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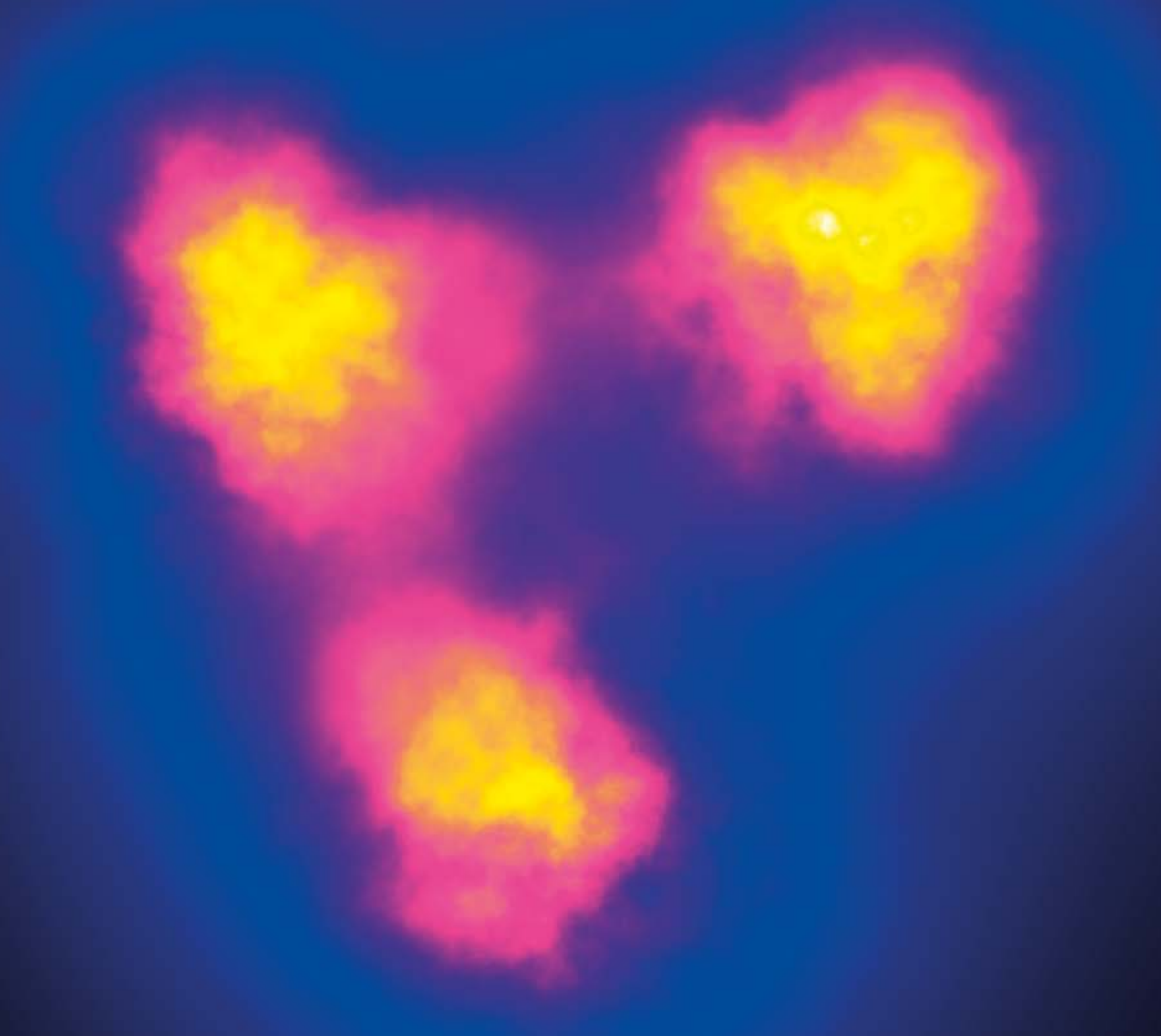

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RUTHERFORD, TRANSMUTATION AND THE PROTON

The events leading to Ernest Rutherford's discovery of the proton, published in 1919.

Artist R Mathews; McGill University

Nuclear giant *Ernest Rutherford in Canada in 1907.*

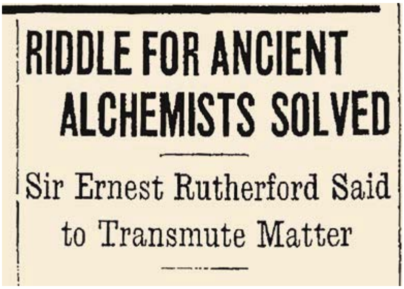
In his early days, Ernest Rutherford was the right man in the right place at the right time. After obtaining three degrees from the University of New Zealand, and with two years' original research at the forefront of the electrical technology of the day, in 1895 he won an Exhibition of 1851 Science Scholarship, which took him to the Cavendish Laboratory at the University of Cambridge in the UK. Just after his arrival, the discoveries of X-rays and radioactivity were announced and J J Thomson discovered the electron. Rutherford was an immediate believer in objects smaller than the atom. His life's work changed to understanding radioactivity and he named the alpha and beta rays.

In 1898 Rutherford took a chair in physics at McGill University in Canada, where he achieved several seminal results. He discovered radon, demonstrated that radio-activity was just the natural transmutation of certain elements, showed that alpha particles could be deviated in electric and magnetic fields (and hence were likely to be helium atoms minus two electrons), dated minerals and determined the age of the Earth, among other achievements.

In 1901, the McGill Physical Society called a meeting titled "The existence of bodies smaller than an atom". Its aim was to demolish the chemists. Rutherford spoke to the motion and was opposed by a young Oxford chemist, Frederick Soddy, who was at McGill by chance. Soddy's address "Chemical evidence for the indivisibility of the atom" attacked physicists, especially Thomson and Rutherford, who "... have been known to give expression to opinions on chemistry in general and the atomic theory in particular which call for strong protest." Rutherford invited Soddy, who specialised in gas analysis, to join him. It was a short but fruitful collaboration in which the pair determined the first few steps in the natural transmutation of the heavy elements.

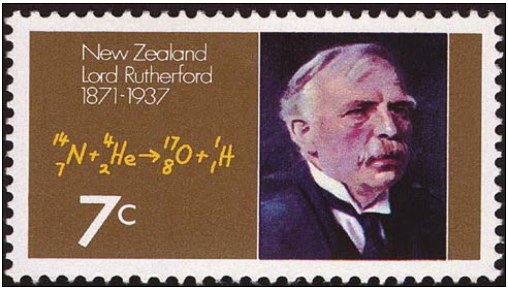
Manchester days

For some years Rutherford had wished to be more in the centre of research, which was Europe, and in 1907 moved to the University of Manchester. Here he began to follow up on experiments at McGill in which he had noted that a beam of alpha particles became fuzzy if passed through air



RIDDLE FOR ANCIENT ALCHEMISTS SOLVED

Sir Ernest Rutherford Said to Transmute Matter



Atomic history *How the* Boston Globe *reported the discovery of the proton on 8 December 1919 (left), and a commemorative New Zealand stamp from 1971 (right).*

or a thin slice of mica. They were scattered by an angle of about two degrees, indicating the presence of electric fields of 100 MV/cm, prompting his statement that "the atoms of matter must be the seat of very intense electrical forces".

At Manchester he inherited an assistant, Hans Geiger, who was soon put to work making accurate measurements of the number of alpha particles scattered by a gold foil over these small angles. Geiger, who trained the senior undergraduates in radioactive techniques, told Rutherford in 1909 that one, Ernest Marsden, was ready for a subject of his own. Everyone knew that beta particles could be scattered off a block of metal, but no one thought that alpha particles would be. So Rutherford told Marsden to examine this. Marsden quickly found that alpha particles are indeed scattered – even if the block of metal was replaced by Geiger's gold foils. This was entirely unexpected. It was, as Rutherford later declared, as if you fired a 15 inch naval shell at a piece of tissue paper and it came back and hit you.

One day, a couple of years later, Rutherford exclaimed to Geiger that he knew what the atom looked like: a nuclear structure with most of the mass and all of one type of charge in a tiny nucleus only a thousandth the size of an atom. This is the work for which he is most famous today, eight decades after his death (*CERN Courier* May 2011 p20).

Around 1913, Rutherford asked Marsden to "play marbles" with alphas and light atoms, especially hydrogen. Classical calculations showed that an alpha colliding head-on with a hydrogen nucleus would cause the hydrogen to recoil with a speed 1.6 times, and a range four times, that of the alpha particle that struck it. The recoil of the less-massive, less-charged hydrogen could be detected as lighter flashes on the scintillation screen at much greater range than the alphas could travel. Marsden indeed observed such long-range "H" particles, as he named them, produced in hydrogen gas and in thin films of materials rich in hydrogen, such as paraffin wax. He also noticed that the long-ranged H particles were sometimes produced when alpha particles travelled through air, but he did not know where they came from: water vapour in the gas, absorbed water on the apparatus or even emission from the alpha source, were suggested.

Mid-1914 bought an end to the collaboration. Marsden wrote up his work before accepting a job in New Zealand. Meanwhile, Rutherford had sailed to Canada and the US to give lectures, spending just a month back at Manchester before heading to Australia for the annual meeting of the British Association for the Advancement of Science. Three days before his arrival, war was declared in Europe.

Splitting the atom

Rutherford arrived back in Manchester in January 1915, via a U-boat-laced North Atlantic. It was a changed world, with the young men off fighting in the war. On behalf of the Admiralty, Rutherford turned his mind to one of the most pressing problems of the war: how to detect submarines when submerged. His directional hydrophone (patented by Bragg and Rutherford) was to be fitted to fleet ships. It was not until 1917 when Rutherford could return to his scientific research, specifically alpha-particle scattering from light atoms. By December of that year, he reported to Bohr that "I am also trying to break up the atom by this method. – Regard this as private."

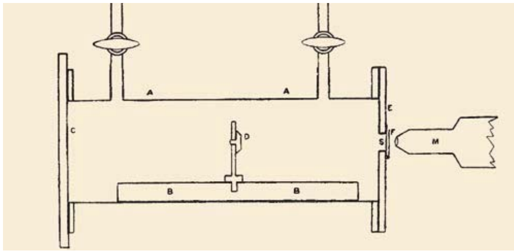
He studied the long-range hydrogen-particle recoils in several media (hydrogen gas, solid materials with a lot of hydrogen present and gases such as CO_2 and oxygen), and was surprised to find that the number of these "recoil" particles increased when air or nitrogen was present. He deduced that the alpha particle had entered the nucleus of the nitrogen atom and a hydrogen nucleus was emitted. This marked the discovery that the hydrogen nucleus – or the proton, to give it the name coined by Rutherford in 1920– is a constituent of larger atomic nuclei.

Marsden was again available to help with the experiments for a few months from January 1919, whilst awaiting transport back to New Zealand after the war, and that year Rutherford accepted the position of director of the Cavendish Laboratory. Having delayed publication of the 1917 results until the war ended, Rutherford produced four papers on the light-atom work in 1919. In the fourth, "An anomalous effect in nitrogen.", he wrote "we must conclude that the nitrogen atom disintegrated … and that the hydrogen atom which is liberated formed a constituent part of the nitrogen nucleus." He also stated: "Considering the enormous intensity of the forces brought into play, it is not so much a matter of surprise that the nitrogen atom should suffer disintegration as that the α particle itself escapes disruption into its constituents".

In 1920 Rutherford first proposed building up atoms from stable alphas and H ions. He also proposed that a particle of mass one but zero charge had to exist (neutron) to account for isotopes. With Wilson's cloud chamber he had observed branched tracks of alpha particles at the end of their range. A Japanese visitor, Takeo Shimizu, built an automated Wilson cloud chamber capable of being expanded several times per second and built two cameras to photograph the tracks at right angles. Patrick Blackett, after graduating in 1921, took over the project when Shimizu returned to Japan. After modifications, by 1924 he had some 23,000 photographs showing some 400,000 tracks. Eight were forked, confirming Rutherford's discovery. As Blackett later wrote: "The novel result deduced from these photographs was that the α was itself captured by the nitrogen nucleus with the ejection of a hydrogen atom, so producing a new and then unknown isotope of oxygen, ^{17}O."

As Blackett's work confirmed, Rutherford had split the atom, and in doing so had become the world's first successful alchemist, although this was a term that he did not like very much. Indeed, he also preferred to use the word "disintegration" rather than "transmutation". When Rutherford and Soddy realised that radioactivity caused an element to naturally change into another, Soddy has written that he yelled "Rutherford, this is transmutation: the thorium is disintegrating and transmuting itself into argon (sic) gas." Rutherford replied, "For Mike's sake, Soddy, don't call it transmutation. They'll have our heads off as alchemists!"

In 1908 Rutherford had been awarded the Nobel Prize in Chemistry "for his investigations into the disintegration of the elements, and the chemistry of radioactive substances".



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Experimental sketch *Rutherford's apparatus for splitting the atom, showing the alpha emitter (D), which could be slid along B; metal absorbers equivalent to the stopping power of about 5 cm of air (S); and the ZnS scintillation screen (F).*

There was never a second prize for his detection of individual alpha particles, unearthing the nuclear structure of atoms, or the discovery of the proton. But few would doubt the immense contributions of this giant of physics. ●

Further reading

J Campbell 1999 *Rutherford Scientist Supreme* (AAS Publications).

A Romer 1997 *Am. J. Phys.* **65** 707.

E Rutherford 1919 *Philos. Mag.* **37** 581.

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