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Recollections of Nuclear Physics in the Early Nineteen Thirties

E.T.S. Walton, Dublin

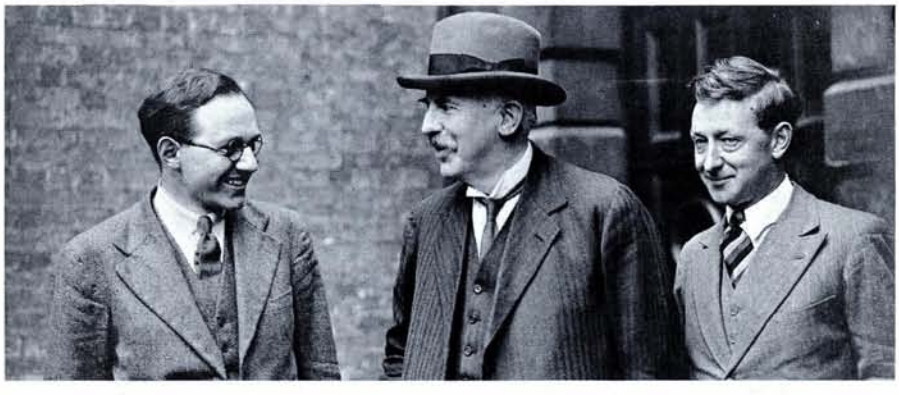
(Trinity College, University of Dublin)

In the last five years of the last century, some remarkable discoveries in physics were made, namely, X-rays, radioactivity, the electron and the quantum. These gave rise to the new subjects of atomic and of nuclear physics. Studies of the properties of radioactive substances led Rutherford and Soddy to the theory that the decay of a radioactive substance produced a transmutation of one element into another. In 1911, Rutherford, who had played a leading part in these investigations, saw that in order to explain the scattering of α-particles it was necessary to make the novel assumption of the nuclear model of an atom. In 1919, he showed that the bombardment of nitrogen by α-particles could eject fast protons which meant that nitrogen was being transmuted into another chemical element. Thus Rutherford may justly be called the father of nuclear physics. In that same year (1919) Rutherford moved from Manchester to Cambridge to follow J.J. Thomson as director of the Cavendish Laboratory. It was there that Thomson had discovered the electron and Aston had developed the mass spectrometer and was making precision measurements of the masses of the isotopes of many of the chemical elements. It was there also that C.T.R. Wilson had developed his cloud chamber to such an extent that beautifully clear pictures could be obtained of the paths of individual ionizing particles. Research of this quality and Rutherford's fame attracted to the laboratory able young physicists from many countries. So the stage was set for a continued advance in the new subject of nuclear physics, which even at that time was generally referred to as atomic physics.

It was my good fortune to be admitted to the Cavendish Laboratory in 1927 as a research student. At that time, space, equipment and facilities were very inadequate for the number of research workers. Nevertheless excellent research was being carried out in areas such as the details of the α, β and γ-ray spectra of radioactive substances and of the properties of these radiations. Chadwick, who had come to Cambridge with Rutherford, and also others were investigating the details of the disintegration of various elements by α-particle bombardment. These experiments were at that time tedious and not very accurate because the counting of the number of ejected protons depended on the visual observation of scintillations produced in a willemite screen. They yielded some rough values of the energy levels in nuclei but in two respects the results were disappointing. Only some elements could be disintegrated by the available α-particles and only one type of disintegration was found to occur, namely, the alpha-proton type in which an α-particle enters a nucleus and a proton is ejected.

It was obviously desirable to have beams of fast particles of various sorts available, preferably in numbers greater than were emitted from radioactive sources and preferably of energies greater than those of natural α-particles. There would be no difficulty in getting large numbers of particles since a beam of only one microampere of helium is, in this respect, equivalent to the total α-particle emission of about 100 g of radium. But to give to ions energies comparable with those of natural α-particles would require the use of accelerating potentials of some millions of volts. Such potentials would have to be housed in a very large room and no vacuum tubes had been developed which would withstand potentials of more than about one tenth of such voltages. Because of these difficulties, people began to think about possible methods of overcoming them or about in-

E.T.S. Walton (left) who shared the 1951 Nobel Prize for physics with J.D. Cockcroft (right) on either side of Ernest Rutherford in 1932.



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direct or trick methods which would avoid the use of high voltages.

I was one of such people and on starting to work as a research student at Cambridge, suggested to Rutherford the idea of accelerating electrons by letting them move many times round in a circular electric field as in the modern betatron. The suggested method of producing such a field was not very practicable. Rutherford pointed out that the time required was too long and stray fields would have time to cause particles to fly off the orbit. He suggested the use of a high frequency current in a circular coil. As he indicated, this would be much the same arrangement as used by J.J. Thomson in his work on the electrodeless discharge in gases. I used the only source of high frequency current then available to me, namely the trains of damped oscillations obtained from spark discharges. It was hoped that the alternating magnetic field combined possibly with a steady uniform magnetic field would constrain the electrons to move along the lines of the circular electric field. However no trace of evidence was found for the presence of fast electrons.

Calculations showed that a uniform oscillating magnetic field was twice too strong to maintain electrons on the circular orbit and so they would spiral into the centre. The situation was even worse in the experimental arrangement used because the magnetic field increased on moving out in the radial direction. Detailed calculations showed radial stability could be produced by a magnetic field falling off inversely with radial distance if a suitable high frequency radial electric field was also present. Experiments along these lines failed because the arrangements used were too crude and no provision was made for stability in the axial direction. When I suggested this method to Rutherford I was unaware that just about two weeks previously in his presidential address to the Royal Society, he had stressed the importance of developing methods of producing particles of energies greater than α and β-particles. So perhaps he was glad to find someone anxious to work in this difficult new field! I was lucky that my suggestion was made at an opportune time.

In December 1928, I suggested to Rutherford another method for the production of fast particles. It was the method now called the linear accelerator in which a high frequency voltage is applied to alternate members of a line of cylinders. Rutherford did not appear to have heard of the principle but some rapid simple calculations which he made convinced him of its feasibility. Experiments on the method were not successful for two reasons. Only spark-produced high frequency currents were available and very little was known about the focussing of a beam of particles at a succession of gaps. Indeed, the ends of cylinders were covered with gauze in order to secure a field-free space inside the cylinders and this removed the focussing action now known to occur.

Late in 1928, an important paper by R. Wideroe appeared in which he described experiments to verify the principle of accelerating electrons in the circular electric field produced by the changing magnetic flux in the core of a transformer. He was able to follow electrons 1½ times round the circle. This was not the first publication of the betatron principle as Slepian had taken out a United States patent on the method in 1922. Wideroe's paper also contained a reference to a little known paper by G. Ising which was published in 1924 in a Swedish journal. In it, Ising proposed the acceleration of particles in the gaps between a succession of cylinders at which the potentials were to be obtained from a spark gap connected to the various cylinders by suitable delay lines.

Wideroe's paper was also of importance in another respect. It was responsible for drawing Lawrence's attention to the problem of accelerating particles to high velocities. He came across the paper accidentally while browsing through journals in search of ideas for a new line of research. The result was that by 1931 he and Sloan were able to report the production of mercury ions of 1.26 MeV in a linear accelerator using a potential of only 42 kV. The potential limit imposed by the capacity of the cylinders led Lawrence to invent the cyclotron which in effect uses the same pair of cylinders over again many times.

The disintegration of elements by artificially accelerated particles did not have to await the development of accelerators using various indirect methods. In 1928 Gamow and, independently, Condon and Gurney applied the then new wave mechanics to account for the details of the emission of α-particles from radioactive bodies. The theory explained the statistical character of the emission and the well-known relation betwenn the energy of the α-particles emitted and the half-life of the body. In January 1929, Gamow gave a lecture on the theory in Cambridge and Cockcroft saw that the theory could be applied in reverse to the penetration of charged particles into the nuclei of atoms. Calculations showed that protons of quite moderate energies had a reasonable chance of penetrating into the interior of light nuclei and if they did so, disintegrations might be expected to follow in many cases. Estimates showed that a few microamperes of protons accelerated by a few hundred thousand volts should produce an ample number of disintegrations in light elements for easy observation.

Cockcroft showed these results to Rutherford who agreed that the theory should be tested experimentally and that Cockcroft and I should work jointly in this new area. It was obvious that the most suitable high voltage generator would be one giving a steady potential, as a continuous beam of particles all of the same energy would be produced. At that time one reliable type was available, namely, a power frequency transformer with its output rectified by thermionic valves and smoothed by a capacitor. An output of 300 kV was planned, it being thought that a single accelerating tube could be built to withstand this voltage. Two similar continuously pumped tubes could then be used in series as a rectifier which would withstand the back voltage of 600 kV. Shortly after the building of this was completed, a large lecture theatre became available and it was decided to move into this and to build a generator to produce voltages approaching 800 kV. A special voltage multiplying circuit was used which enabled the four rectifiers used to be stacked to form a column 3.6 m tall, all of them being pumped continuously by a single diffusion pump at ground level. The apparatus produced a voltage of 700 kV but most experiments did not require so high an output. To detect disintegrations, a fluorescent screen was placed inside the vacuum, this being for more than two decades the standard method of observing the emission of fast protons and α-particles.

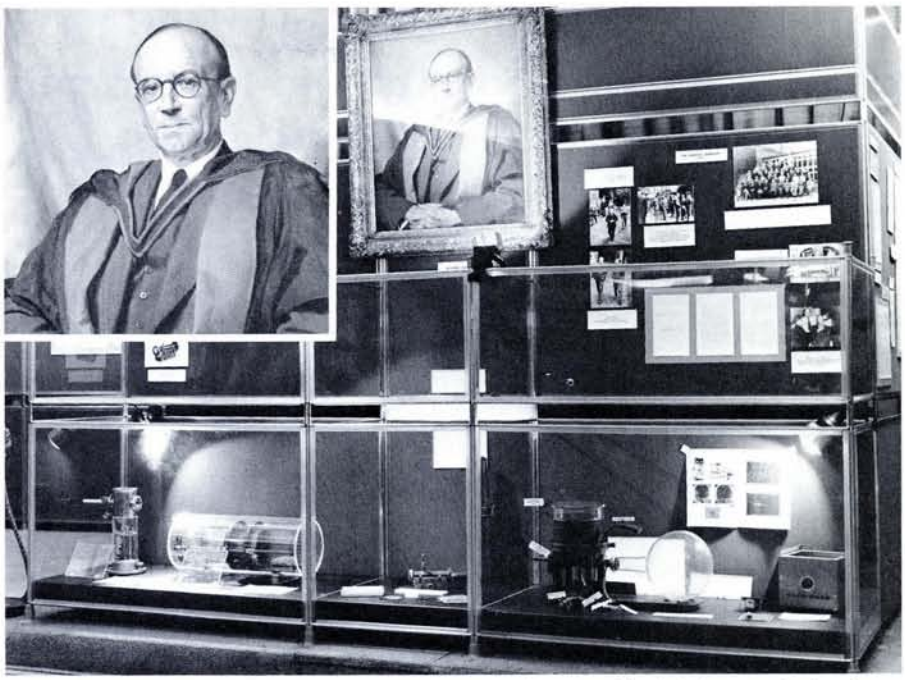
On the morning of 14 April 1932, I carried out the usual conditioning of the apparatus. When the voltage had risen to about 400 kV, I decided to have a look through the microscope which was focussed on the fluorescent screen. By crawling on hands and knees to avoid the high voltage, I was able to reach the bottom of the accelerating tube. To my delight, I saw tiny flashes of light looking just like the scintillations produced by α-particles which I had read about in books but which I had never previously seen. After making some simple tests to ensure that I was not imagining things, I phoned Cockcroft who was at that moment doing something for Kapitza. He came immediately and satisfied himself that he too was observing genuine disintegrations. Rutherford was informed and very soon came to see for himself — he always became much more interested when new results were being obtained.

We manouvered him into the small hut which we had built under the accelerating tube to protect us from the high voltages and the X-rays produced in the apparatus. After giving instructions about the voltages and currents to be used, he told us to switch off. He came out of our hut and spoke along the following lines:-"Those scintillations look mighty like α-particle ones and I ought to be able to recognise an α-particle scintillation when I see one. I was in at the birth of the α-particle and I have been observing them ever since". This was good news to hear from so eminent a person. Indeed he might have added that he was in at their christening for it was he who

gave them their name. Rutherford always had a great affection for α-particles. By their use he made his two greatest discoveries, namely, the nuclear structure of atoms and the disintegration of nitrogen. After observing the artificially produced α-particles, he bound us to secrecy and it was agreed that we would not tell anyone inside or outside the laboratory about the results. This was a wise precaution for it enabled us quickly to carry out various experiments without being interrupted by people wanting to see the scintillations or to discuss the results. Within a few days we were able to get more information such as the range of the particles and the appearance of their tracks in a Wilson cloud chamber.

In the following months the lithium disintegrations were investigated in detail. The simultaneous emission of two α-particles in opposite directions was checked by placing fluorescent screens on opposite sides of a thin lithium target. Both of us observed the scintillations and every time one of us saw a scintillation a mark was made on a moving paper tape. A study of the tape showed that there were definitely more coincidences than would occur by pure chance. We claimed this arrangement to be the first coincidence counter! At that time electrical counters were replacing visual counting and we were fortunate to get the use of an amplifier built by Wynn-Williams who played an important part in the development of this new technique. Further work involved the disintegration of other light elements by protons and by deuterons when heavy hydrogen became available. Very good pictures of the tracks of the emitted particle in a cloud chamber were obtained with the help of P.J. Dee who was an expert in this area. In 1934 the Curie-Joliots produced a radioactive isotope of nitrogen by α-particle bombardment of boron. We were able to produce the same isotope by bombarding carbon with protons.

The year 1932 was the notable start of an exciting period for those working on nuclear physics. In February, Chadwick working in the Cavendish Laboratory discovered the neutron and Urey discovered heavy hydrogen. In 1933 Anderson discovered the positive electron and Blackett working in the Cavendish Laboratory followed this up with a counter-controlled expansion chamber which gave information about positive electrons much more rapidly. Shortly after the disintegration of lithium by fast protons had been achieved, Rutherford got Oliphant to drop his work on positive ions and build an accelerator which would produce up to 200 keV particles in larger numbers than were previously available. With this apparatus Rutherford and Oliphant discovered two new isotopes, tritium and helium of mass 3 units and obtained precise values for their masses. By 1932, Lawrence had his 23 cm cyclotron in working order and was able to confirm and extend the disintegration results which had been reported.



The fiftieth anniversary of the discovery of the neutron by Sir James Chadwick was marked at the annual Conversaziones of The Royal Society in London in May and June of this year by an exhibition organised by Oxford University in collaboration with AERE, Harwell. In the photograph of the central stand can be seen (left) equipment used by Böthe in Heidelberg and (right) a Wilson cloud chamber of the period and, in the centre, Chadwick's own apparatus surmounted by his portrait (see also inset) that normally hangs in Gonville and Caius College, Cambridge. The Institute of Physics was commemorating the occasion by organising in Cambridge on 13-17 September, a conference on "The Neutron and its Applications", that was sponsored by the EPS. (Photo AERE)

The development of the Cavendish accelerator took about three years. When one looks at the well known photograph of it, one may be surprised that an apparatus which looks so simple should have taken so long to build. It took time to find a design of vacuum tubes which would withstand the high voltages applied to the rectifiers and accelerating tube. The finances of Cavendish Laboratory at that time were quite inadequate for the amount of research being done. Research students had to improvise and build their apparatus often from scrap materials. There was a chronic shortage of equipment. Even simple things like ammeters and voltmeters were in very short supply.

The disintegration of lithium by protons can be observed using quite low potentials, even down to less than 20 kV. The experiments could thus have been carried out more than a decade earlier, but no reputable physicist would have tried it, for it was well known that nuclear potential barriers were some millions of volts high. If anyone had dared to try the experiment, his scientific reputation would have been ruined at least temporarily. So we can conclude that it may sometimes be worth while to try a foolish experiment provided that it can be done without much waste of time and provided that it is carried out behind locked doors!