IV. Ernest Rutherford

"If it were ever found possible to control at will the rate of disintegration of radio-elements, an enormous amount of energy could be obtained from a small quantity of matter."[348] (1904)

Ernest Rutherford was born 30 August 1871 on a farm near Nelson, South Island, New Zealand. He was the fourth child and second son of Martha Thompson (1843–1935) and of James Rutherford (1839–1928), who married (1866) and reared twelve siblings. Martha had gone to New Zealand when she was 12 years of age with her mother, a schoolteacher from Hornchurch (Essex), England; James and his father, a wheelwright, had come from Perth, Scotland.[204] Ernest Rutherford was endowed with a remarkable intellect, he was raised in the rugged splendor of the mountains, streams, and fjords of the South Island, and educated in the tottering remoteness of a rising British colony. He became the outstanding atomic physicist of his time: amid a constellation of brilliant protagonists, he was second to none; in an era of rapidly developing, new revolutionary concepts, his own prevailed.

Young Ernest attended school in Foxhill and Havelock. In 1886, he earned a secondary school scholarship to Nelson College; he was given a start in mathematics by Prof. W. S. Littlejohn and graduated (1889) with top honors in all subjects. He won a scholarship to Canterbury College on the South Island main city of Christchurch. At Canterbury the fledgling scientist received his initiation to experimental science from Prof. A. W. Bickerton ("*...his enthusiasm and versatility,*" wrote Rutherford, "*were of great value in promoting an interest in science...*").

Rutherford obtained his Bachelor of Arts degree (1892) and his Masters degree (1893) at Canterbury with first class honors in mathematics and physical science. (Fig. IV-1.) He engaged in research work on the magnetization of iron by rapidly alternating (high frequency) discharges[342] while preparing for a Bachelor of Science degree (1894). When he was 23 years of age, Rutherford fell in love with his widowed landlady's daughter and became engaged to Mary Newton in the gracious garden city of Christchurch, on the banks of the Avon.

In 1895 a valuable university scholarship was awarded in New Zealand to a young chemist. Because he was married, J. S. McLaurin declined the privilege to go abroad, and the award went to the alternate, Ernest Rutherford. One cannot gainsay that Rutherford would have become a notable figure in whatever field of endeavor, but without this timely turn of fortune, the loss to atomic physics would have been imponderable. Rutherford intended to continue work on electro-

Fig. IV-1. Bachelor of Arts Rutherford in New Zealand (1894).

Fig. IV-2. Professor Thomson at Cavendish Laboratories in Cambridge, surrounded by his research associates and students (1897): Spencer William Richardson (1869–1927), John Henry (1871–?), Edward Bruce Herschel Wade (1872–1945), Gilbert Arden Shakespear (1873–1951), Charles Thomas Rees Wilson (1869–1959), Ernest Rutherford (1871–1937), William Craig Henderson (1873–?) Joseph Herbert Vincent (1871–?), George Blackford Bryan (1876–?), John Alexander McClelland (1870–1920), Clement Dexter Child (1863–1933), U.S.A., Paul Langevin (1872–1946), France, Joseph John Thomson (1856–1940), John Zeleny (1872–1951), U.S.A., R. S. Willows (1875–?), Harold Albert Wilson (1874–?), John Sealy Edward Townsend (1868–1957).

magnetism, and chose Cambridge University; under new rules, he was the first outsider to be accepted for research work at Cavendish Laboratories under the prestigious leadership of Prof. Joseph John Thomson (1856–1940).

Rutherford had found that an alternating electric field diminished the power of a previously magnetized needle; this discovery led him to devise a detection of wireless signals[343] and to hope for its pragmatic application in lighthouse to shore communications. His work impressed a number of Cambridge dons. Rutherford's device was abandoned because of development costs: later it was picked up by Guglielmo Marconi (1874–1937) and used for a decade.

Within weeks of Rutherford's arrival to England, the announcement was made of Röntgen's discovery of the new rays. Prof. Thomson, who had been studying electrical discharges through gasses under varying conditions of pressure, invited the resourceful colonial to join him on a study of the effects of Röntgen rays. Their initial efforts brought forth a theory of ionization: that in the molecules of gas, the rays produced an equal number of positive and negative carriers of electricity (ions)[390]; Thomson commented on Rutherford's ingenious methods which made the subject "metrical" rather than descriptive. Rutherford proceeded to study the rate of recombination of gas ions,[344] following shortly upon the discovery of Antoine Henri Becquerel (1852–1909) of the radioactivity of uranium, he tested its ionizing effects.[345] Without suspecting it, Rutherford had already embraced his lifetime endeavor: from then on, there was no element of chance in his choice.

Rutherford's candid comments in his letters home are interesting as well as amusing; he was pleased to find that J. J. was "*not at all fossilized*" and admitted to admiring him as much as he had expected. He also remarked on the "*alarming modesty*" of the British female.[174] His admiration was well reciprocated by the esteem in which he was held. "I have never had a student", said Thomson, "with more enthusiasm and ability than Mr. Rutherford." Prof. Thomson introduced him to the game of golf ("*I don't think...I am old enough for golf yet*", said the New Zealander). The Trinity College's Coutts Trotter Studentship was awarded to the young scientist but not the Fellowship or Lectureship he had hoped for. (Fig. IV-2.)

In the summer of 1898, less than 3 years after his arrival, Rutherford left Cambridge to assume the McDonald Research Professorship of Physics at Montreal's McGill University. "*I am only a kid for such a position*," he admitted candidly, *I will have to carry it* *off somehow.*" A generous endowment made the facilities among the best of its kind. The scholarly chairman of the department, Prof. John Cox (1851–1923), was quite willing to relieve Rutherford of administrative duties to facilitate his research. "*...the salary is only* £500," he wrote to his fiancée, "*but enough for you and me to start on.*"

Rutherford was a big frog in any size pond; he took up research at McGill where he had left it at Cavendish. He had recognized that uranium and thorium emitted two different kinds of rays, that some would be easily stopped by a thin sheet of metal, whereas others would pass through; "*for convenience*" he named them *alpha* and *beta* emissions, a designation that has remained. Eventually Rutherford also found that alpha and beta particles were positive and negative, respectively, in their electric charge. André Louis Debierne (1874–1949) subsequently designated as *gamma* rays the more penetrating radiations emitted by radium.

In measuring the ionizing intensity of a thorium source, a perturbing difference was noted; it depended on whether the door of the laboratory was open or shut: it became evident that a radioactive "emanation", given off by thorium and blown about by the air draft, was capriciously affecting the electroscope. Rutherford studied this emanation (thoron) and showed that its own radioactivity diminished rather rapidly, to half of its strength every minute; thus, he discovered the first case of exponential radioactive decay.[346] The emission of a similar radioactive gas by radium (radon) was soon demonstrated.

The New Zealander was a competitive man; to him, science was a race with other sprinters on the track. "*The best sprinters on this road of investigation,*" he wrote to his mother, "*are Becquerel and the Curies in Paris, who have done a great deal of very important work.*"[174] Advantages on his side were his uncanny ability to pick out the significant facts from a mass of confusing details and his flair for experimental design with crude setups. A quarter of a century later, he said reflectively: "I think that a strong claim can be made that the process of scientific discovery may be regarded as a form of art... . A well constructed theory is in some respects undoubtedly an artistic production."[344]

In 1900 Rutherford returned to the South Island to marry the lady who was to be his life companion; they made their home at St. Famille Street in Montreal. In March 1901 they had their first and only child; they christened her Eileen Mary (1901–1930), although Ione had been suggested.

Rutherford needed a chemical associate; he chose a versatile and ambitious young chemist, Frederick Soddy (1877–1956)†, who was working as a demonstrator at McGill. "I abandoned all to follow him," said Soddy, "and for more than 2 years, scientific life became hectic to a degree rare in the lifetime of an individual." Becquerel had observed that a sample of inactive uranium nitrate resumed its radioactivity. Sir William Crookes (1832–1919) also had noted that after removal of its highly radioactive component, the resulting loss of radioactivity of uranium was followed by recovery.[174] Rutherford and Soddy put forward a theory of radioactivity according to which radioactive elements undergo a series of successive changes in which chemically different elements with decreasing radioactivity are successively formed. They concluded that most radioactive elements are themselves products of decay, with their own characteristic duration of activity, deriving from thorium, actinium, or uranium (Figs. IV-3 and IV-4). Iconoclastically, they stated that radioactivity is at once an atomic phenomenon and a spontaneous chemical change of one element into another. Seeking support from Sir William Crookes for the publication of their paper, Rutherford wrote: "*I believe that in the radioactive elements we have a process of disintegration or transmutation steadily going on which is the source of energy dissipated in radioactivity.*"

The *disintegration theory* of radioactivity was an unquestionably bold hypothesis well supported by Rutherford and Soddy's experimental findings[362,363]; it proved to be a major intellectual effort that eventually shook fundamental concepts of chemistry. "...the energy latent in the atom must be enormous compared to that rendered free in ordinary chemical change," they wrote, "There is no reason to assume that this enormous store of energy is possessed by the radioelements alone."[364] Indeed, the disintegration of the atom and the formation of new elements sounded

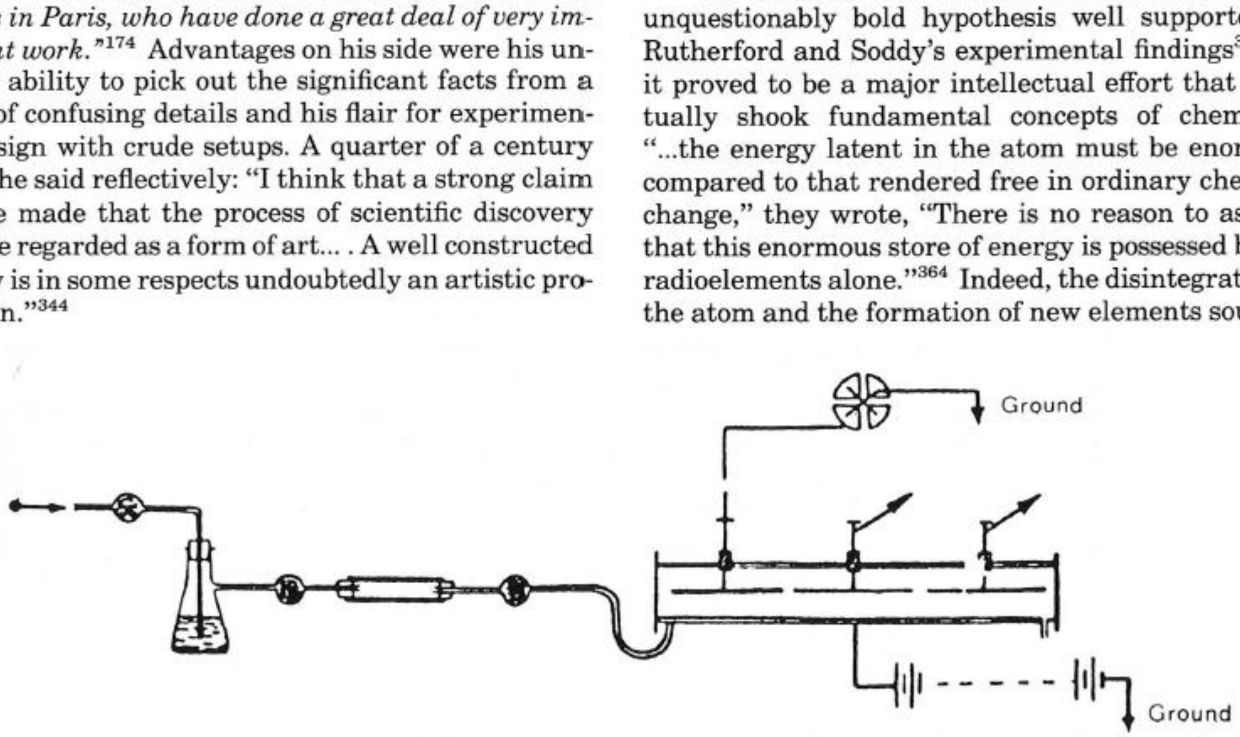

Fig. IV-3. Experimental setup used by Rutherford and Soddy to compare the "emanating" power of various substances (1902).

---

† See Biographical Notes on page 171.

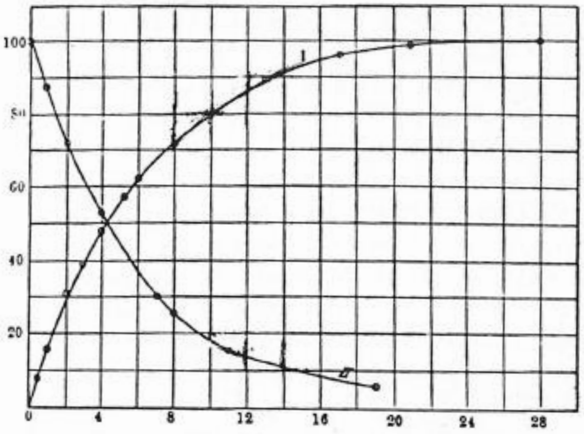

Fig. IV-4. Graph originally presented (1902) by Rutherford and Soddy showing that the rate of recovery of the radioactivity of thortium (rising curve) was related to the rate of decay of a chemically separable product which they called Thorium X.

to many as though the long exorcised ghost of alchemy had returned; moreover, the views were unacceptable to those who took literally the indivisibility of the atom and the immutability of elements. Lord Kelvin [Sir William Thomson (1824–1907)] expressed his disagreement at a meeting of the British Association for the Advancement of Science. "*I admire his confidence*," commented Rutherford caustically, but in private, "*for talking about a subject about which he has taken the trouble to learn so little.*"

In 1903 Rutherford was elected a Fellow of the Royal Society, a long coveted honor. He wrote his book *Radioactivity* (1904), a simply worded account of the work done and of all knowledge on the subject.[347] "Rutherford," said J. J. Thomson, "has not only extended the boundaries of knowledge on this subject but has annexed a new province." In May 1904 Rutherford returned to London to deliver the Bakerian Lecture on the fundamental facts of radioactivity; in it he is said to have laid the foundation for all subsequent theories of radioactive change.[348] Before the year ended, he also received the Rumford Medal of the Royal Society and shortly afterward accepted to deliver the Silliman Lecture at Yale.

Rutherford contributed greatly to raising the academic standards at McGill because of his presence and the importance of his research. Researchers were attracted from Europe and elsewhere to work at the McDonald Laboratories; among these were E. Godlewski, a graduate of Cracow, Poland; another, Otto Hahn (1879–1968) from Germany, was to play an important role in atomic fission (Nobel 1944). In his autobiography Hahn recorded reminiscences of a year in Montreal, the evenings in conversation with the professor, entertainment by Mrs. Rutherford at the piano.

"*Isolation is the great drawback of colonial appointments*," wrote Rutherford, "*I feel myself out of things scientific.*" He declined enviable offers from American universities: "*My chief reason...was to return ultimately to England to a position where I would not have to sacrifice laboratory facilities... .*" In 1907 he agreed to become the Longworth Professor of Physics at the Victoria University of Manchester. The incumbent, Sir Arthur Schuster (1851–1934), a fine physicist himself, suggested the move and diplomatically conducted the arrangements; moreover, he bequeathed the department a personally endowed readership in mathematical physics. In addition Rutherford inherited the valuable assistance of Schuster's German collaborator, Hans W. Geiger, the support of William Kay, an exceptionally gifted laboratory steward and of Otto Baumbach, an expert German glassblower. The facilities had been enriched by personal contributions of Professor Schuster, and soon Rutherford attracted a host of brilliant collaborators (15 to 20 research workers) (Fig. IV-5).

In Manchester ("...a city of grim streets but of warm hearts," said Andrade[16]), the Rutherfords settled in Withington, 2 miles from the university; their home was a busy place on weekends with friends and students flowing in. Rutherford wrote: "*Except for the climate Manchester has a number of advantages...the students here regard a full professor as little short of Lord God Almighty, quite refreshing after the critical attitude of Canadian students. It is always a good thing to feel that you are appreciated.*"[174] He was only 35 years of age, and this new station in his eventful career proved most fruitful.

In the summer of 1907, Rutherford resumed his study of alpha particles ("*the jolly little beggars*") in Manchester. He was convinced that alpha particles were atoms of helium and set out to prove it; he studied their deflection in magnetic fields, showing that they were relatively heavy, positively charged particles. Bertram Borden Boltwood (1870–1927) left Yale to work with Rutherford; he was put in charge of 450 mg of radium, a loan of the Akademie der Wissenschaften of Vienna; the radium was kept in solution in order to utilize the radium emanation (radon). Rutherford and Boltwood found that the alpha particles emitted by radium corresponded closely with its rate of production of helium.[357,358] An ingenious final test was conceived by Rutherford with Thomas A. Royds as his collaborator: a large amount of radon was put into a specially blown, extremely thin glass bulb, allowing the passage of alpha particles through its walls, the whole being enclosed in a sealed outer vessel; after a time, the particles trapped in the intermediate space gave off spectral lines clearly identifiable as coming from helium.[361]

In 1908 Rutherford was awarded the Nobel Prize of Chemistry for his "investigations into the disintegration of elements and the chemistry of radioactive substances."[290] While speaking informally at the traditional Nobel ceremonies banquet, he stated that he had observed many transformations with various time periods, but none quite as fast as his own from physicist to chemist! The Rutherfords enjoyed themselves greatly in Stockholm. In this same year, the Turin Academy of Science offered Rutherford the Bressa prize for his book.

A *scintillation* method of identifying collisions visually was already in use. With Geiger, Rutherford developed a method to identify collisions electrically; they refined their electrometer and other components of the gadget that was to be known as the *Geiger counter.*[360] "*Geiger is a good man,*" wrote Rutherford, "*and worked as a slave.*"[174]

In 1910 an International Radium Standards Committee was set up during the Congress of Radiology-held in Brussels; it was agreed that the amount of radon in equilibrium with one gram of radium should be called a *Curie.* The next meeting of this committee in Paris took charge of comparing radium preparations from Austria and from France. Members of the committee in attendance were: Madame Curie, André Debierne, Ernest Rutherford, Frederick Soddy, Otto Hahn, Stephen Meyer, and E. Schweidler.

Rutherford's most important conceptual innovation was initiated by a casual observation that could have been judged trivial by someone else. Geiger and a student, Ernest Marsden (1890–1970)†, were carrying on some work when they observed that alpha particles that entered a thin metal foil were sometimes deflected at wide angles.[273] Rutherford asked Marsden to investigate further the scattering of alpha particles. Within a week Marsden was able to report that he had collected reflected alpha particles from a variety of metal surfaces and that some of the alpha particles came right back! Rutherford reasoned that the large number of deflected alpha particles could not result from collisions with electrons but by their encounter with a larger size, positively charged *mass*; he instructed Marsden to round up his observations for publication.[215]

J. J. Thomson conceived the atom as a positively-charged, evenly distributed substance in which "corpuscles," later called "electrons" by Antoon Hendrik Lorentz (1853–1928), were thought to be embedded "as raisins in a round loaf of raisin bread."[214] ⭑ Phillipp Anton Edward Lenard (1862-1947), who had found that metals were transparent to electrons, conceived an atom model with a center, the *dynamid.*[62]

It was the discovery of the existence of electrons as constituents of the atom and the speculation as to their arrangement within it that opened the door of inquiry into the atomic secrets. Early one morning in the beginning of 1911, Rutherford entered the laboratories humming "Onward Christian Soldiers" and declared to Geiger: "*I know what the atom looks like.*" Rutherford conceived an atom with a relatively large, positive

Fig. IV-5. Staff and research students of the Department of Physics, University of Manchester (1910). Seated: Harold Roper Robinson (1889–1955), D. C. H. Florance, Margaret White, J. N. Pring (1884–?), Rutherford, Walter Makower (?–1945), E. J. Evans, Charles Galton Darwin (1887–1963). Standing, first row: Albert B. Wood (1890–1964), Ernest Green (1890–?), R. H. Wilson (1891–?), Shigemi Oba (1877–?) (Japan), Ernest Marsden (1890–1970), Harold Gerrard (1888–1975), James Chadwick (1891–1974), F. W. Whaley (1878–?), Henry Gwynn-Jeffreys Moseley (1887–1915). Second row: Harry Richardson (1891–?), John Mitchell Nutall (1890–1958), Bernard Williams (1894–?), William Kay. Last row: T. S. Taylor (1883–?) (U.S.A.) and A. S. Russell (1888–?). (From Meredith, W. J.: What Manchester thinks. The 1967 Sylvanus Thompson Memorial Lecture. *Br. J. Radiol.* **41**: 2–11, 1968.)[280] (Courtesy of Dr. Jack Meredith.)

⭑ See Subject Notes on page 183.

central charge (the word nucleus was only used later), surrounded by a sphere of negatively charged electrification.[349,350] It was Rutherford's discovery of the atomic nucleus, his concrete quantitative ideas on the atomic structure, that finally brought hold on a new concept of the atom.[62] A supporting theory was yet to evolve.

Niels Henrick David Bohr (1885–1962), a pale, heavy-boned, shy but ambitious, young Danish physicist, went to Cambridge; he brought Prof. J. J. Thomson a paper on the electron theory of metals that he hoped would be published in England (an editor found it too long, and it was never published).[283] Bohr attended the annual Cavendish dinner and heard Rutherford presented as a man without match in his ability to swear at the laboratory equipment; after the roar of laughter died down, Bohr was enthralled as the New Zealander extolled Wilson's *cloud chamber* as the most wonderful instrument in scientific history. Bohr, who had not been able to capture Thomson's interest, was himself captured by Rutherford's contagious enthusiasm. Upon his return from the first Solvay Conference (1911), held in Brussels and attended also by Albert Einstein (1879–1955) and Max Planck (1858–1947), Rutherford agreed to Bohr's quiet transfer of his interest to Manchester. "*Bohr, a Dane, has pulled out of Cambridge and turned up here to get some experience in radioactive work.*"

In Manchester Bohr was a regular attendant to the half-past-four informal conferences and Friday afternoon colloquia, that Rutherford conducted; they took place over tea, buttered bread and cake. It required an effort of imagination to conceive of matter as being made mostly of *empty space*; gradually, a *planetary* disposition of electrons evolved.* Bohr added stimulating thoughts; perhaps, he suggested, the solid, gaseous, or liquid state of the elements is explained by a different arrangement of their electrons. As he ventured into this no-man's land of ideas while Rutherford sucked quietly at his pipe, Bohr's tea usually turned cold. Bohr was also brought to participate in the private monthly gathering of a group of Rutherford's friends that included an historian, a philosopher, an anthropologist, and a chemist (later turned statesman), Chaim Weizmann (1874–1952).

Rutherford had given George Charles de Hevesy (1885–1966)† the task of separating some radioactive materials from their nonradioactive counterparts; de Hevesy was unable to do it. Bohr suggested that this was probably because since they were identical in their electrons, the inseparables differed only in their nucleus; de Hevesy was impressed, but Rutherford cautioned Bohr against building too much on theory. Yet, within a short time, Soddy gave the explanation of *isotopes*. Both Bohr and Rutherford probably never forgot it; their confirmed interchange did not reflect any resentment. Bohr persisted in his view that radioactivity was of the nucleus.

"In the spring of 1912," wrote Bohr, "I became convinced that the electronic constitution of Rutherford's atom was governed throughout by the quantum of action"[100]; he was thinking in Planck's terms. Thereafter, he could not be separated from his pasted sheets of calculations; Rutherford again warned against too much theory but this time urged Bohr to prepare a text for publication. Despite his convictions, Bohr had been unsuccessful in his effort to find a theory for the structure of the atom. After a year while he was looking over books of spectroscopic data, he happened upon the numerical relationship of spectral lines and found his mathematical solution: a formula that described the actual spectrum of hydrogen[45] but also accounted for this spectrum on the basis of quanta of energy, a theory accounting for the fact that atoms are not ordinarily radioactive and that electrons do not spiral into the nucleus. Electrons may fall to an inner orbit, causing emission of radiations, but they can go no further towards the nucleus than the innermost quantum orbit. It was one additional consequence of the transformation of concepts of time and space.

He sent an elaborate text to Rutherford; it was written in faulty English. Rutherford read it most carefully with "angelic patience" according to Bohr; he proposed changes of grammar (don't start every paragraph with "however"), suggested avoidance of repetition and reduction in length. Bohr's subsequent version was longer than the first; it was eventually published in three instalments.[42–45] With one stroke of genius, Bohr vindicated both Planck's concept of radiations as discontinued surges of energy and Rutherford's miniature solar system.[46] Although Bohr's theory was somewhat remote from his own way of visualizing things, Rutherford was impressed with the manner in which it gave the correct value for atomic constants, and he eventually accepted Bohr's theory completely. Arnold Sommerfeld's ultimate addition of quantum eliptical electron orbits and final structural cosmetics of the atom, including the so-called state of Johannes Rydberg (1854–1914).

In 1913 the meeting of the British Association for the Advancement of Science took place in Birmingham and was attended by a crowd of notables. As reporters attempted to reach the shy, self-possessed Madame Curie, she parried their questions by saying: "Dr. Rutherford is the man living who promises to confer some inestimable boon on mankind as a result of the discovery of radium."

William Henry Bragg (1862–1942) and his son, William Lawrence Bragg (1890–1971), showed how to measure the wavelengths of roentgen rays by reflecting them from crystals. Rutherford, working with Andrade†, obtained spectra of gamma rays.[356] One of his young students, Henry Gwynn-Jeffries Moseley (1887–1915) persuaded Rutherford to let him study the wavelengths of radiations emitted by the various elements. Moseley used a yard long tube containing movable blocks of a variety of elements (like cars in a toy train) that were brought into the path of cathode rays; he

---

* See Subject Notes on page 183

† See Biographical Notes on page 171.

E Rutherford

Fig. IV-6. Pencil portrait of Rutherford by Sir William Rothenstein (1925) at Cavendish. Signature.

demonstrated that the roentgen rays emitted by these elements, when reflected and spread out from a crystal, comprised *characteristic frequencies*, lines in their spectra that made their recognition by photography rather simple. Moseley further observed that the characteristic wavelength of the rays emitted by the tested elements varied in regular steps; he concluded that only the charge of the nucleus could change in such regular amounts.[285] Moseley decided that the elements should not be listed in order of their weight but of their *atomic number* or nuclear charges, relating them to the magnitude of their electric charge. Moseley's roll of known elements gave scientific precision to the periodic classification of Dmitri Ivanovitch Mendelelev (1824–1907); it left four slots that were eventually filled by hafnium, rhenium, technetium, and promethium. Moseley's law renewed interest in the configuration of the atom and disposition of electrons and reaffirmed the view that it was the charge of the nucleus that determined the properties of the element.[58] "*This proof of Moseley*," wrote Rutherford, "*ranks in importance with the discovery of the periodic law of the elements and of spectral analysis and in some respects is more fundamental than either.*" Few events in modern history of physics have motivated such general interest as Moseley's discovery. "*They were happy days in Manchester*," Rutherford said later, "*and we wrought better than we knew.*"[174]

Rutherford was very active in the Radium Committee that led to the founding of the Manchester and District Radium Institute, later the *Holt Radum Institute* of the Christie Hospital of Manchester. Acting for the committee, he purchased (1914) the first 200 mg of radium from the Standard Radium Chemical Company of Pittsburgh, Pennsylvania for clinical use by the staff of the Institute.

Geiger returned to Germany to a position in Berlin; James Chadwick (1891–1974) joined him to continue some of their work. G. de Hevesy went to work in Vienna, whence he wrote of Einstein's concurrence with the new ideas on the atom.[98] Marsden took a position at the University of New Zealand, but as the 1914–18 war broke out, he entered the army to serve in France. Chadwick was interned in Germany as an enemy alien for the duration. Foreigners left Manchester, and British subjects either returned to their dominion or entered military service: Pring got a commission with the Royal Fusiliers; Florance, Andrade, H. P. Walmsley, and Harold Roper Robinson (1889–1955) went to the artillery. John Mitchell Nutall joined the Royal Engineers. Baumbach, the skillful German glassblower, would not tone down his anglophobic vituperations and was taken into custody by the authorities. Young Moseley became an early casualty in the Gallipoli campaign. "*Our regret*," said Rutherford, "*is all the more poignant because...his services would have been far more useful in...fields of scientific inquiry...* ." Rutherford became a member of the Admiralty Board of Invention and Research; he was drawn into military projects, in particular, that of detection of submarines. Work at the laboratories continued at a much reduced rate. Bohr was asked to replace Darwin in the Schuster readership and shared with Evans and Makower almost the entire teaching schedule.

In spite of the war, Rutherford's thoughts kept returning to his battleground of preference. Marsden, Geiger, and Charles Galton Darwin (1887–1963) had initiated a study of the results of encounters of alpha particles with the relatively light hydrogen nucleus. Marsden had found that some of the resulting particles of the collision had a range of 10 cm or more and had thought that the particles could come from the radioactive source itself. Rutherford decided to investigate the matter further with only the help of the laboratory steward, William Kay; he delicately "cleared" his intention with Marsden, who contributed help after demobilization; he eventually identified the long-range particles as hydrogen nuclei resulting from the disintegration of the nitrogen nucleus upon collision with alpha particles.[352] In time at the suggestion of Darwin and Fowler, he named the newly recognized particles *protons*. This was the first step into the artificial transmutation of atoms, the *newer alchemy*,[355] which was to have transcendental repercussions. Meanwhile, as part of his war obligations, he traveled to New York and to Paris to make contact with American and French war researchers.

At war's end Bohr wrote: "All here are convinced there can never more be a war in Europe of such dimensions... ." The end of the war brought difficult decisions. Prof. J. J. Thomson became Master of Trinity College, Cambridge, and resigned the directorship of Cavendish; Rutherford was the natural, though reluctant, heir to the exalted position. He was offered the added title of Cavendish professor (Fig. IV-6). Once again he faced the responsibility of building up a staff of capable collaborators. James Chadwick returned from Germany and became his principal associate and eventual deputy. Chadwick was a dedicated and unselfish teacher: he was greatly responsible for the eventual success of many students. Darwin followed him to Cavendish but soon left for Edinburgh. Ralph Howard Fowler (1889–1943), who married Eileen Rutherford on December 6th, 1921, became Rutherford's principal collaborator in theoretical matters; he proved to be a most congenial son-in-law. There was talk of confiscating the Austrian radium, which Rutherford had brought from Manchester, as "enemy property," but Rutherford, who was grateful for the work that this generous loan had allowed, insisted on having the radium released and paid for, rather than appropriated. G. R. Crowe became Rutherford's personal assistant.

Rutherford played an important role in connection with the Cambridge *Diploma of Medical Radiology and Electrology*; as a member of its committee, he was responsible in great part for the support that it received and for its success. He delivered the first Sylvanus Thompson Memorial Lecture (1918) and the McKenzie Davidson lecture (1920) of the British Institute of Radiology.

A list of visitors and temporary workers at Cavendish would be interminable. Bohr, who had founded the *Institut fur Teoretisk Fysik* in Copenhagen, was frequently invited to lecture. Arthur Holly Compton (1982–1962) came for one year (1919) to do work on the scattering of gamma radiations.[359] Peter L. Kapitza,† a Soviet citizen, went to Cavendish in 1921; he was a handsome young man with a strong personality and self-confidence, and is said to have acquired great influence on Rutherford (Fig. IV-7). Kapitza was trained as an electrical engineer, and was engaged in costly electromagnetic research; he produced powerful magnetic fields to deflect alpha particles and the liquefaction of helium, but otherwise, his work had no consequences in atomic research.

A remarkable example of Rutherford's foresight and intuitive feeling with respect to the atom was given his second Bakerian Lecture (1920) at the Royal Society: "*...the neutral hydrogen atom is regarded as a nucleus of unit charge with an electron attached at a distance. Under special conditions, it may be possible for an electron to combine much more closely with the hydrogen nucleus, forming a kind of nuclear doublet: such an atom would have very novel properties. Its external field would be practically zero...and in consequence should be able to move more freely through matter...enter readily the structure of atoms and...untie with the nucleus or be disintegrated by its intense field, resulting in the escape of charged hydrogen atom or an electron or both... . The existence of such atoms seems almost necessary to explain the building up of the nuclei of heavy elements, for...it is difficult to see how any positively charged particle can reach the nucleus of a heavy atom against intensive repulsive field.*"[353] However, the existence of Rutherford's chargeless particle could not as yet be demonstrated.

Upon his return from a trip to Australia and New Zealand, Rutherford received the Order of Merit at Buckingham Palace, the highest distinction in the gift of his king; he was also elected president of the Royal Society. He was awarded the Copley Medal of the Royal Society (1922), the Franklin Medal of the Franklin Institute of Philadelphia (1924), and was elected a Fellow of the Royal College of Physicians (1928). He also received the Faraday Medal of the Institute of Electrical Engineers (1930). On New Year's Day, 1930 he became Baron Rutherford of Nelson, a title that honored also the South Island city of his youth. An affectionate telegram went to his 87-year-old mother: "*Now Lord Rutherford, more your honour than mine.*" These worthy recognitions coincided with the unfortunate, premature death of his only daughter; she had given him three grandchildren, Peter Howard (1923–), Elizabeth Rutherford (1925–), Elliott Patrick (1926–), and died upon the birth of a fourth, Ruth Eileen Fowler (1929–).[174] *

In 1930 Walther Wilhelm Georg Franz Bothe (1891–1957) and H. Becker of Giessen irradiated boron and beryllium with a polonium source of alpha particles; they were surprised to find that these metals gave off a beam of radiations more penetrating than the gamma rays of radium. Irène and Frédéric Joliot-Curie verified these findings at the Radium Institute of Paris. The resulting beam of radiations passed without much loss through 10 cm of lead; a thin layer of aluminum or cellophane, fortuitously interposed in the resulting beam actually increased its intensity.

This discovery led the Joliot-Curies to interpose a layer of paraffin wax and to study the results in a cloud chamber: they found that 5 MeV protons, which neither attracted nor repelled electrons, were knocked out of the wax. The Joliot-Curies had not read Rutherford's Bakerian Lecture, had not heard or thought of chargeless particles, and therefore failed to recognize them; they reported their observations (January 1932)[243] and concluded, logically, that the effects resulted from a Compton effect of gamma rays on protons, an interpretation that proved untenable.

In Cambridge Chadwick was involved in similar verification of the Bothe–Becker radiations; he remembered Rutherford's prediction of a chargeless particle, and he rapidly gave the findings the adequate interpretation: he said the highly penetrating radiations consisted primarily of electrically neutral parti-

Fig IV-7. Bas relief of Rutherford by Eric Gill, commissioned by Kapitza and nicknamed "The Crocodile" (1930).

---

† See Biographical Notes on page 171.

* See Subject Notes on page 183.

Fig. IV-8. Rutherford in the company of Ernest S. Walton and John D. Cockcroft, developers of first high-energy linear accelerator of nuclear particles (1932).

cles of the approximate mass of the hydrogen nucleus and christened them *neutrons* (February 1932). Within another month Norman Feather (1904–1978) showed at Cavendish that neutrons were effective in disintegrating both oxygen and nitrogen.[177] Joliot said later: "The word neutron had already been used by the genius Rutherford in 1923 to denote a hypothetical neutral particle which, together with the protons, made the nucleus. This hypothesis had escaped the attention of most physicists, including ourselves, but it was still present in the atmosphere of the Cavendish Laboratory, where Chadwick worked, and it was natural and just, that the final discovery of the neutron should have been made there."[217] Chadwick received the Nobel Prize of Physics in 1935; Bothe received it in 1954 for the *coincidence method* and consequent discoveries.

Rutherford had long wished to be able to utilize an abundant supply of particles with energies transcending those emitted by radioactive substances. Ernest Thomas Sinton Walton (1903–   ) had been working on a high voltage accelerator without success. John Douglas Cockcroft (1897–1967), an electrical engineer, sought to find a possibility of accelerating *protons*; Walton joined him in this effort. They built a high energy unit with a potential of 700,000 V accelerating 50 million protons per sec at such velocity as to permit them to enter the nucleus; they used lithium as a target and were successful in transforming the lithium isotope of mass 7 into two alpha particles. Their achievement of artificial transmutation confirmed in all details the quantum theory prediction of dependence of effects on the energy of protons (Nobel, 1951). (Fig. IV-8.) Contemporaneously, Ernest Orlando Lawrence (1901–1958) and Milton Stanley Livingston (1905–) were perfecting their cyclotron at Berkeley, an invention which brought Lawrence the Nobel Prize (1939).

Takeo Shimizu (1890–?), a Japanese physicist who had done spectrographic work with William Duane (1872–1935) at Harvard, worked at Cavendish on an improved cloud chamber with double right-angle photography every 15 sec. Shimizu returned to Kyoto, and the work was taken over by Lord Patrick Maynard Stuart Blackett (1897–1974), who developed the chamber into an ingenious automatic system to photograph nuclear reactions and the path of cosmic rays. Blackett was able to show that the reaction between the alpha particle and the bombarded atomic nucleus had mostly the nature of a synthesis (Nobel, 1948); he also observed tracks of positively charged electron-like particles. Simultaneously, Carl David Anderson (1905–), using an ordinary cloud chamber, discovered the *positron* (Nobel, 1936) that had been predicted by Paul Adrien Maurice Dirac (1902–1984) (Nobel, 1933). The Joliot-Curies produced the first cloud chamber photographs showing paired positive and negative electrons.

Wolfgang Ernst Pauli (1900–1958),† the brilliant Viennese theoretician, had long urged his experimental colleagues to find an atomic particle that would reestablish the balance of energy impaired by the continuity of beta-ray spectra; Pauli's theoretical particle (which he originally had called neutron) had practically no mass and carried *no electric charge,* so that paired with a beta particle, the sum of their energies would always be the same but the identification of the neu-

---

† See Biographical Notes on page 171

tral particle would be almost impossible. In Zürich, Copenhagen, and Tübingen Pauli had argued for the acceptance of this concept, but it was in Rome that he found support. In consideration of its negligible mass and of the fact that in Italian the word *neutrone* suggests an augmentative suffix, Fermi proposed the word *neutrino*, using the Italian diminutive suffix: simultaneous baptism and pun! ("I neutroni di Pauli sono piccoli e leggiere; essi debonno essere chiamati neutrino.")[217] The evidence of the existence of neutrinos remained circumstantial until years later when they were demonstrated in the Savannah River Project.

In 1933 the Joliot-Curies resumed their irradiation of aluminium, fluorine, sodium, and boron; they found that the emission of positrons by these elements was associated with neutron emission. They were rather disappointed when their report of this work to the Seventh Solvay Conference (Brussels, 1933) found surprising opposition. They renewed their efforts because they wanted to prove themselves. They irradiated aluminium with progressively diminishing energies of alpha particles; they observed that below a certain minimum velocity, neutrons were no longer emitted, but positrons continued to appear "like radiations from a naturally radioactive element," even after the source had been withdrawn. A serious test of all their equipment was in order, but the repeated experiments brought the same results: radiophosphorous had been produced and chemically identified within the brief 3 min and 15 sec of its half life.

They hastily proceeded to prepare a demonstration in the basement of the laboratories, rue Pierre Curie; as they started their demonstration, a door opened behind them, and Marie Curie and Paul Langevin entered.[217] On 15 January 1934, in the presence of their beloved mentors, Irène and Frédéric Joliot-Curie had opened much wider doors, among them that of *nuclear medicine*.[242] The artificial production of radioactive elements, what came to be called *artificial radioactivity*, brought a prompt note from Rutherford: "I congratulate you both on a fine piece of work." This discovery brought the brilliant workers of the *Institut du Radium* fame in their own right and, without delay, the coveted message from the Swedish Academy of Sciences offering them the Nobel Prize of Chemistry for 1935.

In the early 1930s, there was a surge of interest in England in radiotherapy of cancer. The *Holt Radium Institute* of Manchester gained new vigor under James Ralston Kennedy Paterson (1897–1979): the *Marie Curie Hospital* of London, an institution for the treatment of cancer in women by women, opened its doors: Jean Stewart Riach (1905–1974) was its specially trained roentgentherapist. Rutherford was among those favoring the development of the *Radium Beam Research*. Constance Ann Poyser Wood (1900–) divided her attention between this new opportunity of clinical research and her service duties at the established *Royal Cancer Hospital* of London. Sir Brian Windeyer at the *Middlesex Hospital* set an exemplary pace for clinical radiotherapists to follow.

Shortly after the discovery of the Joliot-Curies, Enrico Fermi decided to try the use of neutrons instead of alpha particles to produce artificial radioactivity; his preliminary results using polonium and beryllium were not encouraging. A large radon source was made available by Prof. Giulio Cesare Trabacchi,[204] who thus became their "divine providence." With the help of Amaldi, Rasetti, Segré, and later Pontecorvo†, Fermi proceeded to irradiate elements of increasing atomic numbers; their rapidly accumulating results amount to a fascinating story that was reported in weekly installments in their letter to *La Ricerca Scientifica*. The nuclei of the irradiated elements captured neutrons and became artificially radioactivated, emitting a negative electron (electrically equivalent to absorbing a positive charge); after the emission, the nucleus became stable and took one number higher in the periodic table. Patiently, Oscar d'Agostino identified the isotopic products of the irradiation of elements (59 elements at the end of the second report); eventually, they reached uranium and the end of the periodic table. They hoped to produce a new element, 93, but the

Fig. IV-9. Rutherford in the garden of Newham Cottage (1933).

---

† See Biographical Notes on page 171.

results were confusing, and the possibility of fission did not occur to them.

"I congratulate you on your successful escape from...theoretical physics!," wrote Rutherford, " *You seem to have struck a good line."* Yet, to Fermi, the results had not been very rewarding until, whimsically, he decided to interpose a block of paraffin wax in the beam of neutrons: it resulted in a 100 fold unexpected enhancement of the effects.[198] Fermi theorized that the neutrons were slowed down by their encounter with hydrogen, thereby becoming more effective. This work brought Fermi the Nobel Prize of Physics in 1938; his discovery was to be of paramount consequence in the eventual production of controlled atomic fission and in the production of atomic power.*

In the later years of his work, Rutherford was greatly assisted by Marcus Lawrence Elwin Oliphant (1901–), who dedicated himself to the study of high-energy particle acceleration. In the United States, Harold Clayton Urey (1893–1981) discovered *deuterium* and named its nucleus *deuteron.* At Cavendish, Rutherford and Oliphant as well as Paul Harteck (1902–1985) irradiated deuterium with deuterons and produced *tritium.* Although Rutherford did not foresee the utilization of atomic energy, he put his finger on the essential prerequisite: the release of large quantities of neutrons.

In rapid succession since the beginning of this century, new discoveries have shown the remarkable significance of an understanding of the atom: *electrons, positrons, protons, neutrons, neutrinos* were to be joined by *mesons* and still others. The protagonists of this saga are varied and numerous, but in almost every milestone the thoughts of Rutherford had played a role. A complete list of Rutherford's students and short- or long-time collaborators has not been produced. In addition to those names in the text and those who appear in Fig. IV-5, the list would include: C. D. Ellis, R. W. Boyle, L. H. Gray, C. W. Gilbert, W. Makower (?–1945), Sidney Russ, R. W. Varder (1889–?) (South Africa), D. C. H. Florance (New Zealand), A. D. Fokker (Holland), Kasimir Fajans (Poland), K. T. Bambridge (U.S.A.), and innumerable others.

In Cambridge the Rutherford's home was known as Newham Cottage, an old two-story house on Queen's Road, not far from Cavendish (Fig. IV-9). Sunday afternoon tea was offered to friends and students under spreading trees; then the Rutherfords dined at the High Table at Trinity. For years they also had a summer cottage, *Celyn,* at Gwynant, North Wales; in 1935 they decided on a closer location: *Chantry Cottage* on Wiltshire Downs, not far from Andover. Although his game brought him no justifiable praise, Rutherford played golf in congenial company: his notable colleague, Francis William Aston (1877–1945) (Nobel 1922), Geoffrey Ingram Taylor (1886–1977), and his son-in-law, Ralph Howard Fowler; they were known as the "talking foursome," for they truly enjoyed each other's company more than the game.

In the fall of 1937, Rutherford suffered a strangulated hernia while he was working in his wife's garden, a minor surgical intervention was followed by complications. On 19 October 1937 he died in the 67th year of his fruitful life, just as the progress of nuclear physics was about to give his work the fullness it deserved. His compatriots offered his remains lasting peace in Westminster Abbey in the historical company of Isaac Newton (1642–1727) and other prestigious countrymen. He was recognized during his lifetime as an exceptional scientist,[149] and was to be widely memorialized throughout the world. "For those who had the privilege of knowing intimately the personality and achievement of Rutherford," wrote de Hevesy, "his death removes one of the great attractions of life." "His book, *Radioactivity,*" wrote Geiger, "is a record of selflessness; how often does the name of a disciple accompany a discovery which was yet completely his own creation." "Now that we have lost him", wrote the Duke de Broglie, "we can see more clearly the magnitude of the part he has played during the past 40 years in creating, to a great extent, the physics of the atom and of the nucleus."[149,281] "...Rutherford managed to reach profound conclusions," wrote Einstein, "on the basis of almost primitive reflection combined with relatively simple experimental methods."[98] His volcanic energy and capacity for work was matched only by his enthusiasm. "He brought to his work", wrote W. H. Bragg, "a singleness of purpose, a simplicity of conception, and a bravery of attempt which carried him straight to the point." "He was", said Chadwick, "the greatest experimental physicist since Faraday."[174] "It is given to few men to achieve immortality, still less to achieve Olympian rank during their own lifetime", proclaimed the *New York Times,* "Lord Rutherford achieved both."[267] (Fig. IV-10.)

Ernest Rutherford was a genial man with exceptional intellectual gifts. He was also a deceptively simple, bucolic appearing, unsophisticated person with a boyish sense of humor and natural energy; his exuberant enthusiasm commanded confidence. In his younger years, he had frankly questioned his own ability to supervise the work of others; he proved a shrewd judge of character with a great capacity to orchestrate the work of his collaborators, correcting, "gingering up," chaffing without malice, and disconcerting occasionally by sudden anger over trivia. He had a loud voice (he was incapable of whispering) and an assertive, boastful manner; his transparent honesty, his genius for friendship and his unrestrained laughter inspired affection: his students kept memories of "Papa" more cherished than their recollections of exciting research. He was raised as a Presbyterian, and was a puritan at heart. Rutherford presented science as a happy thing of beauty and Strove to lead his students into possession of their own strength. "He came to regard the training of students in methods of research as of almost equal importance to the advancement of knowledge," said Chadwick. He talked with a touch of

---

* See Subject Notes on page 183.

Fig. IV-10. J. J. Thomson and Rutherford (1934).

arrogance, of his associates and students as "my boys"; with freshness and joy, he was pleased to talk of their work. He was basically an experimental scientist; he had a natural distrust of theoreticians and avoided mathematics. *He often said "one should be able to explain the laws of physics to a barmaid,"* but his paper on scattering (1911) is said to be beautifully mathematical.[349] Also, he often took theory's counsel or went to its support. He was an aggressive competitor, but was most gracious and generous in the praise and recognition of the work of others. He was intolerant of pomposity, and was nevertheless appreciative of rewards and signaled recognition of work done. He told Arthur H. Compton: *"Let others who do not know me call me Lord."*

A succinct listing of Rutherford's contributions should include: (1) discovery of magnetic detection of radio waves, (2) theory of ionization of irradiated gases, (3) discovery of alpha and beta radiations, (4) discovery of exponential radioactive decay, (5) discovery of radioactive gaseous emanation of thorium, (6) elucidation (with Soddy) of the principle of radioactive decay (disintegration theory), (7) discovery of the atomic nucleus, (8) proof that alpha particles are helium nuclei, (9) development (with Geiger) of electronic means to identify particle collisions, (10) identification of protons and first step of transmutation of elements. He also surmised the existence of neutrons. These enumerated, naturally interconnected links, important as they are, fail to give full credit to Rutherford's genius. "His achievements are indeed so great," said Bohr, "that, where progress in our science is discussed, they provide the background of almost every word that is spoken."