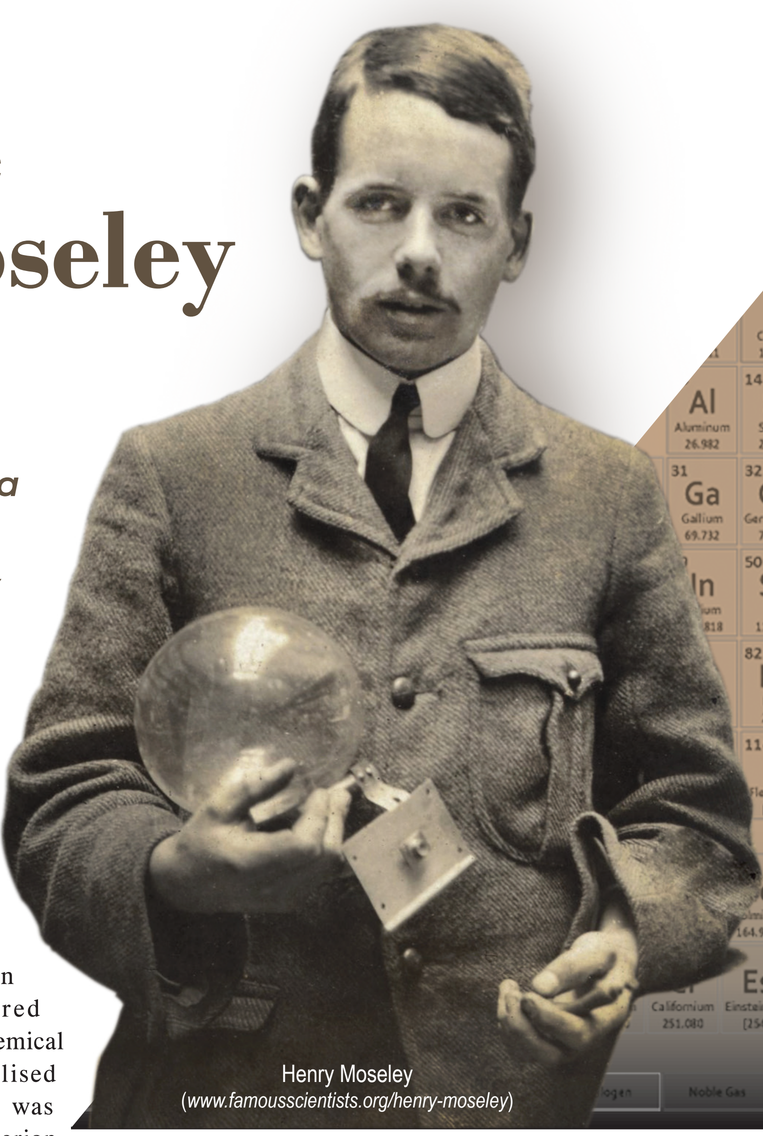
Periodic Table and Henry Moseley

Vilas B. Sapre & Sanjay D. Jain

Although Mendeleev is credited with developing the Periodic Table, it was a young British physicist named Henry Moseley who provided a scientifically rigorous classification scheme.



Henry Moseley
(www.famousscientists.org/henry-moseley)

SCIENCE students are familiar with the modern periodic table, which organises the chemical elements based on their properties and atomic numbers. However, there have been earlier attempts too at organising elements. In 1789, for example, Antoine Lavoisier grouped his list of 33 elements into gases, metals, earths and non-metals. But Chemists longed for a classification scheme that evinced more precision.

Dmitri Ivanovich Mendeleev, a Russian Chemist (Feb. 7, 1834-Feb. 2, 1907) provided a better framework in 1869 with his precursor to our modern periodic table of elements, organising them according to the sequence of atomic masses. To celebrate the 150th anniversary of this pivotal moment in science, the United Nations has proclaimed 2019 to be the International Year of the Periodic Table.

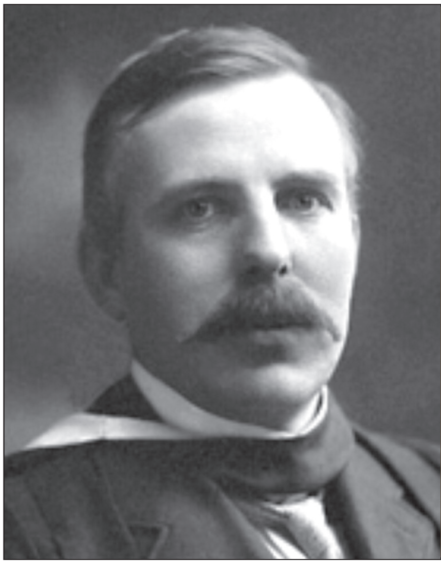
However, there were issues with how he chose to order the elements in his table. For instance, Mendeleev assigned the atomic numbers 27 and 28 respectively to the metals cobalt and nickel, based on their physical and chemical properties, even though cobalt had a slightly larger atomic weight and technically should have followed nickel. It was an intuitive leap. Mendeleev based his decision on the known chemical and physical properties of both elements.

There were also irregularities in the location of argon and potassium, as well as the positioning of the rare earth elements. When chemists discovered the existence of chemical isotopes, they realised that atomic weight was not the optimal criterion for ordering the periodic table. A young British physicist named Henry Moseley provided a scientifically rigorous classification scheme.

Moseley was born on November 23, 1887, into a distinguished family with a long educational heritage. His father was a professor of anatomy at the University of Oxford. His paternal grandfather, Henry Moseley, had been an eminent physicist, mathematician and astronomer at Kings College, London. His maternal grandfather, John Gwyn Jeffreys, had been an outstanding oceanographer and authority on shells and mollusks.

In spite of his father's untimely death in 1891, his mother had sufficient income from family estates to keep her three children in school and allow Henry to build and equip a simple private laboratory when he grew older. Moseley spent five years at Eton, after which he entered Trinity College, Oxford, with a scholarship in natural science. Before he graduated with honors in natural science, he was already dreaming of a career in pure science.

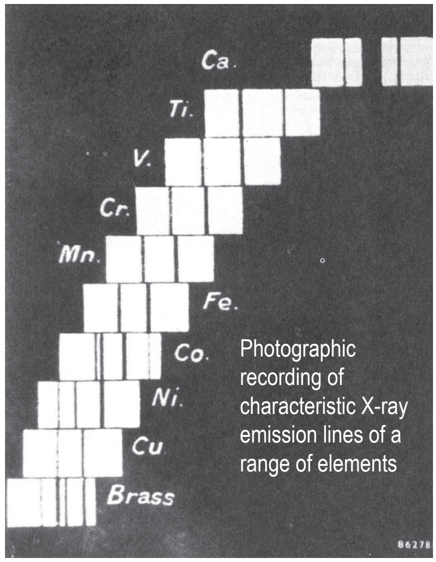
He was greatly inspired to do research by Ernest Rutherford at Manchester. Rutherford recognised young Moseley's potential talents as a born investigator and suggested that the latter pursue research in his own specialty, radioactivity. After working for a while at Rutherford's laboratory, Moseley became so engrossed in his task of studying electron emission during the radioactive decay of the element radium that he was compelled to resign from the teaching position at the University of Manchester to provide more time for research.



Ernest Rutherford

1871-1937

- Nucleus Theory 1910 — alpha particle gold foil experiment
- An atom's mass is mostly in the nucleus
- The nucleus has a positive charge (Moseley)
- Electrons in fixed orbit



Photographic recording of characteristic X-ray emission lines of a range of elements

While completing additional research on radioactivity, Moseley learned of a most important discovery by Max von Laue of the University of Zurich. Laue had observed that pure crystals of salt acting like a prism can split up X-rays into an X-ray spectrum which is invisible to the human eye, but can be photographed.

Just prior to Laue's discovery, Rutherford had propounded a major theory of the nucleus of the atom. He theorized that the main mass of the atom was concentrated in a very tiny nucleus of positively charged hydrogen atoms (now known as protons) which were surrounded by enough electrons to make the atom electrically neutral. Rutherford shot alpha particles (helium nuclei) through various gases and by very precise measurements of the scattering of these particles he had calculated the positive charge in the nuclei of several atoms of different elements.

His experiments indicated that the greater the atomic weight of an element, the greater was the positive charge in the nucleus and that the atomic numbers were approximately one half of the atomic weights. The force binding an atomic nucleus together is imagined to act in much the same way as surface tension binds a drop of liquid. In this 'liquid drop' model of the nucleus, a balance is maintained between the surface tension which holds it together and the force of repulsion between its positively charged protons which threatens to tear it apart. Both forces increase as the size of the nucleus increases, but the force of repulsion increases more rapidly, eventually overwhelming the surface tension when the number of protons reaches about 100.

This is the reason why the periodic table does not go on forever. There is an essential limit on the size of an atomic nucleus imposed by the cumulative force of repulsion between its positively charged constituents. Perhaps in a uranium nucleus, with its 92 protons, this balance is very delicate. Addition of a single electron is enough to cause the nucleus to distort and finally split to form two smaller 'drops'.

It was necessary to determine whether Rutherford's hypothesis could stand up under further experiments. Because this problem was only suitable for the most brilliant of his students, Rutherford naturally discussed this project with Henry Moseley. It was decided that Moseley would compare the photographs of the X-ray spectra of many different elements so as to help determine the nature of electric charge on their nuclei.

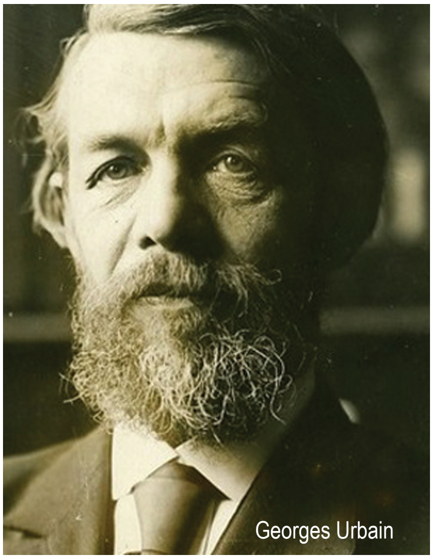
Moseley had done some basic research in which he had photographed X-rays that were refracted by atoms of a crystalline grating. Now Moseley was to use this photographic method not only to confirm most of Rutherford's theory, but to change the basic physical and chemical theories of the atom from relationships with atomic weights to those of atomic numbers, and would also remove the major discrepancies from Mendeleev's magnificent periodic arrangement of the chemical elements.

By 1911, scientists had already discovered that the X-rays emitted by the anti-cathode (plate) of a Crookes' tube depended solely on the metallic composition of this electrode and hence were called the characteristic radiation. These characteristic radiations were first observed by C.G. Barkla in 1909.

He also found that there are two groups of characteristic radiations. The long wavelength series was called the 'L series' and the short wavelength series was called the 'K series', now more commonly called as 'K/L radiation' or the 'K/L lines' by analogy with the lines in optical spectra. With this background the first two shells in the Bohr atomic model are called K and L. Transition of an electron from the outer shell to the vacancy in these shells gives rise to K/L lines.

Moseley called the more intense longer wavelength peak the K_α line and the less intense shorter wavelength peak as K_β. He also designated the various L lines as L_α, L_β, L_γ, etc. It was now possible to determine the wavelength and the penetrating power of these rays by absorbing them in thin layers of

Crookes' tube (*www.sharepoint.umich.edu*)



Georges Urbain

aluminum. Moseley allowed the beam of X-rays produced by the anti-cathode of a Crookes' tube to fall as a narrow beam on a crystal mounted on the table of a spectroscope. These X-rays were then photographed after being reflected from the crystal.

This unique procedure was satisfactory only after Moseley constructed a series of plates of the different elements mounted on a movable platform in the Crookes' tube. However, one major limitation was the fact that the first elements could not be tested by this method as most of them either were gases rather than solids at room temperature, or were too difficult to handle in their pure state. Thus, in six months of concentrated and breathless activity, Moseley had examined the X-ray spectra of thirty eight different elements from aluminum to gold.

By means of these experiments Moseley found that each of the thirty- eight metallic elements which had been tested, produced X-ray spectra of different wavelengths, and that heavier the element the shorter and more penetrating were the X-rays produced. This information certainly did help confirm Rutherford's theories on a much more substantial experimental basis. However, Moseley went much further with the experimental data that he had gathered.

On restudying his results for three metals – cobalt, nickel and copper, whose densities were almost identical and whose atomic weights were 58.94, 58.71 and 63.54 respectively (as compared with the element oxygen of atomic weight 16.00) – Moseley found that cobalt had the longest wavelength, nickel the next longest and copper the shortest from the shift of spectral lines. What is more, the shift of lines was uniform and regular, and based on these wavelength calculations Moseley found whole number relationships to identify these three elements too.

As Mendeleev's periodic table of the elements placed nickel before cobalt due to its slightly lower atomic weight, Moseley not only had improved on the former, but had discovered a more fundamental property than atomic weight. He concluded that this property could only be the positive charge on the nucleus of the atom. Thus he had discovered the law of Atomic Numbers (or Moseley Numbers). A mathematical relation connecting the wavelength and the atomic number was given by Moseley:

$$\nu^{1/2} = k(Z - \sigma)$$

Here ν is the frequency of the radiation, Z is the atomic number and k and σ are two constants, the same for the K series of all the elements. By introducing different values of the constants the equation can be made to fit the L series of the elements.

The new periodic table of the elements, which was published in 1912, when Moseley was 26 years old now positively assigned whole number identifications to the elements from hydrogen, with an atomic number of one, to uranium, with an atomic number of ninety-two. Now he was able to predict both the atomic numbers and principal chemical properties for seven as yet undiscovered elements (atomic numbers 43, 61 72, 75, 85, 87, 91) with certainty.

Moseley also found that potassium had an atomic number of 19 while argon's number was 18, even though their accepted atomic weights and Mendeleev's table called for their reversed order. Thus, three discrepancies in Mendeleev's table were immediately corrected, as not only were the elements previously arranged horizontally according to increasing weight, but they were grouped vertically in families of similar chemical properties. Now there were no longer any errors in the order of the elements!

When the news of Moseley's discovery reached France, Georges Urbain, of the University of Paris, rushed to Oxford to meet Moseley and discuss his own research of twenty years with a group of fifteen chemical elements called the rare earths. Owing to the extreme similarity of their properties, it was then impossible to separate a group of elements between barium and tantalum in the periodic table.

The Periodic Table

The periodic table published by Mendeleev in 1869 underwent several refinements as the periodicity was understood better with discoveries of new theoretical models and new elements.

Edward Mazurs collected an estimated 700 different published versions of the periodic table within 100 years of Mendeleev's table, many of which have been developed in shapes different than the usual rectangular one such as circle, cube, cylinder and spiral.

Today the periodic table includes a total of 118 elements, from element 1 (hydrogen) to 118 (oganesson). The first 94 of these elements occur naturally whereas the next 24 can be synthesized only in laboratories. New research bringing forth more truths about the underlying periodicity of elements will continue to enrich our knowledge of periodic table in the future.

Mendeleev could not find a place for them and Sir William Crooks pessimistically categorized them as "perplexers of our researches and haunters of our dreams". Perhaps Moseley could unravel the mess created by the existence of these rare earths with his new method of analysis. Soon after Urbain handed Moseley an ore sample containing an unknown of these rare earths mixed together in tiny quantities for the purpose of chemical analysis, the latter handed him a complete and perfect report on this ore sample after a few short and rapid calculations, based on his spectroscopic analysis of the various X-ray spectra which he had photographed. Professor Urbain was truly astounded!

Thus, Moseley's work had provided a solution for what had appeared to be insolvable with respect to the placement and the separation and identification of rare earths. The seven missing and yet undiscovered elements which were empty spaces in Moseley's table (and which Moseley had prophesied in terms of X-ray spectra and chemical properties) were all discovered by 1945. Thus, the soundness and genius of this magnificent worker were fully confirmed, forty years after his death, with the discovery of the element promethium (the last of these seven elements) in the laboratories of the Massachusetts Institute of Technology.

So, the atomic numbers of the elements were not as arbitrary as physical chemists originally thought. Moseley's work provided a firm experimental foundation for Mendeleev's earlier intuitions, resulting in more accurate positioning of the elements within the periodic table.

In fact, Moseley was able to use this mathematical relationship to correctly identify gaps in the periodic table, predicting that there should be elements with atomic numbers 43 (Technetium), 61 (Promethium), 72 (Hafnium) and 75 (Rhenium). All these elements were subsequently discovered: two radioactive synthetic elements – technetium and promethium, both created in nuclear reactors – and two naturally occurring elements, hafnium and rhenium. It should be noted that Mendeleev also predicted the missing element we now know as technetium, 50 years earlier. Moseley's work also established that there were only 15 members in the lanthanide series of rare earth elements.

In 1914, Moseley left Rutherford's Manchester laboratory, planning on returning to Oxford to pursue his physics research, but the outbreak of World War I put a wrench on those plans. Instead, he enlisted in the Royal Engineers of the British Army, serving as a technical officer of communications during the months-long Battle of Gallipoli in Turkey.

On 10 August 1915, Moseley was in the midst of sending a military order when a sniper's bullet caught him in the head and killed him. He was 27. Given all that he had accomplished at such a young age, Isaac Asimov noted that Moseley's death "might well have been the most costly single death of the War to mankind generally." Indeed, because of it, the British Government established a new policy barring the country's most prominent scientists from engaging in active combat duty.

Asimov also famously speculated that had he lived, Moseley might well have won the Nobel Prize the following year. Certainly, the trend for Nobel Prizes in Physics at the time seemed to favour work related to Moseley's research. The Committee chose X-ray crystal diffraction in 1914 (Max von Laue), and the first use of X-ray spectroscopy to study crystalline structure in 1915 (W.H. Bragg and W.L. Bragg), while the 1917 (C.G. Barkla) prize honoured work determining the tell-tale X-ray frequencies emitted by different elements. (No Nobel Prizes were awarded in 1916 in physics or chemistry.)

Moseley's work was certainly on a comparable level, and also provided solid experimental data in support of the Rutherford model of the atom, later refined by Niels Bohr. It is easy to forget that this model, which held that the atomic nucleus contains positive nuclear charges equal to its atomic number in the periodic table, was not immediately accepted by the scientific community. "You see actually the Rutherford work was not taken seriously," Bohr observed in 1962. "We cannot understand today, but there was no mention of it in any place. The great change came from Moseley."

Who knows what that talented young scientist might have gone on to accomplish had he survived the war?

Dr Vilas B. Sapre, Retired Professor of Physics, R.T.M. Nagpur University, Nagpur. Address: 101, "Parijat", M-5, Laxminagar West High Court Road, Nagpur-440022.
Email: vilas1943@gmail.com

Dr Sanjay D. Jain, Head, Knowledge Center, Priyadarshini Institute of Engineering and Technology, Hingna Road, Nagpur.
Email: sanjaylambade@rediffmail.com