THE BIRTH OF THE ATOMIC NUCLEUS

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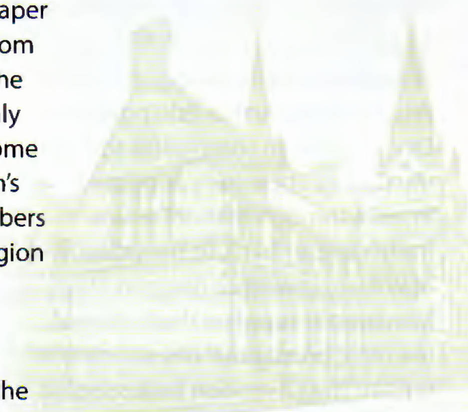
The first evidence for the atomic nucleus was found a century ago in an experiment carried out by Hans Geiger and Ernest Marsden in Manchester. The scientific and social events that led up that discovery, its interpretation by Earnest Rutherford and the subsequent work that cemented the phenomenon into physics knowledge, are described in this article.

1 The first movements

When Hans Geiger and Ernest Marsden, almost exactly a century ago, published their paper signalling the entrance of the atomic nucleus into physics knowledge, it was not a random happening, nor the result of a chance observation. The sequence of events that led to the birth of the nuclear age in Manchester in 1909 had begun a century earlier, driven mainly by sociology. During the early part of the 19th century, the city of Manchester had become restless. It was at the heart of the industrial revolution, a major contributor to the nation's economy but was barely represented in parliament, which was still dominated by members whose presence was based on privilege and corruption. It had no university and in a region where non-conformist churches were strong, entrance to the established universities elsewhere was barred to anyone who would not declare an oath of allegiance to the established Church of England.



Manchester itself became unpopular in London because of its strong local support for the People's Charter of 1838, demanding political and social reform. A pre-Chartist meeting of 70000 in the city centre in support of parliamentary reform had been brutally suppressed in 1819 by local cavalry, leading to the deaths of 10 civilians. Against this background of the "Peterloo Massacre" and Chartism, repeated representations to government, even by eminent advocates such as John Dalton and James Joule, failed to gain sympathy for the establishment of a university in the city and it was left to a local benefactor, John Owens, to endow a new college, which carried his name. Owens College opened its doors in 1851, with a strong emphasis on science and along with University College, London, whose degrees it awarded, was one of only two institutions in the country to teach physics at undergraduate level, to offer no religious instruction and to allow entry to all (males) irrespective of religious belief. Fresh sources of hitherto ignored talent could now be tapped. Young boys (women were allowed in later) could be prepared for scientific and technical careers in local industry and just as important, local school teachers could also take courses in the sciences so that they could better prepare their pupils for entry to the college.

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Despite the unambiguous condition attached by Owens to his bequest of £96 000, worth £74 million today if scaled by average earnings, that there should be no religious instruction in the college, the Bishop of Manchester sought to overturn the terms of the legacy with a perverse logic. "John Owens was clearly a charitable man and hence must have been a Christian. Therefore he would approve of Christian teaching in the college he has thus endowed." The college governors chose a smart path of response. Instead of engaging in debate with the Bishop, they simply published his correspondence in the local broadsheet, thereby enraging the liberalists. They subsequently overlooked to invite the Bishop to the opening ceremony.

Physics flourished in Manchester from the outset, producing graduates of the stature of John Joseph Thomson, Charles Thomson Rees Wilson and James Chadwick, subsequent Nobel Prize winners. Arthur Eddington and Ernest Marsden soon followed. From the date of Thomson's appointment in 1884 through that of Earnest Rutherford in 1919, to the retirement of William Lawrence Bragg in 1953, Manchester supplied the holder of the most prestigious physics chair in Britain: The Cavendish Professorship at Cambridge University. Owens College eventually became one of the constituents of the Victoria University of Manchester, chartered in 1880 by Royal Assent. Yet again the next step along the path to the nuclear age was enabled by private donation. In 1900, the new physics laboratories were opened, ranking among the best anywhere in the world. The director of the existing laboratories, Professor, later Sir, Arthur Schuster had toured the world measuring the size of the most eminent science laboratories, from Baltimore to Berlin and set about creating something comparable in Manchester. The annual report to the University Court of Governors [1] contains an item by Schuster, listing the sources of funding for the erection of the building, its equipment and maintenance. The summed cost is given as £30 000, which scales to £6m in 2010 terms. Most of the donations were from private, named individuals but with the highest, £10 000 from "A Friend" who may or may not have been the wealthy Schuster. Lancashire County Council gave £500 and central government provided nothing.

As well as being rich, Schuster could not resist new technology. He bought a typewriter for the department in 1882, the year that Remington put their first models on sale in Britain. He bought his wife a knitting machine with which she made socks for the family friend, H. G. Wells, who had exceptionally small feet. He bought one of the first cars off the production line owned by his friend Mr. Royce. He owned and used the best available camera. As a physicist he was erratic. He made measurements on cathode rays years before Thomson, but deduced they were nitrogen atoms, thus getting their mass wrong by a factor of nearly thirty thousand. His nose for recognising talent in others was, however, unsurpassed. After securing the laboratory, he turned his attention to finding someone worthy of running it. That "someone" was Earnest Rutherford, New Zealander and professor at McGill University in Montreal. The academic staff salary budget in the physical laboratories in Manchester at the time was £3200 per annum, of which half was shared among 9 lecturers, Rutherford receiving the rest, of the order of half a million pounds in today's money, when scaled by the average earnings index, but still a bargain when seen in the light of the Nobel Prize he brought the University a year after appointment and the subsequent discoveries which he made or directed.

2 The entry of the virtuosos

Rutherford arrived in Manchester in the summer of 1907 and soon had a team in place, which, in modern parlance might be called "galacticos", a mixture of home-grown and international talent, many of who have gone down in history. One of Rutherford's tasks was to report to the University Court on what was happening in his department. He tended to be laconic: "Dr. Bohr continued his mathematical investigations on the structure of the atom." [2]. Niels Bohr had indeed continued his work and it led to a trilogy of Nobel Prize winning papers, laying down the Bohr theory of the atom. The 1912 group photograph (fig. 1) includes James Chadwick, eventual discoverer of the neutron and Henry Gwyn Jeffreys Moseley who established the role of atomic number in the periodic table. Hans Geiger who had been recruited to the laboratories by Schuster is there. The group photograph also includes Harold Roper Robinson, later Vice-Chancellor of the University of London, and mathematician Charles Galton Darwin, grandson of the evolutionist, who was later Master of Christ's College, Cambridge and then director of The National Physical Laboratory.

Within days of arriving in Manchester, Rutherford began setting up and making new apparatus. He and Geiger, described as having a gluttonous appetite for work by contemporary Robinson [3], invented a new device for electrically counting α-particles and measuring their charge, eventually known as the Geiger-Müller counter. Robinson called it "an amazing technical feat", to produce such a new detection technology and to publish the results within a few months [4]. The need for the instrument appears to have arisen from the different responses of Rutherford and Geiger themselves to the existing detection methods which involved the scientists staring for hours at a zinc sulphide screen and counting

Fig 1 Manchester Physics Department Staff 1912. Left to right: Back rows: (standing) G. C. Darwin, J. A. Gray, D. Florance, J. M. Nuttall, Miss Margaret White, W. Kay, Miss May Leslie, H. P. Walmsley (partially obscured), J. Chadwick, H. R. Robinson, A. S. Russell, W. Schrader, Y. Tuomokoski. 2nd row: (seated) H. Geiger, W. Makower, A. S. Schuster, E. Rutherford, R. Beattie, H. Stansfield, E. J. Evans. Front row: (on the ground) R. Rossi, H. G. J. Moseley, J. N. Pring, H. Gerrard, E. Marsden. The style of the names, especially the male-female asymmetry, conforms to contemporary usage.

scintillations. Geiger was known as a demon at work and could count scintillations all night, whereas Rutherford himself admitted that he "damned" after two minutes. Although the embryonic Geiger counter worked, it proved too cumbersome for regular use and Rutherford preferred and continued to use the method of scintillation counting, provided he did not have to do too much of it himself. The laboratory steward, William Kay (see fig. 1), much admired by Rutherford, added to his many other talents by becoming the department's stalwart scintillation counter. When Rutherford resumed serious research in 1918-19 at the end of the Great War, with virtually his whole team dismantled, Kay was almost the only other person left and did all the counting for Rutherford in the experiments that showed that nitrogen could be transmuted into oxygen via nuclear collisions. Kay and Rutherford were the first successful alchemists.

In September 1961, the Rutherford Jubilee Conference [5] was held in Manchester and four of Rutherford's colleagues, Sir Ernest Marsden, Sir Charles Darwin, Edward Neville da Costa Andrade and Niels Bohr spoke at a special commemorative session of the conference. These four, together with Sir James Chadwick who did not speak on account of a throat infection [6], were photographed together on the day (see fig. 2) and were clearly in good spirits. Their speeches were recorded on tape, as delivered, as well as being published in a more formal and edited form in a special volume. The audio recordings of these speeches are a reliable source of information here, since they are authenticated through being spoken by the people involved and include informal items, not written up in the proceedings.

It had long been a practice in the department to recruit the more able

Fig. 2 The boys are back in town. Sir James Chadwick, Sir Charles Galton Darwin, Sir Ernest Marsden, Edward Neville da Costa Andrade and Niels Bohr at the commemorative session of the 1961 Rutherford Jubilee conference.

undergraduate students into the research laboratory. Marsden was one of these and was already taking part in the research programme during Schuster's last year in charge. He helped with measurements on the atmosphere by flying kites from nearby Glossop Moor along with meteorologist Miss Margaret White, (see fig. 1), fellow student William Eccles and engineering student, later philosopher Ludwig Wittgenstein. Wittgenstein, together with the local instrument maker Charles Cooke, had designed and made jet engines to drive the kites higher, but there is no record in the detailed annual reports that they ever worked. Marsden was then put under the supervision of new recruit Geiger to learn about the preparation of radioactive sources. The Vienna Academy of Science had generously loaned a significant amount of radium for the joint use of Rutherford and Sir William Ramsay. Ramsay thought that the interests of science were best served if he kept all of the radium in his laboratory at University College, London, a delicate situation which was overcome by Rutherford's persuasive diplomacy, resulting in the further loan of 450 mg of radium bromide by Vienna which was sent directly to Manchester. The radium salt would have been refined sometime in the decade since Marie Curie's discovery of the element in 1898, from pitchblende mined from the area around Jáchymov in what is now the Czech Republic, but was then part of the Austro-Hungarian Empire. So it was fresh.

Robinson [3] adds "swift evasive action" and "purchase" as reasons why Rutherford retained the use of the radium for the rest of his life. The radium arrived in January 1908, was put into solution and the responsibility for its handling and use controlled by Rutherford himself, together with his old friend and fellow radiochemist, Bertran Borden Boltwood, of Yale, who was on a year's sabbatical in Manchester. Rutherford therefore took delivery of a radioactive source with a strength of about a quarter of a Curie or 10 billion Becquerels, powerful by any standards. There is a tendency to believe that all contemporary scientists were reckless with radioactivity, probably driven by the fact that Marie Curie's fatal leukaemia was almost certainly radiation induced and that her notebooks are still too radioactive to handle. But Rutherford, Boltwood and Geiger were "street-wise" about the dangers and as Marsden said in his speech in 1961 [7], the radium was kept and samples prepared in a shed outside the laboratory building, which itself was regarded as not a proper place to keep it. Perhaps just as important, the price of radium to hospitals at that time was £20 000 per gramme [8] so Rutherford's cache was worth several million pounds in today's money, and was one of the reasons for the spat between him and Ramsay. Despite the protective ownership, he still found it possible to loan some of it to the Manchester Royal Infirmary, for radiation therapy, continuing the close connection between physics and medicine in Manchester which began with Schuster, who started taking X-rays for medical purposes within weeks of Röntgen's discovery in 1895.

Marsden [7] enthused about the quality of Geiger as a supervisor and teacher. Robinson [3] does the same and also describes Geiger's role as "watch-dog over the research apparatus and jealous guardian" which he successfully balanced against his popularity and prestige. Robinson recalls the homily he received from Geiger as a battery of 2400 volts, housed in delicate glass test tubes was handed over with sorrow: "Never touch the battery connections while standing on the concrete floor! Always keep a dry wooden board to stand on whilst making adjustments! Always hold one hand behind your back whilst touching any part of the battery!" Then before Robinson had any chance to express gratitude for the gracious solicitude for his welfare, Geiger continued with solemnity and singleness of mind: "You see, if you get a bad shock, you may kick out before you realise what you are doing and the Prof (Rutherford) would not like it if some of the cells got broken."

For some time, Geiger and Marsden had been working together with α-particles and were experiencing difficulties in getting consistent results from their α-particle "firing-tube". This device was a $4\frac{1}{2}$ metre long glass tube, $1\frac{1}{2}$ inches wide, into which had been placed brass collimators, to "canalise" the α's, which emanated from a sample of radium at one end of the tube. The narrow collimated beam emerged from the other end. Geiger had already done calculations on what was called at the time "compound", and later "multiple" scattering of α's by atomic electrons and Rutherford thought that the problems with the tube might be caused by compound scattering off molecular protuberances. Whether Rutherford did an experiment himself or directed others to do it, the apparatus and procedure were designed with insight and foresight. The experiment itself had to be carried out with the utmost care, the results checked and double-checked and nothing must be missed.

Marsden, in the recorded version, tells how the original α-scattering experiment came about. "Marsden! It's time you did something properly." Rutherford had told him. "You go and see if you can find α-particles reflected from metals."

According to Marsden, Rutherford was worried by the technical difficulties in their α-experiments. It was not a hunch, but just something that annoyed him about the experimental arrangement and he thought it had better be exploited as to whether a reflection was actually taking place. It was this notion that a problem could be exploited that set Rutherford apart from others. In 1874, Schuster's predecessor, Balfour Stewart was supervising the student J. J. Thomson who was trying to measure the EMF of a cell using a deflection galvanometer. The results are written up in Stewart's handwriting in the daily notes of the teaching laboratory [9]. In the next room, student Mr. Morgan was a firing off a Ruhmkorff coil, thus wrecking Thomson's efforts to gain a consistent deflection of his galvanometer needle. Such a coil, later called a "spark coil" generated high-voltage (over 100 kV) pulses that could yield enormous sparks between terminals. That problem was solved by silencing Mr. Morgan's coil, instead of realising that Mr. Morgan could signal wirelessly that it was time for lunch and possibly discovering radio waves, 12 years before Heinrich Hertz. By worrying about a problem in a firing-tube, by taking the exploitation path, Rutherford, with the help of Geiger and Marsden, discovered the nucleus.

3 The crescendo of discovery

Marsden gathered samples of polished metals ranging from aluminium to lead and he and Geiger proceeded to fire α-particles at the surface, counting the reflections by the scintillation method. Let Marsden himself say what happened next [5]: "I knew full well that my number was up, colloquially, if there was any effect and I'd missed it, so I took special care to try and get it. To our amazement, within a few days, I found that α-particles could be reflected from a metal surface if only one had a strong enough source, because the number reflected was such a small proportion of those incident."

If it seems here that Marsden in 1961, might be stealing all the personal glory from the now dead Geiger and Rutherford, his version is confirmed by Robinson [3] who described in his

1942 Rutherford memorial lecture how "Rutherford's most fruitful contribution to general atomic physics arose directly out of the results of an experimental problem which had been given to Ernest Marsden, one of the first of the Manchester trainees." Robinson goes on to quote Rutherford himself: "I agreed with Geiger that young Marsden, whom he had been training in radioactive methods, ought to begin a research." Rutherford made a daily tour of the projects in the laboratory and in the afternoon, everyone sat round the laboratory tea-table [3], situated in the radio-activity training laboratory.

It was a period of relaxation and gossip, often becoming an informal colloquium with Rutherford, who provided the tea and biscuits, as well as taking charge.

It is certain that Rutherford would have been up to date with Marsden and Geiger's progress, knowing within minutes or hours what they had measured. If Marsden and Geiger were amazed by what they saw, they would have talked about it over tea. From their analysis, they told him that the observed effect varied with atomic weight like $A^{\frac{3}{2}}$ and not like $A^{\frac{1}{2}}$, as for compound scattering, and therefore whatever they were seeing had to be a different phenomenon. Rutherford instructed the two to round off the experiment in a form suitable for publication, which they quickly did. As Robinson pointed out [3], Rutherford was far from indifferent to questions of priority in discovery – he liked "to get in first" and to waste as little time as possible in doing it.

The dependence on $A^{\frac{3}{2}}$ needs some explanation and it was at the time, an empirical observation, demonstrated in this first paper. The eventual dependence of the scattering yield is understood today to be proportional to the atomic number squared, Z^2. At that time, it was believed that Z could be set equal to $A/2$ so this implies a $Z^{\frac{3}{2}}$ dependence in the data. The approximation was sufficient, given the quality of the data. The reason why a power law different from A^2 was observed was due to the fact that when large angle deflections occurred, the α's could interact and be reflected from any atoms in a thin layer at the surface of the metal. Some of these α's would be absorbed through energy loss according to the Bragg curve and this introduced an extra dependence on the square root of Z making the overall dependence appear to be according to a $\frac{3}{2}$ power law.

The amazement at the reflection of α-particles was later likened by Rutherford as if a 15-inch shell had been reflected by a sheet of tissue paper. The analogy, although striking, is a poor one in some respects since compound scattering ensured that the α's were absorbed, even though not reflected by a thin layer at the surface of the metal. A shell fired into a deep vat of treacle might be a better analogy although it is less evocative than a sheet of tissue paper.

The epoch-making paper "On a Diffuse Reflection of the α-Particles" was first presented at a meeting of the Manchester Literary and Philosophical Society (known as the Lit and Phil) and then read before a meeting of the Royal Society of London on 17th June 1909 by Rutherford himself [10] rather than Geiger or Marsden, since only Fellows of the Society could present papers at that time. The paper was essentially factual, with few conclusions made about possible new phenomena, nor were any theoretical comparisons put forward. The most striking point made by the authors (converting to modern units) was that a mere 0.6 micrometres of gold was able to deflect some of the α-particles by more than 90°, an effect which would require a magnetic field of 10000 tesla. This was a profound statement and presaged the eventual need to introduce a new force of nature into the understanding. The comparison with a large magnetic field sent out a powerful message, although few at the time understood it. It was, in any case erroneous as Rutherford's subsequent interpretation showed. At the time, (gold) atoms were regarded as rather homogeneous and only a magnetic field could send the charged α's on a circular path and hence reverse their direction of motion. A uniform electric field, such as that in Thomson's plum pudding model for the atom, could only deflect charged particles sideways but not backwards. Moreover, Geiger had calculated that the most probable angle of deflection by compound scattering off electrons in this thickness of gold would be less than one degree. The distribution of this probability gave a vanishingly small chance that a deflection of 90° or more could occur by this mechanism, whereas the measured frequency was 1 in 20000. The paper concluded with some remarks on its original motivation namely that some α-particles at grazing incidence were indeed deflected by the surface and hence the output beam from the firing-tube contained not only particles that had traversed the tube directly, but also some that had bounced off the walls.

It was about this time that Geiger and Rutherford posed in the laboratory for this famous photograph (fig. 3). The version here is digitised from an original sepia print on the back of which is written " From the estate of H. R. Stansfield" (see fig. 1 for Stansfield).

Rutherford went away to think and spent the rest of 1909 and the whole of 1910 on the problem. In February 1911, he presented his interpretation to the Manchester Lit and Phil, before submitting a full version of his paper "The Scattering of α and β particles by Matter and the Structure of the Atom" to the *Philosophical Magazine* [11].

In this paper of 19 pages, Rutherford presented the theory of what is now known as "Rutherford Scattering".

He deduced that the atom was the seat of an intense electric field, which could cause a large angle deflection of an α-particle in a single atomic encounter,

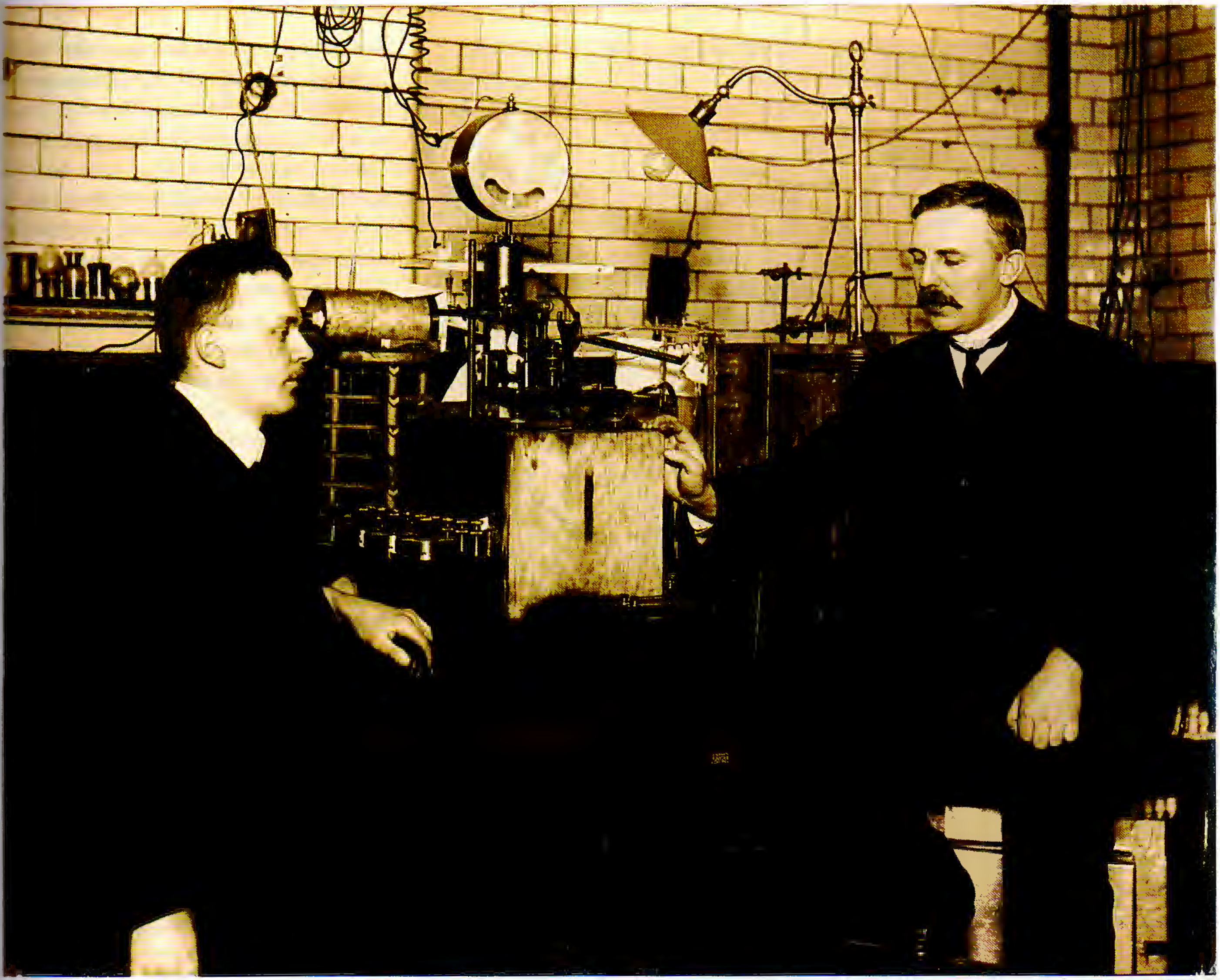

Fig. 3 Hans Geiger and Earnest Rutherford pose with equipment in the Manchester Physical Laboratories, circa 1910.

and not via compound scattering.

He showed that the data were consistent with a model of the atom, which had a positive charge *of* Ne *in a small region at the centre of the atom, and a negative* charge $-Ne$ distributed uniformly throughout the whole of atomic volume. He calculated that an α-particle travelling at 2.09×10^9 cm s^{-1} towards an atom with $N = 100$, would come to rest at a distance of 34 fm from the central charge before being turned back. The distance of 34 fm is significant because Rutherford's theory which described the data was based on scattering by an electric force between two points separated by a distance r, varying like $1/r^2$ (Coulomb). This meant that any deviation from a point nucleus had to be much less than 34 fm and in addition, although unknown to anyone at the time, the nuclear force could also not contribute, being confined within a radius of less than 8 fm in gold.

But Geiger and Marsden had made measurements on a range of metals from lead to aluminium. For aluminium, with an atomic number of 13, the α-particles would have got to within 4.4 fm of the centre of the atomic nucleus, which we now know to have a nuclear radius of some 3.4 fm. Of the large-angle deflections, those defined to be 90° or more, only a very small number would have been scattered by as much as 180° and so the presence of the nuclear force and its potentially huge effect, remained tantalisingly just out of reach.

By 1911, Marsden had graduated and was taken on as a research fellow. He continued to work with Geiger and the two of them, at the suggestion of Rutherford, carried out a systematic study of large-angle α-scattering, extending the range of targets down to carbon and varying the α velocity. Rutherford had produced his new theory on the basis of a small but nevertheless compelling amount of data. The theory had predictive power and the next step was to broaden the scope of the measurements and put the theory to the test. On carbon, the distance of closest approach would now be only 2 fm, less than the carbon nuclear radius of 2.6 fm. The substantial paper was published in the *Philosophical Magazine* in 1913 [12] and also communicated to the Academy of Science in Vienna, a courteous recognition of their radium loan. The experiment was a spectacular success and the summary in the paper lists five tests that Rutherford's theory passed when confronted with the systematic survey of data:

(1) The distribution of the scattering angle ϕ was found to be $1/\sin^4(\phi/2)$.
(2) The number of scattered particles was proportional to target thickness.
(3) The scattering per atom varied with the square of atomic weight.
(4) The amount of scattering was approximately proportional to the inverse fourth power of the α velocity.
(5) The number of elementary charges at the centre of the nucleus is equal to half the atomic weight.

It lay in the future to be established that item 5 and hence item 3 here, were only approximate. An interesting question is whether Geiger and Marsden in this experiment, saw or could have seen the effect of the nuclear force in their carbon data. They assert that within experimental error (table VI in their paper) that the data from gold to carbon were consistently proportional to the $A^{\frac{3}{2}}$. Rutherford's theory gives a Z^2 ($\simeq A^2$) dependence and if in addition, a correction of $\sqrt{A}$ is applied in accordance with contemporary knowledge of the Bragg curve, this gives $A^{\frac{3}{2}}$. Even numerically correcting the data by scaling from A^2 to Z^2 does not change the original conclusion. Although the carbon result is suspiciously high, 30% higher than the trend, gold is abnormally low by about 20%. The most we can say with hindsight is that the nuclear force was not recklessly overlooked in the data and was buried in experimental error and possible uncertainties in the Bragg correction.

Although his income was prodigious by the English University norms of the day, Rutherford did not emulate his predecessor with an obsession with gadgets. He bought a car, but did not compete with Schuster's Rolls-Royce which could be seen parked around the University, despite its owner's retirement. In the photograph here, (see fig. 4) which is the left half of a stereo pair, Rutherford is wearing identical clothes and shoes to the ones in the dual portrait with Geiger (fig. 3). Even his tie and fob watch and chain are identically placed. Whether he always dressed so precisely or this was the day the laboratory portrait with Geiger was taken, history does not record.

4 New variations

The legacy of these experiments was taken by Rutherford to Cambridge, along with his radium, when he left Manchester in 1919. Former Manchester student James Chadwick joined Rutherford's new team and was immediately put to the task of refining Geiger and Marsden's work especially using targets of lighter atoms. In 1921, Chadwick and a rising star of Canadian physics, Etienne Bieler, on leave from McGill, measured the scattering of α-particles by hydrogen [12], thus ensuring a short-range interaction for large-angle scatters. A spectacular large angle deviation from what was expected on the basis of Rutherford's Coulomb scattering theory was clearly seen, both in the angular distribution and the number of scattered particles, which were "many times greater than for point nuclei". Not yet having enough information to introduce the concept of a new force of nature, the interpretation converged on the shape of the charged nucleus, an oblate spheroid being the favoured choice. In the final discussion, Chadwick and Bieler declared: "The present experiments do not seem to throw any light on the nature of the law of variation of the forces at the seat of an electric charge, but merely show that the forces are of very great intensity".

It was another six years before Chadwick, this time with Rutherford himself, addressed the problem again. Bieler in the meantime had returned to McGill and was on secondment with a geophysical expedition to Australia when he was fatally stricken with pneumonia in 1929. The new experiment had an ingenious double concentric array of circular graphite collimators, which not only defined the scattering angle but also the fiducial volume of scattering material, in this case helium gas. The results [13] confirmed the violation of Coulomb scattering, although the focus of discussion was still on the shape of the nuclear charge or the presence of magnetic effects and not on a new force. Nevertheless, Rutherford and Chadwick concluded with the remark: "At close distances, very strong additional forces come into action." The notion of the "strong force" had entered the language of nuclear physics for the first time.

The sequence of events was now complete. Marsden, supervised by Geiger had started it off by finding an unexpectedly large amount of wide-angle scattering [10]. Within two years, Rutherford came up with a theory which is still valid today [11]. The theory can be derived using classical or quantum mechanics, largely because a fortuitous choice of a spinless particle (the α) was forced on them. Geiger and Marsden then confirmed all the hitherto untested predictions of the theory [14]. A decade later, first Chadwick and Bieler [12] and then Rutherford and Chadwick [13] carried out precisely the same experiment using precisely the same source of α-particles that was used in Manchester, but with refined apparatus, to extend the measurements to the very lightest elements, helium and hydrogen, thus finding the region where Rutherford's theory failed and at the same time, bringing the strong force into physics knowledge.

The specific character of this experimental technique and the specific route to discovery – wide-angle scattering – has been used over and over again in nuclear and particle physics to this day. The means by which partons, (quarks and gluons) were discovered as constituents of the proton and neutron was essentially the same, with an electron beam being used instead of α-particles.

The kinematic variables used in deep inelastic scattering appear daunting to the newcomer and one such variable, *y*, is used in order to simplify the theoretical expressions for the scattering probability. In words, it is known as the fractional energy loss of the incoming particle, which is an electron in deep inelastic scattering or an α in the case of Rutherford scattering. There is a direct connection between *y* and figure 1 in Rutherford's paper [11], which was reproduced, gold plated, on the front cover of the Jubilee Conference commemorative session proceedings [5]. In this diagram, shown in fig. 5 here, for heavy nuclei like gold, the angle ϑ is related to *y* by the simple equation $y = \frac{1}{2}(1 + \cos 2\vartheta)$. For no deflection $\vartheta = 90°$ and $y = 0$. For a maximum deflection of 180° in the laboratory frame, $\vartheta = 0°$ and $y = 1$.

Fig. 4 Earnest Rutherford standing outside his house in Wilmslow Road, Manchester with his new 15 horsepower Wolseley-Siddeley.

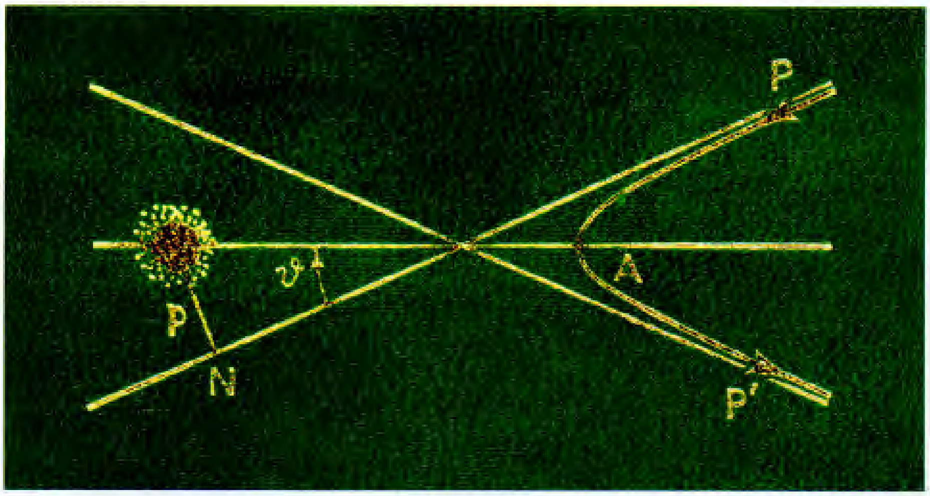

Fig. 5 Figure 1 from Rutherford's paper as reproduced in gold on the front cover of the Jubilee Conference proceedings.

5 Finale

In going down in history as the cradle of nuclear physics, Manchester has itself to thank in the sense that the University's governing body agreed to entice Rutherford with a large salary and then funded his research unconditionally with an annual equipment grant of £420, about £80000 in modern terms. Robinson [3] regarded this amount as modest and was also at pains to mention that the salaries of junior staff (£120 to £150 per annum) were low, especially since the word "junior" was interpreted elastically. It is a recent fad of government funding of science in Britain to make a component of the funding dependent on the *a priori* subjective assessment of the perceived beneficial impact of the research outcome on society. Had such a scheme been in operation in the past, the discoveries of the electron and the atomic nucleus, the structure of DNA and the invention of the World Wide Web would not have met this funding criterion in Britain. Yet most of these now underpin the economies of the world.

J. J. Thomson, one of the many sons of Manchester, made a short film in 1934 for the Institution of Electrical Engineers [15], discussing the role of the electron in the context of the economic depression of the time and the serious unemployment: "Any new discovery contains the germ of a new industry. The great electrical firms in America instruct the members of their research department to discover something, no matter what, and to leave to another department the business of making money out of it. Experience shows that that department generally does. Scientific discoveries are a very efficient way of creating employment and it is in laboratories rather than in Houses of Parliament, that a cure (for unemployment) will be found." The same can be said about the nucleus, which was discovered as a result of Rutherford becoming annoyed by the performance of his α-particle firing-tubes. France currently generates 80% of its power from nuclear sources and is a net exporter of energy. Britain, a net importer of energy, generates 20% of its power from the nucleus. Thomson's assessment of the connection between discovery and employment was perfect.

Not only did Geiger, Marsden and Rutherford change the face of physics, but also they did it in an atmosphere of joy despite working in a city that did not always appeal to outsiders in those grim times, as Mark Twain pondered: "I would like to live in Manchester, England. The transition between Manchester and death would be unnoticeable." Whereas Rutherford, in a letter he wrote to Geiger on the 2nd September 1932, enthused [16] : "They were happy days in Manchester and we wrought better than we knew."

References

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