Henry Moseley and the Search for Element 72

by K. M. Frederick-Frost

“Unfortunately the new element for the examination of which he came over, proves shy and will not disclose itself. I cannot imagine what it can be, and seriously doubt its existence. This is disappointing and leaves one more gap in the list of the known elements.”

When Henry Moseley penned this statement to his sister on 7 June 1914, he was not in a celebratory mood. It was less than a week after an experiment in which he collaborated with the famous rare earth chemist, George Urbain. Together they hoped to show that Urbain’s preparation “celtium” was the missing element with atomic number 72. The data only delivered disappointment. After putting the scientific community on its head and the elements in their place with two papers on the “High-Frequency Spectra of the Elements,” this null result failed to excite Moseley. But it should excite us. He not only used X-ray spectroscopy to identify gaps in the list of known elements, he used it to rule out a candidate for one of those gaps. In this International

Source: History of Science Museum, University of Oxford

Fig. 1. X-ray spectra aligned according to the angle of reflection. Source: H. G. J. Moseley, “The High-Frequency Spectra of the Elements,” *Philosophical Magazine* 26 (1913): PI XXIII.

Year of the Periodic Table, let’s consider element 72, before it was called hafnium, when the possibility of its discovery brought together chemists and physicists in a new way. Let’s consider Moseley’s research.

Henry Gwyn Jeffreys Moseley (1887-1915) might have begun his education at Eton and the University of Oxford, but his time as a demonstrator and researcher at the University of Manchester under Ernest Rutherford (1871-1937) is what provided him with access to the ideas, people, and infrastructure needed to support the scientific research that would earn him fame. Moseley was in the right place at the right time, but he was ultimately drawn to the wrong kind of ionizing radiation. Rutherford was more at home with radioactivity, so it was arranged for Moseley to learn about experimenting with X-rays from another famous scientist, W. H. Bragg (1862-1942), at Leeds University. W. H. Bragg, with his son, W. L. Bragg (1890-1971), would share the 1915 Nobel Prize for their work analyzing crystals with X-rays.

When Moseley returned to Manchester, he partnered with another young scientist drawn to Rutherford’s group, C. G. Darwin (1887-1962), and, much like the Braggs, they started looking closely at the intensity and angular distribution of X-rays reflected from a crystal. Moseley and Darwin found five peaks with specific wavelengths that stood out from a background

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of heterogeneous reflected radiation. These characteristic X-rays were associated with the platinum target in their X-ray tube. Moseley next set his sights on investigating the characteristic radiation of a series of elements in the periodic table, which was largely organized by increasing atomic weight and shared chemical properties. He was sure to include two misfits in his study—Co and Ni—whose atomic weight did not fit the overall pattern. The question he set out to answer: Would the atomic weight or the element's order in the periodic system determine the X-ray spectra?

For his first foray in to the “High-Frequency Spectra of the Elements,” Moseley used a customized X-ray tube with a trolley of interchangeable elemental targets that he could pull under the tube's cathode in relatively quick succession. Unlike his first study of X-rays, where he used an ionization detector to measure the intensity of the radiation as a function of the angle of reflection, he imaged the spectra with photographic plates. This captured the strongest two emission lines, but that was enough to create a powerful visual when all the images were arranged according to the angle of reflection (Fig. 1). The X-ray data, unlike the atomic weight, were decisive in placing Ni between Co and Cu.

Right in the middle of this famous research, Moseley gave up his fellowship at Manchester and moved to the University of Oxford to work as an unpaid researcher in the Electrical Laboratory. He was angling for a new position. Compared with the frenzy of activity under Rutherford, the Electrical Laboratory moved at a slower pace and had less support staff to assist with the construction and repair of his apparatus, which is why Moseley still contracted with the Manchester instrument maker to provide some of the equipment needed for the next phase of his study. Part II, which he published in April 1914, expanded his dataset from 12 elements to 45.

Moseley derived the relationship between the square root of the frequency of characteristic X-rays and an element's atomic number in his first paper, but the graph in his second paper makes Moseley's Law manifest. (Fig. 2) The data were grouped into the two flavors of characteristic radiation he studied, K and L rays (bottom and top set of lines respectively). Because this radiation was related to the structure of the atom, so, too, was the atomic number. Far from just a serial number in the periodic system, Moseley concluded, “there is every reason to suppose that the integer which controls the X-ray spectrum is the same as the number of electrical units in the nucleus,” which supported a hypothesis proposed by a Dutch solicitor-turned-scientist, Antonius van den Broek (1870-1926).

While the gaps in the dataset for known elements didn't detract from Moseley's overall accomplishment, the gaps in the dataset for *unknown* elements added to it. He declared that “known elements correspond with all the numbers between 13 and 79 except three. There are here three possible elements still undiscovered.” Not only did his research provide experimental evidence that the atomic number was a physical property of the nucleus of an atom, it made the hunt for new elements specific and finite. However, he was wrong about the number of elements yet to be discovered.

Moseley's original hand-drawn plot hangs in Oxford's Clarendon Laboratory. A close look at the y-axis reveals corrections made post-publication and his original confusion about elements 66-72 (Fig. 3). It was shortly after publication that he realized that there were actually four unknown elements (43, 61, 72, and

Fig. 2. Plot of X-ray data (square root of frequency vs atomic number). Source: H. G. J. Moseley, “The High-Frequency Spectra of the Elements, Part II,” *Philosophical Magazine* 27 (1914): 709.

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75) yet to be discovered. The one he overlooked was the only one he would have an opportunity to hunt—element 72.

“As the X-ray spectra of these elements can be confidently predicted, they should not be difficult to find.” Not too long after publishing this statement in his second paper on the “High-Frequency Spectra of the Elements,” Moseley was about to get an education for just how hard it could be. A possible hiding spot for number 72 was in the rare earths, which were famously hard to separate and therefore held the promise of new discoveries. For example, both George Urbain (1872-1938) and Carl Auer von Welsbach (1858-1929) claimed to separate ytterbia into two different elements in 1907. The two researchers locked horns over priority, and Urbain won out. They were both a natural choice for Moseley to approach if he wanted samples to examine that would enable him to fill the holes in his plot between 69-72. Moseley asked George

von Hevesy (1885-1966) to approach Auer for samples of the rare earths, but Moseley was especially interested in getting a crack at a new element Urbain reported discovering in 1911: celtium.

Urbain was also keen to collaborate with Moseley, and in June 1914, he traveled to Oxford with several samples, celtium included. Moseley agreed that celtium had a “very definite” visible spectrum, but the absence of a handful of X-ray emission lines with frequencies expected for element 72 was conclusive. The lines he did measure were more consistent with Lu and Ny

(Yb). Figure 4 shows some of his data for celtium, with the relative percentage concentrations for Lu and Ny (Yb) in the rightmost column.

The two researchers not only spoke different languages but they came from different scientific traditions. Urbain had a successful career utilizing visible spectra and magnetic susceptibility measurements to analyze elements. His explanation for the missing lines in the X-ray spectra was that they were just too faint to see. In fact, he would later note, “the negative result given by Moseley’s method in the case of celtium was due only to the insensitiveness of the method.” He believed he ultimately achieved success finding those faint lines with physicist Alexandre Dauvillier (1892-1976) in 1922 using the same sample that Moseley examined in 1914.

Despite Moseley’s failure to find X-ray data to support celtium as element 72, Urbain still wanted him to publish his endorsement of this idea. Instead, Moseley reported that celtium was a mixture of previously discovered elements at the 1914 meeting of the British Association for the Advancement of Science in Australia. Moseley’s involvement in the war effort and subsequent death is largely cited as the reason why these results were never published. He went off to the front disappointed about never submitting his paper, writing to Rutherford on 4 April 1915, “One thing lies heavy on my conscience, and that is my Sydney B. Ass paper, for I have never published it. I must make time to get ready an abstract for the Phil Mag, before I leave, as to chemists the reality and order of the rare earth elements is of much importance.” Urbain and Dauvillier’s claim to the discovery of 72 was not long lived. Physicist Niels Bohr (1885-1962) would wrest the search for 72 from the rare earths altogether while pursuing his new atomic model. We could conclude that the success of Moseley’s spectroscopy in ruling out celtium as a new element was an example of how in science the “truth will out.” But, that isn’t very satisfying.

The story gets interesting when we consider the possible reasons why Moseley’s work was never published—both while he lived and after he died. He knew the data were valuable. He even planned for their future should he not return from the war, instructing his mother, Amabel Sollas (1855-1928), to give his notes, spectra, and calculations to Rutherford. She did so within a month after learning of the loss of her son. According to a note written by Moseley’s sister on 12 June 1933, both she and her mother were shocked when Rutherford failed to find anything worth publishing. Since their close relationship with Moseley provided unique insight as to the nature and value of his

Fig. 3. Corrected hand-drawn version of Moseley’s 1914 plot shown in Fig 2. Originally, he labeled number 72 as Lu, 71 as Yb, 70 and 69 as TmII and TmI, and swapped the order of Ho and Ds. Close inspection shows places where sections excised. Source: History of Science Museum, University of Oxford, by courtesy of the Clarendon Laboratory, University of Oxford).

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Fig. 4. Excerpt from page of Moseley's notes showing data for celtium. Percentage concentration measured from X-ray line intensity shown in rightmost column. Source: History of Science Museum, University of Oxford.

Fig. 5. Excerpt from page of Moseley's notes showing wavelength calculations for Lu, Ny (Yb), Tm, Er. Source: History of Science Museum, University of Oxford

	λ_{23}	7510	4771	$\lambda \times 10^8$
Lu	$16^\circ 46'$	4601	2111	1626
Ny	$17^\circ 19'$	4737	2247	1678
Tm	$17^\circ 53\frac{1}{2}'$	4874	2384	1732
Er	$18^\circ 34'$	5019	2529	1790

work and results, their disappointment in the lack of a posthumous publication should not be discounted.

A rare page of Moseley's notes at the History of Science Museum, University of Oxford related to his rare earth research with Urbain shows that, despite the disappointment with celtium, several new data points for Tm, Ny (Yb) and Lu were ready for incorporation into his famous plot. (Fig. 5) Interestingly, Moseley didn't even prepare a short publication stating these numbers. One possible stumbling block was that the samples that provided the data for these elements were shown to be mixtures. X-ray spectra of samples labeled "Lu" and "Ny" (Yb) were actually combinations of the two elements. This wouldn't be a problem on its own, after all several of the data associated with rare earth elements he previously investigated were from impure samples (The sample of Pr that he obtained from the chemical supply Dr. Schuchardt of Görlitz contained 50 % La, 35 % Ce, 15 % Pr.) It was likely more awkward to point out impurities when Urbain claimed both success and priority in isolating Lu and Ny (Yb). The decision to go public with this information was more fraught than the addition of a few new data points. For all his success, Moseley was a junior researcher. Publishing information that countered Urbain's claims—or at least muddled the waters—would have been a bold step.

As a Nobel laureate and senior researcher, Rutherford held more authority in the scientific community. However, once he reviewed Moseley's rare earth data, he also held his hand, stating in the 1917 Proceedings of the Royal Society that "no record of his [Moseley's]

definite conclusions on this question has been found." There are several possible reasons why Rutherford didn't publish any of the materials. They range from Moseley's sister's accusation of negligence with the data he was given to not having the time in the middle of his own research and war work to devote himself to the completion of Moseley's unfinished paper.

Analysis of the archival documents related to Moseley's rare earth research point to another set of difficulties. His notes, spectra, calculations, experimental setup, and conclusions were all entangled. The data points shown in Fig. 5 required corrections that were different than were described in his two publications on "The High-Frequency Spectra of the Elements." This might have something to do with the fact that he often varied the location and arrangement of various components of his X-ray spectrometer to wrestle the characteristic lines from the background radiation. Like many experimentalists, he readily modified his setup to suit his purposes. However, if he changed the way the data were collected, he could change the way the data were reduced, and that might change more than a few irrelevant decimal places. Talented as Rutherford was, he might not have been able to derive the same level of certainty, if not the same conclusions, as Moseley.

Because Urbain's celtium discovery and the purity of his other elements might have been called into question, the stakes were high. The reward for publishing someone else's work was low. Rutherford remained in the thick of the work to identify element 72, not as an active participant in the hunt, but as a powerful referee. In 1922, when Urbain and Dauvillier announced

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that celtium was the missing element 72, Rutherford included a note of support before the English translation of Urbain's article in *Nature*. A few months later, Bohr privately wrote to Rutherford about "the reliability of Dauvillier's result," because it went counter to his new theory of the atom and to the X-ray absorption data that he and Dirk Coster (1889-1950) were compiling and investigating. This work indicated that 72 belonged in the group with zirconium.

With that opening, George von Hevesy was able to collaborate with Coster and find what we know as hafnium just in time for Bohr to announce it at the acceptance of his Nobel Prize in December 1922. This was also the start of another priority dispute involving Urbain, but unlike Lu and Yb, it wouldn't be decided in his favor. Henry Moseley's results might therefore seem prophetic, but it is more interesting to use his work as a case study of the kind of support and context data need to generate new knowledge. Moseley died young. His data and work on celtium might not have died with him—they just couldn't live without him. 🏴󠁧󠁢󠁥󠁮󠁧󠁿

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Do you want to learn more? A new collection of essays by scientists and historians, *For Science, King & Country: The Life and Legacy of Henry Moseley*, was recently compiled by Roy MacLeod, Russel G. Egdell, and Elizabeth Bruton (eds.). John Heilbron's *H. G. J. Moseley: The Life and Letters of and English Physicist, 1887-1915* is an excellent biography and collection of transcribed letters. To learn more about Moseley's unpublished work with Urbain, see K. M. Frederick-Frost, "For the Love of a Mother—Henry Moseley's Rare Earth Research," *Historical Studies in the Natural Sciences* 47 (2017): 529-567.

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