

### Comments on and criticism on the content of the paper

1 Let me start with a quote from **Mr Krivit's paper**:

“According to the myth, Rutherford bombarded nitrogen nuclei with energetic alpha particles, and in doing so, became the world's first successful alchemist, changing the element nitrogen into the element oxygen.”

Dealing with this first, it is not a myth, it is true and I shall re-write it:

2 “According to all known facts, **Rutherford bombarded nitrogen nuclei with helium nuclei and observed the production of hydrogen nuclei and noting with surprise that the main recoil nucleus behaved more like oxygen than nitrogen, thereby irrefutably demonstrating nuclear transmutation, changing one element into another and becoming the world's first successful alchemist.**”

3 **One can add that he also showed that the hydrogen nuclei (protons) did not come from the  $\alpha$ s** which he had already recognised as being unusually stable, nor from the radioactive source itself, a possibility not excluded by Marsden and Lantsberry's 1913–1914 experiments.

The next fundamental flaw in Krivit's paper is to confuse and make no distinction between the actual physical process that was happening (determined by the way the universe behaves) and what Krivit erroneously thinks that some people were thinking at the time was happening (wrong physics). Krivit even gets the wrong physics wrong.

It is instructive to draw a comparison with two other revolutionary discoveries in physics:

- 1) The parton structure of nucleons via deep inelastic scattering.
- 2) The discovery of the  $J/\psi$  particle.

Both discoveries earned the recognition of a Nobel prize and were unarguably credited to their initial discoverers. And yet at the time, in the case of 1) it was thought that the scattering was just off three charged valence quarks. Only later did the full understanding of the relative roles of valence quarks, sea quarks and gluons become clear. But quite rightly, no credit was taken from the initial pioneers who fully understood the importance and impact of their discovery. Similarly, in the case of the  $J/\psi$ , there was much debate at the time as to what the narrow resonance was and only later was it recognised to be a quark-antiquark bound state. But both Sam Ting and Burt Richter knew the huge importance of the demonstration of new physics. Today, nobody qualifies the discovery by saying that they didn't know completely what it was at the time.

4 Likewise, Rutherford knew what was happening and that he had changed one element into another. That is irrefutable.

5 It is also not true, despite Krivit's wrong assertion, that Rutherford did not observe the oxygen nucleus. He not only recorded the final state nucleus, which was expected to be nitrogen, but made the "surprising observation" that its range (determined by atomic number and velocity) made it look more like oxygen.

I could stop the discussion here; Rutherford set up an initial state of helium ( $\alpha$  particles) and nitrogen nuclei, observing a final state of hydrogen and what appeared to be oxygen. This is transmutation. To borrow a phrase used by Eddington in his Presidential address to the British Association in 1920 (more of which below) Rutherford's transmutation experiment ensured that corpses were buried. So I shall continue, to ensure coffin lids are screwed down and placed six feet under.

6 Now to the diagrams presented in Krivit's paper. The first one even gives a incorrect picture of what Rutherford thought might be happening and it is wrong in both physics and morals to assign such an image to Rutherford and then criticise him for the author's misconception and mistake. Rutherford made no mention in his paper IV of the fate of the  $\alpha$  that resulted from what he called the disruption. Rutherford accurately and correctly described what is now termed in physics as an "inclusive inelastic scattering process" which means only the proton is observed and all other possibilities for the residue are included. The first of Krivit's diagrams did not happen in the laboratory nor in Rutherford's head.

7 In summary here, both Rutherford and Blackett and indeed, James Chadwick and Étienne Biéler in the immediate years thereafter, all observed transmutation. It is wrong to remove the discovery of artificial transmutation from Rutherford's portfolio, by presenting the first diagram.

At the time, the neutron lay undiscovered and the prevailing model of the nucleus was that it was composed of protons and electrons. Rutherford took this a step further, extending his knowledge of the stability of  $\alpha$  particles to an (incorrect) belief that nitrogen not only had 14 protons and 7 electrons, but that 12 of the protons and 6 of the electrons formed 3  $\alpha$ -particles within the nucleus with two residual protons waiting to be ejected by the projectile. This incorrect view, which Rutherford still propounded in his Göttingen lecture of 1931 (you can listen to him saying it here - via the top link on the page <http://www.robinmarshall.eu/videocatalogue.html>) was shared by all at the time, even Blackett and there is no more justification to strip Rutherford of his transmutation discovery than there would be to strip Blackett.

## What actually happened between 1919 and 1925

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At the 1921 Solvay Conference, Rutherford gave a rapporteur talk, *La structure de l'atome*, reproduced in full in the proceedings in French and surely unread by Krivit. In this talk, which overlaps with his Bakerian lecture the previous year, he discussed the changes to the nucleus in a section called "Artificial disintegration of elements". The Solvay talk described all the details of the transmutation experiments carried out by himself in Manchester. It shows without a doubt that the international physics community in 1921 talked normally about transmutation and used both Rutherford's preferred notation "disintegration", which Blackett himself used later as well as transmutation. In the discussion that followed the talk, Jean Baptiste Perrin<sup>1</sup> made a remark of considerable vision. I have translated it into English:

M. Perrin – I think, in learning of Sir Ernest Rutherford's beautiful discoveries on the dislocation of atomic nuclei by  $\alpha$ -rays, we have all been struck by the fact that the hydrogen atoms extracted from the nucleus can be launched, in any direction, with a kinetic energy greater than that of the projectile (especially for aluminium and phosphorus). The astonishment comes from the fact that the phenomenon can be likened to the action of a projectile that knocks out a piece from an assembly, and launches it from that distant location, roughly in the direction of impact, with an energy necessarily less than of the projectile. The very experiences of Mr. Rutherford seem to prove that we must give up this idea of a mere collision. The projectile has, because of its high speed, and despite a strong electrical repulsion, arrived, very slowly in the immediate vicinity of the nucleus. At this moment, a "transmutation" occurs, probably consisting of an intranuclear rearrangement, with possible capture of the "incident" nucleus (because we do not know what it becomes), emission of the hydrogen nucleus forming the observed H-ray, and perhaps even with other, less important projections. There is no reason, looking at it this way, for the projectile H emitted "to remember" the direction of the initial shock nor for its energy (borrowed partly from the intra-nuclear electrical energy) to be less than that of the incident projectile. If, for example, the struck aluminium nucleus captures the projectile  $\alpha$  and emits no electrons, it remains, after the emission of the projectile H, an atom whose mass is  $(27 + 4 - 1)$ , and whose atomic number is  $(13 + 2 - 1)$ , i.e. 14, therefore an isotopic atom of silicon. Other hypotheses are easy. Perrin in 1921 used the word "transmutation" to describe Rutherford's discovery and Krivit simply cannot undo that, 100 years later. The truth is on the record.

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<sup>1</sup>Born 1870, Nobel Prize 1926

Rutherford laconically replied to Perrin, probably in English but printed in French in the proceedings, so my translation back might not be precisely what he said:

Mr. Rutherford – **It may well be that the particle has entered into some sort of temporary combination with the nucleus.**

Rutherford did subsequently acknowledge Perrin's contribution in a paper *Disintegration of atomic nuclei* published in *Nature* 115, 1915 pp493–494, where he reproduced “a selection of remarks by him (Perrin) in full, as the above publication (Solvay Proceedings) may not be generally accessible to readers of *Nature*”. (i.e. it's in French.) Rutherford also mentioned in this paper, that he had received a short preprint from Pettersson and Kirsch in June 1924, describing preliminary experiments where protons had been liberated from carbon and aluminium by bombarding with  $\alpha$ -particles, where the authors suggested that the  $\alpha$  might be captured. Indeed, Hans Petterssen (Göteborgs Höskola) had already presented his model at a meeting of the UK Physical Society, with the written version received November 8, 1923. The discussion following the verbal presentation was printed together with the paper in Vol 36 of the proceedings, pp194-204 and one of Rutherford's former underlings, Edward Neville da Costa Andrade, immediately launched into a scathing attack, saying “... it is a poor basis for this load of speculation.” He likened Petterssen's work to a man who had measured the size of a box, shaken it and determined it contained pieces of metal and then started speculating on the dates of the coins in the box<sup>2</sup>. To be riled by Andrade was a honour of which only the best were worthy, but in his tirade, Andrade made one remark that is very relevant to Steven Krivit's article and that was “... the distinction between the satellite and explosion theories<sup>3</sup> is mainly a question of words at the present stage.” It still is 96 years later.

Some say that Rutherford clung tenaciously to his satellite model of the nucleus but I find no more evidence for this than I do for Krivit's myth. Rutherford never clung to lost causes and after Perrin's input at Solvay 1921, it was a natural consequence that he got his latest underling, Blackett, a new Royal Society Moseley Fellow, to use a Wilson cloud chamber, which Rutherford adored, to sort out the truth. Rutherford had a tendency to keep his cards close to his chest. Even one of his closest underlings in Manchester, Ernest Marsden, thought that around 1911, Rutherford took the data that Geiger and Marsden had measured on the

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<sup>2</sup>Rutherford is often wrongly attributed as having likened wide angle  $\alpha$  scattering to firing a 15 inch shell at a sheet of tissue paper and having it bounce back at you. In fact it was Andrade who said it. It was the sort of thing Andrade said.

<sup>3</sup>= The two diagrams in Krivit's paper, marked copyright, which I shall respect.

scattering of  $\alpha$  particles off gold and sat in his office till the penny dropped. Nothing was further from the truth. Rutherford did sit in his office but he was writing letters almost daily to W H Bragg (the elder) and J J Thomson discussing the phenomenology whilst keeping the Manchester data up his sleeve so only Rutherford had the full picture. All the evidence is that Rutherford did not blab to Chadwick, Biéler and Blackett about the input from Perrin and Petterssen, but let them get on with it, undistracted.

9 Marsden is worth quoting. In his talk at the Rutherford Jubilee Conference in Manchester in 1961, he said of Rutherford's 1919 experiment "This was the first observed case of artificial transmutation of atoms." This is a first hand statement from someone with close first hand knowledge, who was there at the time and who is credited in Rutherford's paper IV with having helped to collect data.

10 But what does Blackett himself have to say about the situation? Does he give a clue, because I will believe him, a physics Nobel prizewinner, more than Krivit with a business degree. The best text I can find dates from 1954 when Blackett gave the Rutherford memorial lecture of that year. It was reproduced in the 1961 Rutherford Jubilee Conference proceedings and here is what Blackett said in his lecture "Memories of Rutherford" on the 26th of November 1954:

"I succeeded in 1924 in taking within a few months some 25 thousand photographs showing the tracks of 400 thousand  $\alpha$ -particles, and amongst these tracks discovered six which clearly represented the process of atomic disintegration discovered previously by Rutherford. The novel result deduced from these photographs was that the  $\alpha$  was itself captured by the nitrogen nucleus with the ejection of a hydrogen atom, so producing a new and then unknown isotope of oxygen,  $^{17}\text{O}$ ."

This dispatches and demolishes Krivit's main thrust; Blackett also uses the word "disintegration" and gives credit for the discovery to Rutherford.

### Marsden's early work on detecting fast protons

But there is still Marsden's early work to dispose of. He in 1913, and then together with Walter Lantsberry in 1914, observed fast H particles and thought they might be coming from the radioactive source of the  $\alpha$ s itself. This work is significant because the H particles as they were called, were known to be hydrogen nuclei. It was not known however, that they were a constituent of all nuclei. Rutherford was already excited that they might be coming from radioactive nuclei which were known to emit  $\alpha$ ,  $\beta$  and  $\gamma$  rays. Adding H-particles to the list was a minor revolution. They turned out of course to be coming from collisions with nitrogen in the air.

## What does Abraham Pais say?

The most thorough, perceptive, reliable and trustworthy historical account of the development of physics during this period of interest is that by Abraham Pais in his book *Inward Bound*. He lived through much of the period, worked with those in the field and spent over 40 years writing his book. There is not a glimmer in his account of anything that might support Krivit's notion and he also quotes the exchange between Rutherford and Soddy (see below) when they observed natural transmutation. It is probably where I first read the quote which shows Rutherford's aversion to the word "transmutation". Joule's contribution to the law of conservation of energy is not in question just because he never used the word "energy". This was not due to any aversion to the word as such, but because that word was not used to describe what we now call energy. Joule called it *vis vitae*, the force of life.

## Summary of observations

1913–1914: Marsden observed anomalously fast H particles but didn't know their origin.

1919: Rutherford observed fast H particles and correctly deduced that they arose from transmutation and made the "surprising observation" that oxygen also appeared to be present in the final state.

1921: Perrin proposed that an intermediate compound nucleus may be formed following  $\alpha$  capture.

1923–1924: Kirsch and Petterssen proposed Perrin's model without citing him and presented measurements to support their proposal.

1925: Blackett published his cloud chamber work confirming all previous work that transmutation had been observed. At the same time, Rutherford published a separate paper mentioning Blackett's results and linked them to Perrin's proposal four years previously.

The conclusion is that Rutherford was the first to observe AND identify the phenomenon of induced nuclear transmutation. His discovery was then confirmed by further thought and experiment. To him goes the bulk of the credit, and if anyone has not been given enough credit, it is Perrin.

## Alchemy

Rutherford was very reluctant to use the word "transmutation" and used "disintegration" instead, a detail of deliberate vocabulary. When he

and Soddy realised that radioactivity caused an element to naturally change into another, Soddy claims that he yelled “Rutherford, this is transmutation: the thorium is disintegrating and transmuting itself into argon (sic) gas.’ Rutherford replied, “For Mike’s<sup>4</sup> sake, Soddy, don’t call it transmutation. They’ll have our heads off as alchemists.”

Finally, if I may say – far from me be it to interfere with the editorial judgements of your prestigious journal, but if an article is published in 2019 about the first successful alchemy in 1919, and the only place mentioned is Cambridge and not Manchester, I will not be alone in writing a letter to *The Times*. Neither Cambridge nor Manchester has a need for borrowed feathers.

### **Post script for physicists – the actual nuclear reaction**

It is of interest to reconstruct the nuclear process in the light of modern knowledge. This shows Rutherford’s use of the word “disintegration” and his view that the observed proton was peripheral in the nuclear structure, to be actually nearer the truth than a global arm waving transmutation.

11 **In nuclear parlance, the observed reaction was  ${}^{14}_7\text{N}(\alpha,p){}^{17}_8\text{O}$**  and the  ${}^{17}_8\text{O}$  isotope is stable, so no problems there. In trying to understand the intermediate process, there is no perfect absolute picture because it can only be described as a sequence of simultaneously occurring wave-functions with varying time dependent probabilities. The final state wave-function must be finite during the existence of the initial state wave-function or else the whole process could not proceed. In such a process, the nuclear force is a mess and can be likened to a dynamic interaction between molecules bound by ionic, covalent, metallic etc forces, where the fundamental Coulomb force that made the molecules is a simple inverse square law, but the forces between molecules have no simple form. Here, the QCD forces between quarks and the gluon quanta are the equivalent of the Coulomb force and the forces between nucleons in the  $\alpha$  and nitrogen and the forces between the two nuclei are, as stated, a total mess. But we could get a partial picture by using the shell model and liquid drop model, but even then, neither can tell the whole story.

In describing how an  $\alpha$ -particle and a nitrogen nucleus eventually become a proton and an isotope of oxygen, either qualitatively or quantitatively, you first need to write down or at least note the amplitude of the various channels through which the process can proceed. I shall list a few, but the totality is limited only by imagination. This is a good place to dispense with the terms “disintegration process” and “integration process”. These have no more place in the context of this discussion than Rutherford

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<sup>4</sup>Mike was commonly used as a ‘polite’ substitute for Christ up till the end of the 19th century, when it was steadily replaced by Pete.

and Blackett's belief at the time that the nitrogen nucleus contained 14 protons and seven electrons. Better words are "fission", when a nucleus fragments into pieces and "fusion" when two nuclei fuse to form a new one.

1: The  $\alpha$ -particle on encountering the nitrogen, fused (fusion) to form a compound nucleus which would have the quantum numbers of a fluorine isotope ( $^{18}_9\text{F}$ ), by necessity in an excited state. This isotope is unstable and decays by positron emission (indeed exploited in PET scanners for this reason). But some excited states can decay by proton emission to  $^{17}_8\text{O}$  and this is a valid route here, in fact it is probably the dominant intermediate state with the biggest amplitude.

2: When the nuclear extent of the  $\alpha$ -particle and the nitrogen touched and overlapped, energy became available from the fermi motion of the protons and neutrons in the nitrogen to overcome the binding energy of a proton in the alpha particle and it was emitted turning the  $\alpha$ -particle into a tritium nucleus (fission) which then sorted itself out with the nitrogen to form  $^{17}_8\text{O}$  (fusion).

3: When the  $\alpha$ -particle intruder arrived on the doorstep of the nitrogen nucleus the arrival of the kinetic energy, plus if needed, fermi motion, ejected a proton from the nitrogen (fission) forming briefly, an isotope of carbon, and the  $\alpha$ -particle, helium then joined with the carbon (fusion) to form the eventual  $^{17}_8\text{O}$  isotope.

I could go on and write down many more. Quantum mechanically, and there is no viable alternative at the present time, the whole process has to be described by a superposition of the wave-functions of the above and many more channels. If these were available as mathematical functions, the amplitudes (complex functions with real and imaginary parts) would have to be added together and then squared and mathematically integrated to get the total cross section. Mr Krivit failed to do this when trying to demolish what happened in Manchester in 1919, not that it would have helped him.

The bottom line is that quantum mechanically, there is no billiard ball type process where one ball (nitrogen) simply changed colour (oxygen). This is the basic nuclear physics argument why Krivit's paper complete fails to address the physics of what went on, quite apart from his historical gaffes. The lack of understanding of nuclear physics is rather embarrassing.

Rutherford was right, Perrin was right, Eddington was right, Marsden was right, Blackett was right, but both the physics in Krivit's paper and his historical deductions are completely wrong.