerge from the glass and fill the tube T with helium at low pressure. The helium, pushed by the mercury in the discharge tube V, shows a characteristic emission spectrum.](image-url)

These experiments helped also to persuade the English of the merits of the quantum theory, as the electric charge of the electron and other constants determined by Rutherford were so close to the values given earlier by Planck, using blackbody radiation theory.

In counting, Rutherford and Geiger used quite an ingenious method that was later greatly expanded and advanced. The scintillations produced by alpha particles on zinc sulfide screen are not easily visible, and for each observer one can assign an efficiency defined as the ratio \( \eta \) between the number of scintillations that occur and the number observed. Assume that two observers (Rutherford and Geiger) watch the same screen, and each counts the scintillations he sees, indicating each by pressing a key like that used for sending a telegraphic message, thus marking also the instant of observation. There are three kinds of signals: \( (1) \) from the first observer alone, \( (2) \) from the second observer alone, \( (3) \) from both observers together.
Their number is:

\[ n_1 = \eta_1 n \quad n_2 = \eta_2 n \quad n_{12} = \eta_1 \eta_2 n \]

where \( \eta_1, \eta_2 \) are the efficiencies of the observers; \( n \) is the unknown number of scintillations that occurred; and \( n_1, n_2, n_{12} \) are the numbers observed by 1 and 2 separately and together. It follows that \( n = n_1 \eta_2 / n_{12} \).

Today, observing eyes are replaced by electronic devices or by Geiger counters, but the principle of the method is unchanged.

Rutherford faced another problem that seemed much more modest than counting atoms: describing and explaining the phenomena that accompanied the passage of alpha particles through matter. He attacked the problem with help of various students. Around 1904 W. H. Bragg with R. D. Keelmann had found that alpha particles with a given energy have a unique range, and the two Braggs (father and son) had studied the ionization along the trajectory. Ernest Marsden (1889–1970) a student from New Zealand who had come to work with his famous fellow countryman in 1909, by chance observed that occasionally alpha particles, instead of going straight or nearly straight, were deflected by matter and went at considerable angles. When Marsden related this observation to Rutherford, the Professor made him repeat the experiment to confirm it. The big deflections had greatly amazed Rutherford. He later said that it was as if someone had told him that having fired a pistol at a sheet of paper, the bullet had bounced back!

Several weeks passed. Then one day in 1911 Rutherford announced that now he knew why Marsden’s particles were deflected at wide angles. And, moreover, he knew the structure of the atom.

The Atomic Nucleus

What had happened? At that time there were several atomic models. Lorentz used the idea that the electron was elastically bound to a fixed center, thereby explaining the Zeeman effect. There was Planck’s oscillator and other models, including one by J. J. Thomson, who hypothesized an atom made of a positive electric charge diffused in a sphere with electrons interspersed, like raisins in pudding. However, such an atom, popular in England, could not scatter alpha particles at wide angles because if the alpha particle neared the center of the pudding, by penetrating it, it would be in a region of average electric field zero and thus could not be deflected. The same applied if it went far from the center, outside the atom.

Various scientists, including the Japanese physicist H. Nagaoka, had thought of the possibility of an atom built like the planetary system, but this was still vague and speculative. Rutherford provided a solid experimental basis for this theory, creating an atomic model that is still valid today. Although now the atom must be described in terms of quantum mechanics rather than classical physics, fortunately both give the same results in the case of Rutherford’s experiments. Rutherford hypothesized that all the positive charge (Ze) and the mass were concentrated in a small volume in the center, which he called the nucleus. The nucleus was surrounded by Z electrons, which circled around it. The electrostatic attraction between the positively charged nucleus and the negatively charged electrons held the atom together. Rutherford said explicitly that he was not concerned with the stability of the system, a weak point, leading to grave difficulties. An alpha particle considered as a massive point charge, incident on the nucleus, is repelled according to Coulomb’s law, and, as Newton had already calculated, it follows a hyperbolic orbit, with the nucleus as one of the focal points of the hyperbola (Figure 6.2). It seems that Rutherford had learned this as a student in New Zealand. The electrons, thousands of times lighter than the nucleus, do not affect the trajectory of the alpha particle. From this model one can determine the probability that the alpha particle will be deflected at a certain angle \( \theta \) on crossing a material foil.

In concrete terms, the number of alpha particles that fall on a screen that subtends a solid angle \( d\omega \) seen from the target, per particle incident on the target containing \( n \) atoms per unit volume and thickness \( t \), is given by \( n d\sigma / d\omega \) with

\[
\frac{d\sigma}{d\omega} = \frac{(2Ze)^2}{mv^2} \cdot \frac{1}{\sin^2(\theta/2)}
\]

Figure 6.2 Trajectory (from P to P’) of an alpha particle deflected by a nucleus. Deflections of particles passing through thin metal sheets follow a law that was calculated on basis of this figure. This proved the existence of scattered charged centers in the atom, later called the nucleus. [From Rutherford article in Philosophical Magazine 21, 669 (1911]
where \( \theta \) is the angle of deflection, \( v \) the velocity of the particles, and \( m \) their mass. The mass of the nucleus is considered infinite with respect to \( m \). Rutherford sent the manuscript describing his work to the Philosophical Magazine in April 1911.

Using the simple apparatus shown in Figure 6.3, Geiger and Marsden confirmed this formula in all its details by changing the substance on which alpha particles are projected, which changes \( Z \), by varying the velocity of the alpha particles, by changing the thickness of the sheet, or by changing the angle of observation, \( \theta \).

The number \( Z \), characteristic of the chemical nature of the target, was called the atomic number. It represents the electric charge of the nucleus, in units equal to the charge of the electron but with the opposite sign. For hydrogen \( Z = 1 \), for helium \( Z = 2 \), and so on. This discovery shed new light on the definition of a chemical element. To each element could now be associated a whole number, \( Z \), that gives also the number of orbiting electrons. When, around 1869, Mendeleev with brilliant intuition developed his periodic system, he had ordered the elements according to their atomic weight. Now Rutherford’s model revealed that it is the atomic number, not the weight, that counts. This was first noted by Antonius van den Broek (1870–1926), a Dutch amateur scientist, in 1913.

The Planetary Atom

At this point it is quite difficult to follow in detail the nearly simultaneous discoveries of many features of the nuclear atom. We can get an idea of the state reached by reading, for example, a paper written by Rutherford in February 1914, called “The Structure of the Atom” (in Philosophical Magazine VI, 27, 488). In it he discussed the scattering of alpha and beta particles and the conclusions that can be drawn concerning the localization of positive charges. He then gave special attention to the passage of alpha particles in hydrogen and to the collisions with what today we call protons or hydrogen nuclei. In a following discussion on the dimensions and constitution of the nucleus, he noted that Mr. Bohr had produced arguments for attributing nuclear origin to the electrons emitted in radioactive decay, thus distinguishing atomic electrons from nuclear ones. Regarding the nuclear charge, Rutherford related van den Broek’s hypothesis as well as Soddy’s law on radioactive displacement. The latter says that a nucleus changes its chemical nature according to its place in the periodic system, moving two steps back for the emission of an alpha particle and one step forward for the emission of a beta particle. This, of course, follows from the charge of the alpha particle \( Z = 2 \) and from the charge of the electron: \(-1\). By emitting an alpha particle, the nucleus loses two units of charge; by emitting an electron, it gains one.

X-rays are useful in measuring the atomic number using either methods based on diffusion first suggested by W. Barkla, or the very powerful methods just invented by H. G. J. Moseley. Finally, there is the following passage:

Bohr has drawn attention to the difficulties of constructing atoms on the “nucleus” theory, and has shown that the stable position of the external electrons cannot be deduced from the classical mechanics. By introduction of a conception connected with Planck’s quantum, he has shown that on certain assumptions it is possible to construct simple atoms and molecules out of positive and negative nuclei, e.g., the hydrogen atom and molecule and the helium atom, which behave in many respects like the actual atoms or molecules. While there may be much difference of opinion as to the validity and of the underlying physical meaning of the assumptions made by Bohr, there can be no doubt that the theories of Bohr are of great interest and importance to all physicists as the first definite attempt to construct simple atoms and molecules and to explain their spectra.

For the sake of clarity I will refrain from giving more details on Bohr’s work until the next chapter.

Same But Different: The Concept of Isotopism

At about this time it was becoming increasingly clear that atoms existed that were identical chemically but different in terms of radioactivity. Already in 1906 Boltwood had demonstrated at Yale that ionium could not be separated from thorium. In 1910, W. Marckwald, F. Soddy, and O. Hahn had
shown the same inseparability for MsTh (discovered by Hahn) and radium, and further similar examples were found. In 1912 Rutherford gave the problem of separating Radium D from lead to two of his research workers, O. de Hevesy and F. A. Paneth, Austro-Hungarians who were visiting Rutherford's laboratory. He told them, "If you are chemists worthy of your salt, separate them." After two years of work in which they tried everything, the two unfortunate men gave up.

However, de Hevesy and Paneth transformed their defeat into victory by inventing the tracer technique, which, enriched by the later discovery of artificial radioactivity, became one of the most powerful techniques in modern science, perhaps comparable in importance to the microscope. This is how it works: Given substances that are identical chemically but distinguishable by their radioactivity, one can carry out experiments in which the radioactive atoms can always be recognized even after complicated reactions have occurred. For example, if one eats ordinary salt mixed with salt containing radioactive sodium, an examination of the radioactivity in a drop of blood or in a urine sample will reveal how much of the ingested sodium was found in the measured sample. The ability to recognize atoms labeled by their radioactivity allows the solution of very important problems that would otherwise be totally inaccessible.

Thus the concept of isotopism in radioactive substances was being established; Soddy coined the name in 1913. It indicates "same place" in the periodic system. Isotopism was soon to be extended to stable nuclei. In 1912 J. J. Thomson found indications that the phenomenon of isotopism was not limited to radioactive elements, but was a general property shared by many. He measured the ratio of charge to mass for positive ions with the so-called parabola method. In this method perpendicular deflections of an ion beam are produced by means of a magnetic field and an electric field that are parallel to each other and perpendicular to the velocity of ions with a charge \( e \) and mass \( m \). If the electric field \( E \) and the magnetic field \( B \) are directed along the x axis and the ions are moving in the x direction, the deflections are such that ions with the same ratio \( e/m \), independent of their velocity, fall on a parabola located in a plane perpendicular to the beam velocity. (See Appendix B.)

When J. J. Thomson applied this method to neon, he found that the element contained ions of masses 20 and 22 times those of hydrogen. Thomson considered the possibility that ions of a mass 22 could be caused by the compound NeH\(_2\), but he found that this hypothesis presented great difficulties. In 1913 various attempts at fractionating Ne into different isotopes were only partially successful. Thomson's investigations opened the field of mass spectroscopy in which great success was achieved after the First World War by F. W. Aston (1877–1945) who developed spectrometers that gave the ionic mass with greater and greater precision.

One of Aston's important results was that the relative weights of all the atoms examined, except hydrogen and lithium, were found to be a whole number to the accuracy of measurement, 1 part in a thousand, when referred to \(\frac{1}{12}\) of the weight of C\(_{12}\) as unit. Nuclei were then assumed to be made out of protons and electrons. The protons conferred the mass; the electrons adjusted the charge and, being about 2000 times as heavy as the protons, did not greatly alter the nuclear mass. The divergences from the "whole number rule" were interpreted as due to the loss of mass occurring when free particles coalesce, according to Einstein's law \(E = mc^2\) (See also p. 136.)

But let us return to Manchester. The atomic model, after it was formulated by Rutherford, was further developed more by Bohr than by Rutherford. Instead, Rutherford proceeded with the study of beta and gamma rays, obtaining worthy but not revolutionary results. Meanwhile, England had entered the First World War, and the population of the Manchester Laboratory diminished. Rutherford, too, became more and more involved in work for the Admiralty and for the defense of the Empire. These commitments took him to America, where he spent considerable time in Washington. Meanwhile, he had become Sir Ernest. It was a sign of the still relatively civilized times that during the war Rutherford was able to maintain a correspondence with Stefan Meyer in Austria and with Geiger in Germany. Geiger, in turn, arranged for J. Chadwick, one of Rutherford's best students, who was captured and interned in Germany during the war, to continue with research there.

The Disintegration of the Nucleus

By 1917 Rutherford was one of the very few remaining scientists in the Manchester Laboratory, along with his technician, Kay. However, he lacked able students to whom he could entrust experiments. Marsden, the faithful Marsden, before returning as a professor to his native New Zealand, in 1915 had observed a strange phenomenon, the presence of some particles with exceptionally long ranges when he bombarded air with alpha particles. A possible explanation was that they were hydrogen nuclei, because such long-range recoils appear when hydrogen is bombarded with alpha particles. But Rutherford suspected that it was something else of colossal import, and in a long and patient study carried out mainly when his official obligations left him time, he decided to verify the nature of the particle projected. In a paper in November 1917, he asked whether they were atoms of N, He, H, or Li.

By June 1919 Rutherford was ready to publish a paper entitled "Collisions of Alpha Particles with Light Atoms." The work was composed of four parts. The first three are excellent but more or less routine investigations, but the fourth, subtitled "An Anomalous Effect in Nitrogen," states:
Figure 6.4 Apparatus used by Rutherford in observing the first nuclear disintegration. The illustration is taken from Rutherford, Chadwick, and Ellis, *Radiations from Radioactive Substances* (Cambridge University Press, 1931), where it actually appears twice! It shows an air-tight container that can be filled with gas (nitrogen) and contains a source of alpha particles placed in D. Since the range DS is greater than that of the alpha particles, one can conclude that particles causing the scintillations on the screen E are emitted in the disintegration of nitrogen gas nuclei hit by alpha particles. A detailed study shows that the fragments are protons.

We must conclude that the nitrogen atom is disintegrated under the intense forces developed in a close collision with a swift alpha particle, and that the hydrogen atom which is liberated formed a constituent part of the nitrogen nucleus. ... The results as a whole suggest that if α particles—or similar projectiles—of still greater energy were available for experiment, we might expect to break down the nucleus structure of many of the lighter atoms. [Philosophical Magazine VI, 37, 581 (1919)]

This was nuclear disintegration, the alchemists' dream in a modern form. Rutherford had carried out every possible control experiment before announcing his discovery. He wanted to be absolutely certain of his results, and that took him about three years. Figure 6.4 shows the apparatus Rutherford used. Rutherford's apparatus cost less than a millionth of what a modern accelerator costs; however, it needed his eye at the microscope, a requirement not easily fulfilled.

Rutherford's experiments were repeated in Vienna, and Austrian scientists found more disintegrations than Rutherford did. A lively debate arose, but in the end it was found that Rutherford was right. At the Cavendish Laboratory, P. M. S. Blackett obtained images in the Wilson cloud chamber that confirmed Rutherford's results (Figure 6.5).

Figure 6.5 The disintegration of a nitrogen nucleus in a cloud chamber, as observed by Blackett. The source contains Pb$_{208}^{208}$ + B$_{11}^{11}$ + Po$_{210}^{210}$ in radioactive equilibrium and emits alpha particles with two ranges: 8.6 and 4.8 cm. One of the particles with a longer range hits a nitrogen nucleus and breaks it according to the reaction $^7$Li + $^4$He = $^9$Be + $^1$H. The longer transverse trace is that of the proton, the other that of $^7$Be. [From P. M. S. Blackett and D. Lea in *Proceedings of the Royal Society, London*, 136, 323 (1932).]

Director of the Cavendish Laboratory

At the end of the war, J. J. Thomson retired from the Cavendish Laboratory (Figure 6.9) and became master of Trinity College at Cambridge. A worthy successor to the post of Cavendish Professor and director of the laboratory was sought, but it was not an easy task. The new director would have to follow an impressive line of succession: Maxwell, Rayleigh, and J. J. Thomson. In scientific stature the obvious candidate was Rutherford. The successor also had to have considerable self-confidence in view of possible comparisons with his predecessors. Rutherford had no fears and, with good reason, was not modest. However, he wanted to be sure that J. J. Thomson would not try to retain too much influence in the laboratory. With complete openness he wrote this to his former professor, and the two superior personalities clarified and settled this point, avoiding later disagreements.

Rutherford was invited to give the Bakerian Lecture for the second time in 1920. As on the first occasion (in 1904), he summarized the work he
had carried out, this time dealing with the Manchester period from the formulation of the nuclear atom model to the disintegration of the nucleus. In describing the atom, he quoted details from his experiments on scattering alpha particles and then cited works of Barkla and Moseley that established the existence of the atomic number. He was still very reserved about Bohr’s work. He then described in detail his disintegration work. In this lecture, he also expressed some tentative ideas about the possible existence of a neutral particle with a mass similar to that of the proton (a term he had coined to refer to the hydrogen nucleus). He considered this hypothetical particle rather like a hydrogen atom in which the electron had fallen inside the nucleus, neutralizing it electrically. This speculation proved to be important, as we will see later. He also speculated about a possible hydrogen isotope of mass 2 (deuterium).

At the Cavendish Laboratory Rutherford was no longer working in the old style, with his own hands. By now he was in his fifties and was surrounded by a new generation of young scientists who were returning from the war. His main responsibilities at Cambridge were to direct the laboratory and inspire and guide many excellent young physicists, including J. Chadwick, P. M. S. Blackett, C. D. Ellis, J. D. Cockcroft, E. T. S. Walton, M. Oliphant, C. E. Wynn-Williams, and others who were working on problems in nuclear physics (Figure 6.7).

In the same building or nearby there were other physicists who did not move in Rutherford’s circle. Among them were J. J. Thomson, who had maintained his own laboratory, F. Aston, C. T. R. Wilson, and later the Russian P. Kapitza. Although Rutherford was not carrying out experiments himself, he followed what was happening in the laboratory and often provided ideas, including fine working details for anyone who needed them. But above all, he gave general direction to the laboratory and decided on lines of research.

I remember the atmosphere in 1934 when E. Amaldi and I spent a few weeks at the Cavendish Laboratory. Our work in Rome on neutrons procured us a warm reception, and Rutherford showed a lively interest in our results, questioning us on several points. We asked him to communicate our work to the Royal Society. He took the manuscript, and the following day brought it back with numerous corrections in his own handwriting, mainly for the purpose of improving our English. When I asked him if he could arrange for rapid publication, he laughed and promptly answered, “What do you think I was the President of the Royal Society for?”

When he went around the laboratory, he would sit on one of the laboratory stools, extract the butt of a pencil from his waistcoat, and check the results of the experiment in progress. The research workers, when addressed, nearly stood at attention and ran rather than walked. This response certainly did not arise out of formal discipline but from the intrinsic respect that Rutherford elicited. A comment from Rutherford, whether good or bad, was not taken lightly. In other places I have seen famous laboratory directors treated almost condescendingly by young scientists, but this certainly did not happen to Rutherford.

Figure 6.8, Rutherford and J. A. Ratcliffe, is slightly ironic, because it shows an amplifier for detecting alpha particles that could not tolerate any noise. For proper functioning it required silence or at least a subdued voice, which was not one of Rutherford’s characteristics.

Rutherford’s attitude toward theoretical physics was peculiar. He was certainly not a theoretician himself, and he was quick to make fun of theories and theoreticians. Yet he paid close attention to theoretical results and translated them into the concrete terms that he preferred: He went so far as to say jokingly that alpha particles were red, as anybody knew. Bohr, who greatly respected Rutherford, had been his protege, and they undoubtedly must have discussed physics together, but their means of communication, with their differences, remains a mystery.

Though Rutherford was a superb teacher for research scientists who had the good fortune of being near him, his classroom lectures were not
outstanding. He would get embroiled in the subject he was discussing or easily digress, slipping into one of his favorite topics. Once in a lecture, when faced with an integral that should have canceled out but having forgotten the reason, he said with complete seriousness that it canceled out because the differential was infinitesimal.

Tradition reports innumerable anecdotes about Rutherford. Some of them can be found in the books by his friends A. S. Eve and Mark Oliphant, listed in the bibliography. I will relate only a few that help characterize Rutherford’s exceptional personality.

Occasionally, waxing enthusiastic about science, Rutherford would say that his era was comparable, in intellectual vigor, with Elizabethan times, and he left no doubt as to who was the modern Shakespeare.

A famous philosopher and Rutherford were talking about their respective disciplines. Rutherford proclaimed that philosophy was nothing but hot air. Hot air! To which the philosopher replied that Rutherford was a savage. “A noble savage, I admit, but still a savage!” The philosopher then recounted a tale of Napoleon III’s Marshal McMahon: “The Marshal was reviewing a regiment in which there was a Negro cadet, and he had been asked to say something encouraging to him. Having reached the Negro’s platoon, the Marshal stopped, looking at the cadet, and then said to him,
Figure 6.8 Rutherford and Rutcliffe inside the Cavendish Laboratory, about 1932. The sign "Talk softly please" refers to the necessity of avoiding noise that would disturb the apparatus on the cart, the instrument for revealing alpha particles. (Photo by C. E. Wynne-Williams, from Eve, Rutherford.)

"Cadet, you are a Negro," to which the cadet replied, "Yes sir!" A long pause, and then the Marshal said, "Well, go on being one." And that's what I say to you, Rutherford, go on."

Mark Oliphant, one of Rutherford's last collaborators, relates that in using one of the first accelerators, they had found some particles coming from the reaction of deuterium plus deuterium, but the nature of the particles was unclear. After a long day's work Oliphant went home to bed, but in the middle of the night he was awakened by the telephone. Oliphant's wife answered and, slightly alarmed on hearing Rutherford's voice, she called her husband. Lord Rutherford said, "I know what the particles are. They are helium of mass 3." The sleepy Oliphant answered right away, "Yes sir, but why do you think they are helium 3?" to which Rutherford replied, "Reasons, reasons! I feel it in my water." Naturally Rutherford was right, as Oliphant verified the next day.

According to Rutherford's close friend Kapitza, Rutherford's extraordinary intuition can be partly explained by the enormous intellectual activity he carried on. He formulated hypothesis after hypothesis, rejecting them or modifying them according to need, doing everything with inexhaustible energy. He worked all the time, and even his friends and colleagues barely knew a small fraction of his scientific thoughts. Sometimes from little hints they realized that he had attempted an experiment unsuccessfully. This explanation of his "intuition" seems valid to me and I am sure it also applies to other great scientists.

Rutherford had received the highest scientific honors from countries all over the world, and was President of the Royal Society from 1925 to 1930. On January 1, 1931, he was made a peer. He sent a telegram to his mother, then nearly ninety years old, who still lived in New Zealand, It said,
"Now Lord Rutherford, more your honor than mine, Ernest." The coat of arms of the new Baron Nelson shows a stylized rendering of his decay and growth curves going back to his Canadian days (see Figure 3.6b). Politically, Rutherford was rather conservative, and not very active. But when Hitler began the persecution of the Jews, an Academic Assistance Council was formed in England with the aim of helping the victims of the Nazis, and Rutherford became its president.

In his final years (Figure 6.9) Rutherford saw changes in physics that perhaps did not suit his nature. Experiments were becoming more complicated, accelerators were born, and theory was becoming increasingly abstract. This new era of nuclear physics, which began in part at the Cavendish Laboratory, will be treated later. Although some of the protagonists were pupils of Rutherford, many came from diverse backgrounds and from a wide scientific circle.

In 1937, during a meeting commemorating Galvani held in Bologna, word arrived that Rutherford was seriously ill with a hernia. On October 19, 1937, he died. The death was announced at the meeting by Bohr, his voice broken by tears. Although many of the participants at the meeting knew Rutherford only from his scientific works, the expressions on people's faces showed what a great loss it was. He is buried in Westminster Abbey, close to the tomb of Newton.

Chapter 7

Bohr and Atomic Models

The young physicists surrounding Rutherford at Manchester were almost all experimentalists. Rutherford himself had mixed feelings toward theory: He was too intelligent to ignore its importance, but he thought intuitively, using simple models, following the English tradition. The immense success that resulted from his simple experimental and intellectual methods perhaps excessively reinforced his confidence in this approach. It seems that Rutherford had a very limited interest in quanta and in the great new ideas that were revolutionizing theoretical physics; he was intent on his own revolution. An exchange of ideas regarding physics between Rutherford and Einstein was hardly thinkable, at least from Rutherford's point of view. Nevertheless, it was in his laboratory at Manchester that the next theoretical revolution started, fomented by a visitor who participated very actively in the laboratory's life: Niels Bohr (1885–1962).

The Young Bohr and the Hydrogen Atom

Niels Bohr (Figure 7.1) was born on October 7, 1885, at Copenhagen, the son of the distinguished physiologist Christian Bohr and his wife Ellen Adler, the daughter of a wealthy Jewish banker. The family offered every advantage for a full academic and cultural education to Niels and his younger brother Harald, who became a famous mathematician. The two children were doted upon by their mother and her sisters. The Bohrs were an upper-middle-class Danish family, and in such a small country they had access to all the intellectually prominent individuals of the period; they especially associated with philosophers and medical men. There is no evidence that Niels was a prodigy, although he made some remarkably accurate drawings as a child. If I understood him correctly, Bohr once told me of the difficulty he experienced in learning to write.