Henry G. J. Moseley
1887 - 1915

100 years ago, Moseley discovered that the x-ray spectrum of an element is determined by the element's atomic number.

Brief biography

Moseley was born in Weymouth, Dorset, England. His father, Henry Nottidge Moseley was a professor of anatomy and physiology at Oxford, and his mother was the daughter of biologist John Gwyn Jeffreys. He studied mathematics and was introduced to the study of x-rays at Eton. In 1910, he graduated from Trinity College, Oxford. He then went to the laboratory of Ernest Rutherford at the University of Manchester. In 1914, he had planned to continue physics research at Oxford. But with the start of WW1, he became an officer in the Royal Engineers. He was thought to be a candidate for the Nobel Prize in Physics in 1916, but he was killed, at age 27, in 1915 at the battle of Gallipoli in Turkey.

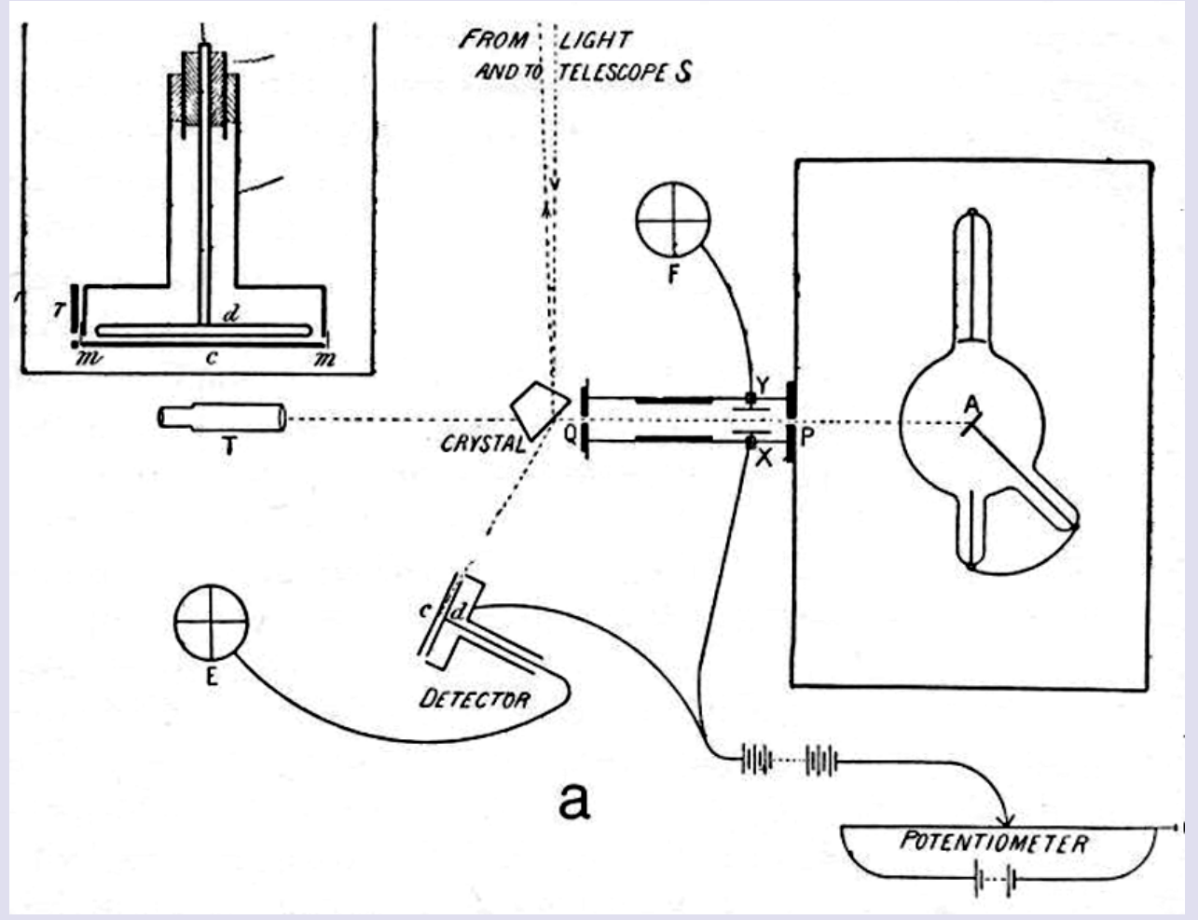
In 1913, while working at the University of Manchester, he observed and measured the X-ray spectra of various chemical elements using diffraction in crystals. Through this, he discovered a systematic relation between wave-length and atomic number. This discovery is now known as Moseley's Law.

His method in early X-ray crystallography was able to sort out many chemical problems promptly, some of which had confused chemists for a number of years. Both the apparent irregularities in the location of elements such as argon and potassium and the positioning of rare earth (inner transition) elements in the periodic table could now be elucidated in the basis of atomic number.

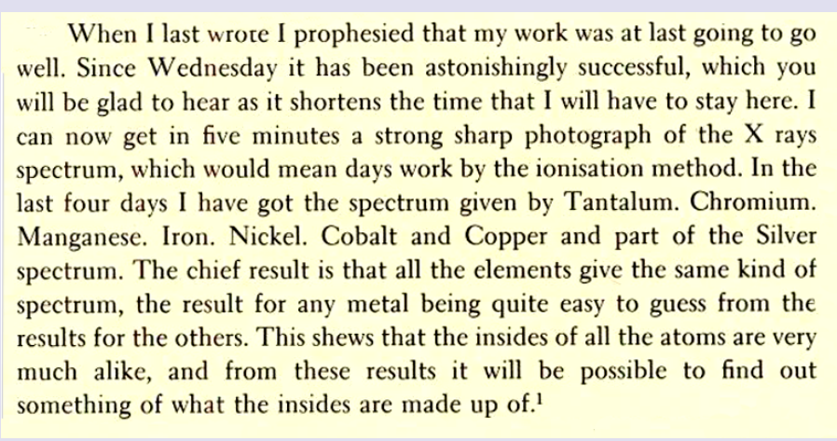
Moseley is also known for the development of early x-ray spectroscopy equipment, which he learned to design with the help of William Henry Bragg and William Lawrence Bragg at the University of Leeds. This device basically consisted of a glass-bulb tube in which the ionization of electrons caused the emission of x-ray photons, finally resulting on lines on photographic film.

Work at Manchester

In Rutherford's lab, holding one of his x-ray tubes.

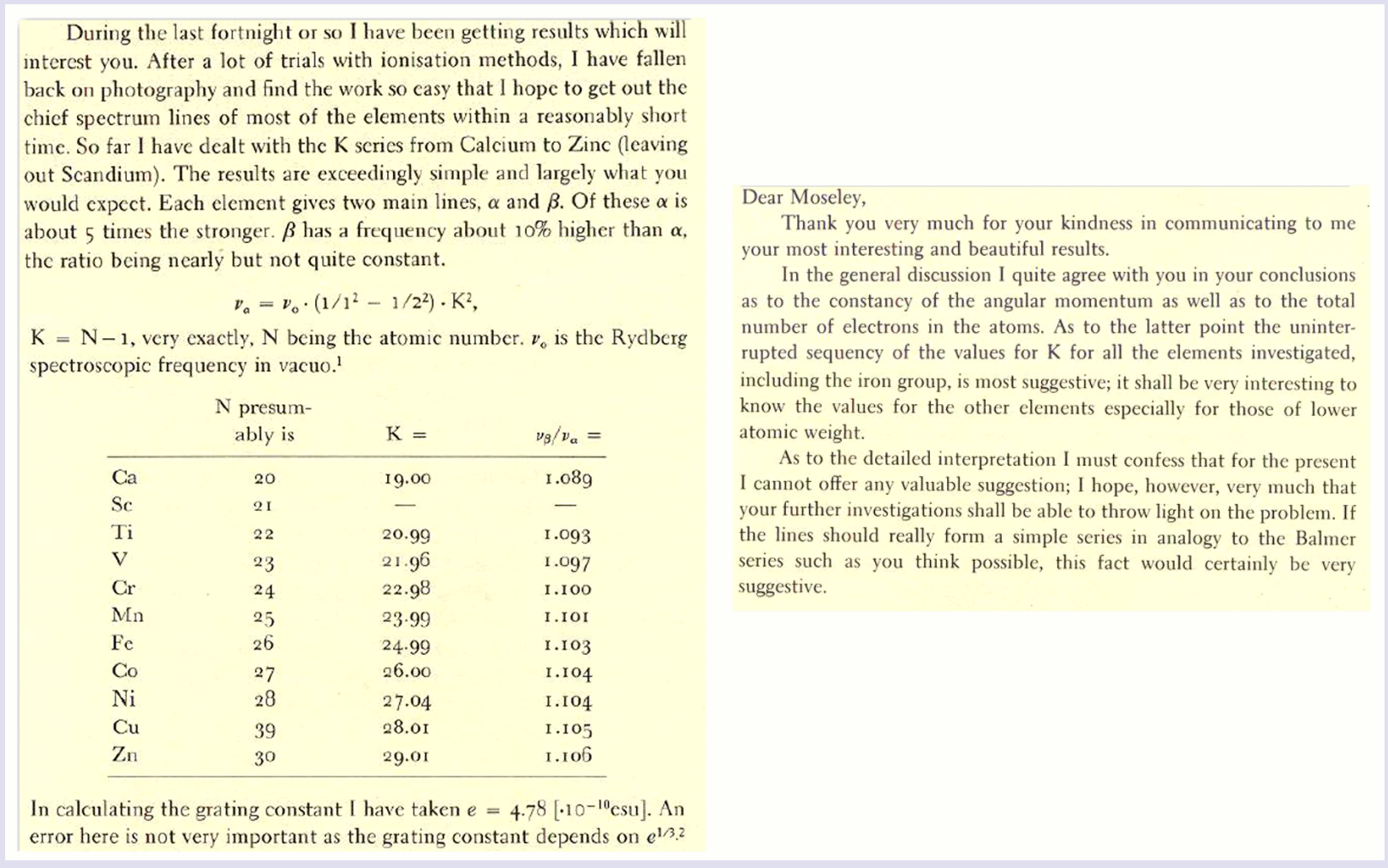


His original drawing of the apparatus.



When I last wrote I prophesied that my work was at last going to go well. Since Wednesday it has been astonishingly successful, which you will be glad to hear as it shortens the time that I will have to stay here. I can now get in five minutes a strong sharp photograph of the X rays spectrum, which would mean days work by the ionisation method. In the last four days I have got the spectrum given by Tantalum. Chromium. Manganese. Iron. Nickel. Cobalt and Copper and part of the Silver spectrum. The chief result is that all the elements give the same kind of spectrum, the result for any metal being quite easy to guess from the results for the others. This shews that the insides of all the atoms are very much alike, and from these results it will be possible to find out something of what the insides are made up of.[1]

A report of his initial success, in a letter to his mother.



During the last fortnight or so I have been getting results which will interest you. After a lot of trials with ionisation methods, I have fallen back on photography and find the work so easy that I hope to get out the chief spectrum lines of most of the elements within a reasonably short time. So far I have dealt with the K series from Calcium to Zinc (leaving out Scandium). The results are exceedingly simple and largely what you would expect. Each element gives two main lines, α and β. Of these α is about 5 times the stronger. β has a frequency about 10% higher than α, the ratio being nearly but not quite constant.

$$\nu_\alpha = \nu_o \cdot (1/1^2 - 1/2^2) \cdot K^2,$$

K = N − 1, very exactly, N being the atomic number. ν_o is the Rydberg spectroscopic frequency in vacuo.[1]

	N presumably is	K =	ν_β/ν_α =
Ca	20	19.00	1.089
Sc	21	—	—
Ti	22	20.99	1.093
V	23	21.96	1.097
Cr	24	22.98	1.100
Mn	25	23.99	1.101
Fe	26	24.99	1.103
Co	27	26.00	1.104
Ni	28	27.04	1.104
Cu	39	28.01	1.105
Zn	30	29.01	1.106

In calculating the grating constant I have taken $e = 4.78\ [\cdot 10^{-10}\text{esu}]$. An error here is not very important as the grating constant depends on $e^{1/3}$.[2]

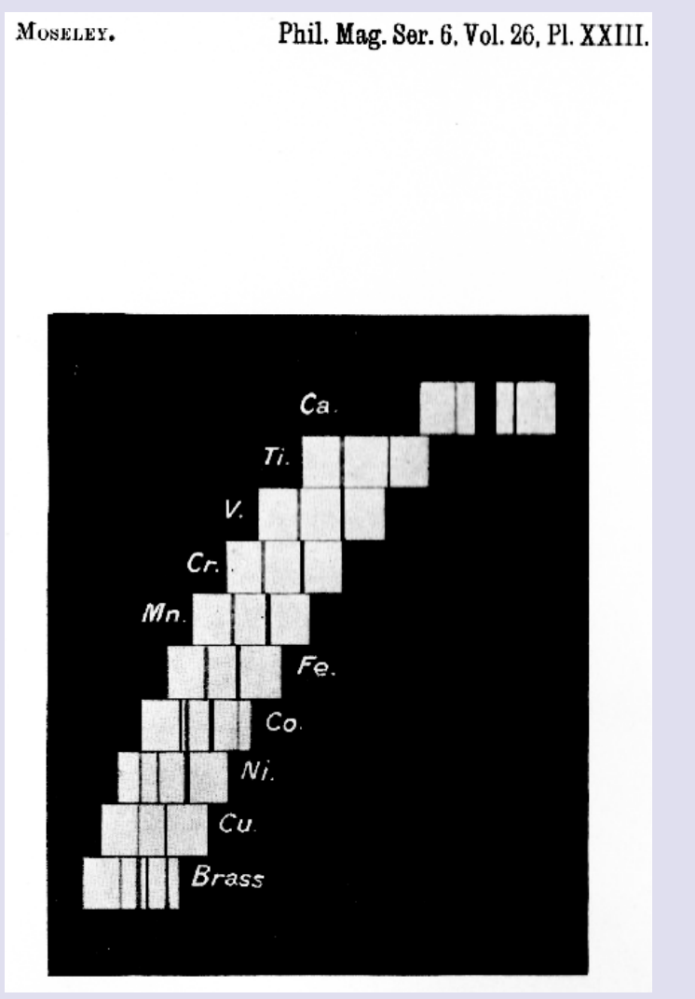
Dear Moseley,

Thank you very much for your kindness in communicating to me your most interesting and beautiful results.

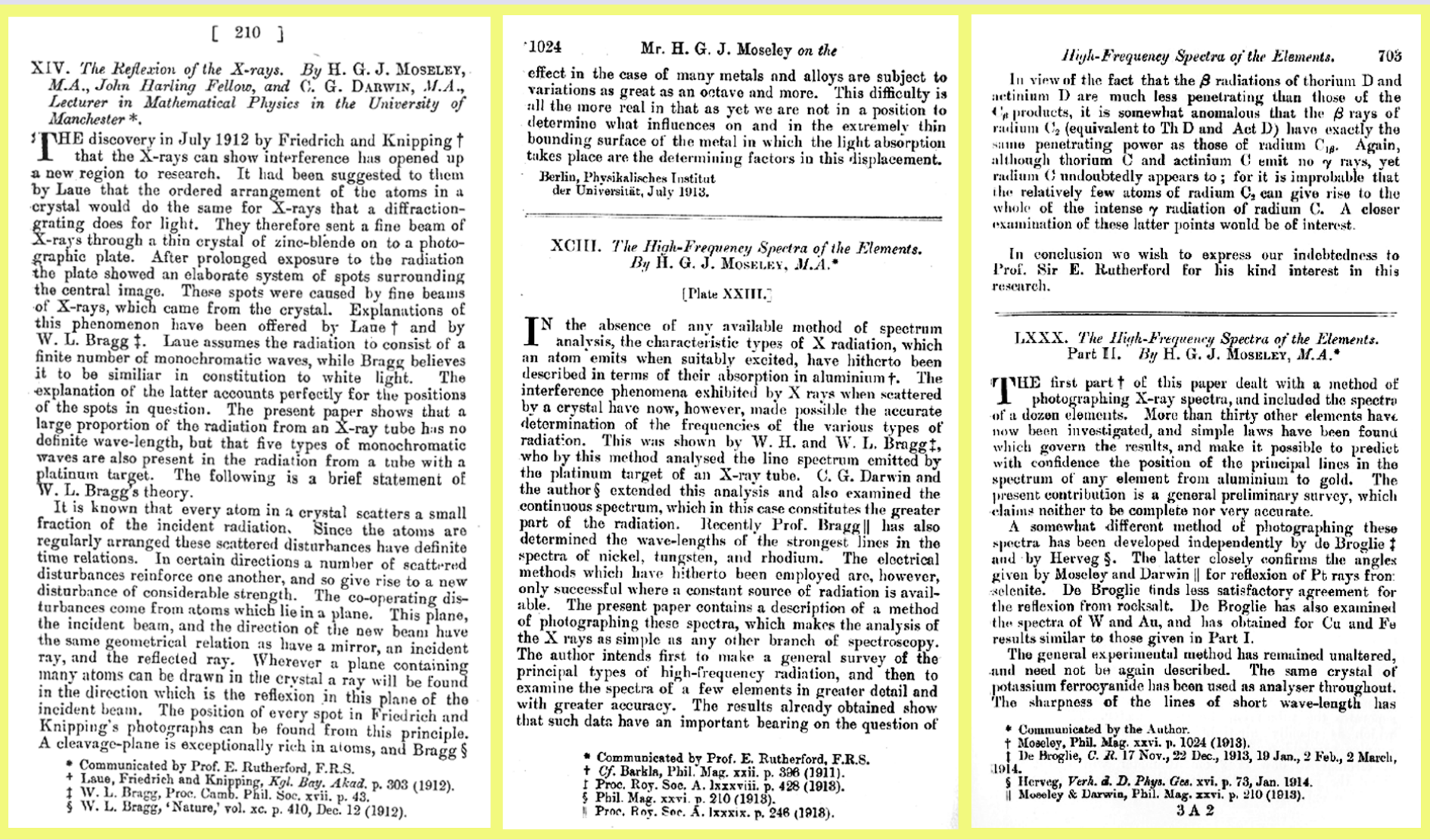
In the general discussion I quite agree with you in your conclusions as to the constancy of the angular momentum as well as to the total number of electrons in the atoms. As to the latter point the uninterrupted sequency of the values for K for all the elements investigated, including the iron group, is most suggestive; it shall be very interesting to know the values for the other elements especially for those of lower atomic weight.

As to the detailed interpretation I must confess that for the present I cannot offer any valuable suggestion; I hope, however, very much that your further investigations shall be able to throw light on the problem. If the lines should really form a simple series in analogy to the Balmer series such as you think possible, this fact would certainly be very suggestive.

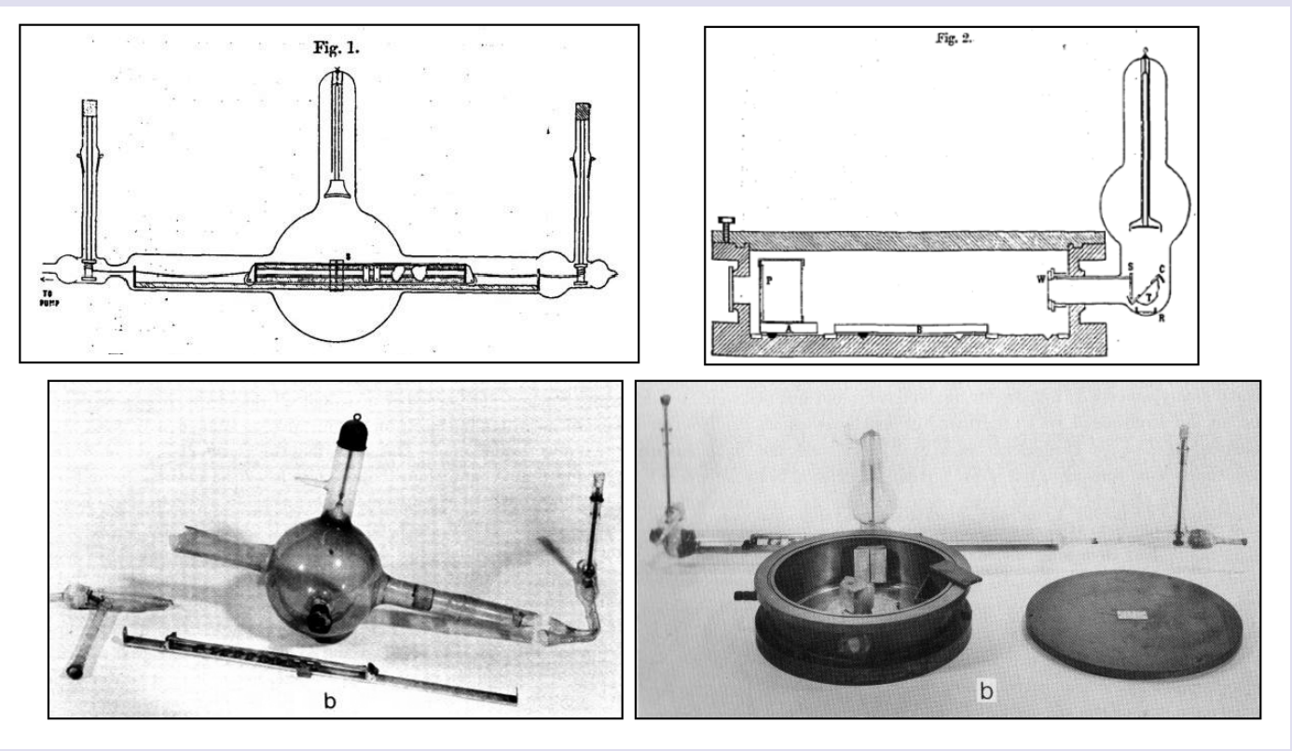
A letter to Niels Bohr about the initial results, and Bohr's answer.



Moseley's famous "staircase" diagram of the spectra of several contiguous elements.



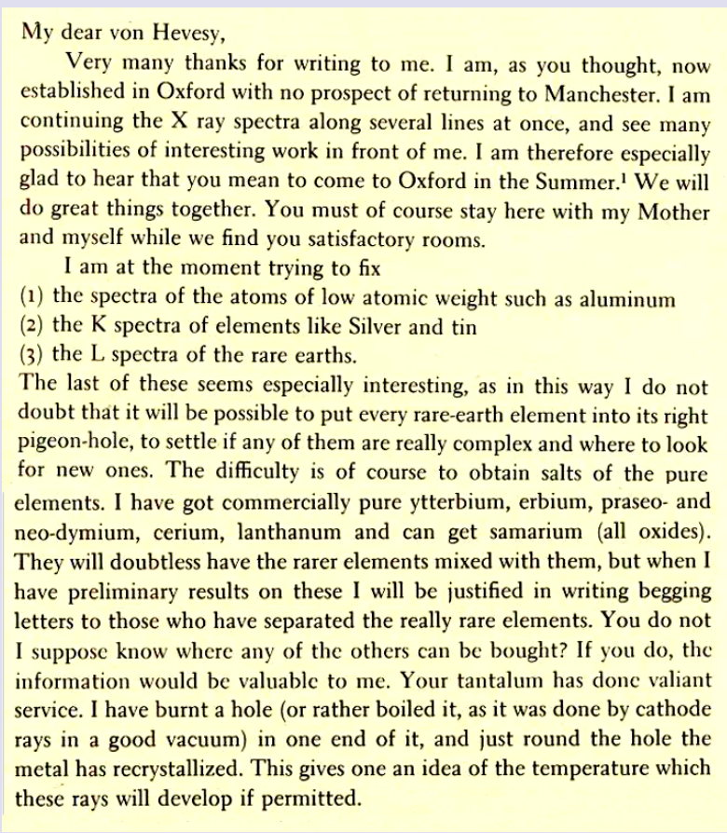
The face pages of his three most important papers.



Original diagrams, and photos of the remainders, of the instruments. On the left, the device for hard x-rays. The targets are mounted on a strip, which can be advanced under the electron beam ("cathode ray") by means of an external magnet, thus avoiding the need to re-evacuate the tube. On the right, the device used for soft x-rays.

Work at Oxford

The X-ray spectroscopy done by Moseley in 1914 showed a direct dependency between characteristic spectral lines and the atomic number. This enabled him to determine the number of lanthanides and showed the gaps in the atomic number sequence at numbers 43, 61, 72, and 75. The discovery of the gaps led to a search for missing elements, generating some unsuccessful claims. With respect to missing element 72, Niels Bohr's theory of its electron-shell structure, indicated that the missing element should not have the properties of a rare earth, but should be similar to zirconium. In 1922 von Hevesy co-discovered Hafnium ("Hafnia" is Latin for Copenhagen, the home of Niels Bohr), with Dirk Coster, based on characteristic X-ray spectra. [Coster, D. and Hevesy, G. (1923) On the Missing Element of Atomic Number 72. Nature 111 (2777): 79.] Hafnium was indeed found to resemble zirconium; this earned von Hevesy the 1943 Nobel Prize in Chemistry.



My dear von Hevesy,

Very many thanks for writing to me. I am, as you thought, now established in Oxford with no prospect of returning to Manchester. I am continuing the X ray spectra along several lines at once, and see many possibilities of interesting work in front of me. I am therefore especially glad to hear that you mean to come to Oxford in the Summer.[1] We will do great things together. You must of course stay here with my Mother and myself while we find you satisfactory rooms.

I am at the moment trying to fix

(1) the spectra of the atoms of low atomic weight such as aluminum
(2) the K spectra of elements like Silver and tin
(3) the L spectra of the rare earths.

The last of these seems especially interesting, as in this way I do not doubt that it will be possible to put every rare-earth element into its right pigeon-hole, to settle if any of them are really complex and where to look for new ones. The difficulty is of course to obtain salts of the pure elements. I have got commercially pure ytterbium, erbium, praseo- and neo-dymium, cerium, lanthanum and can get samarium (all oxides). They will doubtless have the rarer elements mixed with them, but when I have preliminary results on these I will be justified in writing begging letters to those who have separated the really rare elements. You do not I suppose know where any of the others can be bought? If you do, the information would be valuable to me. Your tantalum has done valiant service. I have burnt a hole (or rather boiled it, as it was done by cathode rays in a good vacuum) in one end of it, and just round the hole the metal has recrystallized. This gives one an idea of the temperature which these rays will develop if permitted.

A letter from Moseley to von Hevesy

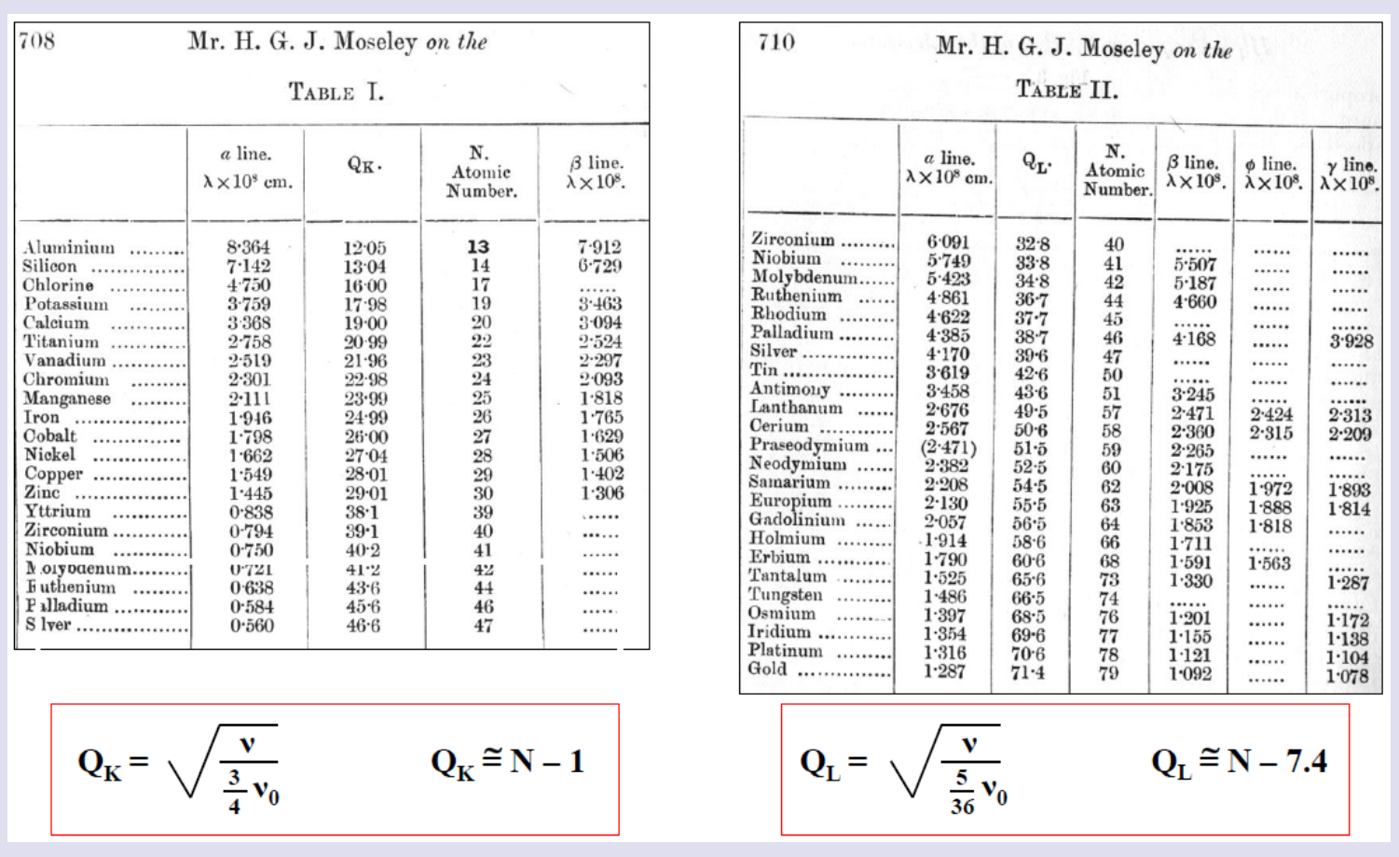


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TABLE I.

	α line. λ×10⁸ cm.	Q_K.	N. Atomic Number.	β line. λ×10⁸.
Aluminium	8·364	12·05	13	7·912
Silicon	7·142	13·04	14	6·729
Chlorine	4·750	16·00	17	......
Potassium	3·759	17·98	19	3·463
Calcium	3·368	19·00	20	3·094
Titanium	2·758	20·99	22	2·524
Vanadium	2·519	21·96	23	2·297
Chromium	2·301	22·98	24	2·093
Manganese	2·111	23·99	25	1·818
Iron	1·946	24·99	26	1·765
Cobalt	1·798	26·00	27	1·629
Nickel	1·662	27·04	28	1·506
Copper	1·549	28·01	29	1·402
Zinc	1·445	29·01	30	1·306
Yttrium	0·838	38·1	39	......
Zirconium	0·794	39·1	40	......
Niobium	0·750	40·2	41	......
Molybdenum	0·721	41·2	42	......
Ruthenium	0·638	43·6	44	......
Palladium	0·584	45·6	46	......
Silver	0·560	46·6	47	......

$$Q_K = \sqrt{\frac{\nu}{\frac{3}{4}\nu_0}} \qquad Q_K \cong N - 1$$

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TABLE II.

	α line. λ×10⁸ cm.	Q_L.	N. Atomic Number.	β line. λ×10⁸.	φ line. λ×10⁸.	γ line. λ×10⁸.
Zirconium	6·091	32·8	40	......	......	......
Niobium	5·749	33·8	41	5·507	......	......
Molybdenum	5·423	34·8	42	5·187	......	......
Ruthenium	4·861	36·7	44	4·660	......	......
Rhodium	4·622	37·7	45	......	......	......
Palladium	4·385	38·7	46	4·168	......	3·928
Silver	4·170	39·6	47	......	......	......
Tin	3·619	42·6	50	......	......	......
Antimony	3·458	43·6	51	3·245	......	......
Lanthanum	2·676	49·5	57	2·471	2·424	2·313
Cerium	2·567	50·6	58	2·360	2·315	2·209
Praseodymium	(2·471)	51·5	59	2·265	......	......
Neodymium	2·382	52·5	60	2·175	......	......
Samarium	2·208	54·5	62	2·008	1·972	1·893
Europium	2·130	55·5	63	1·925	1·888	1·814
Gadolinium	2·057	56·5	64	1·853	1·818	......
Holmium	1·914	58·6	66	1·711	......	......
Erbium	1·790	60·6	68	1·591	1·563	......
Tantalum	1·525	65·6	73	1·330	......	1·287
Tungsten	1·486	66·5	74	......	......	......
Osmium	1·397	68·5	76	1·201	......	1·172
Iridium	1·354	69·6	77	1·155	......	1·138
Platinum	1·316	70·6	78	1·121	......	1·104
Gold	1·287	71·4	79	1·092	......	1·078

$$Q_L = \sqrt{\frac{\nu}{\frac{5}{36}\nu_0}} \qquad Q_L \cong N - 7.4$$

At Oxford, he expanded his work to additional elements, form the rare-earth series.

Legacy

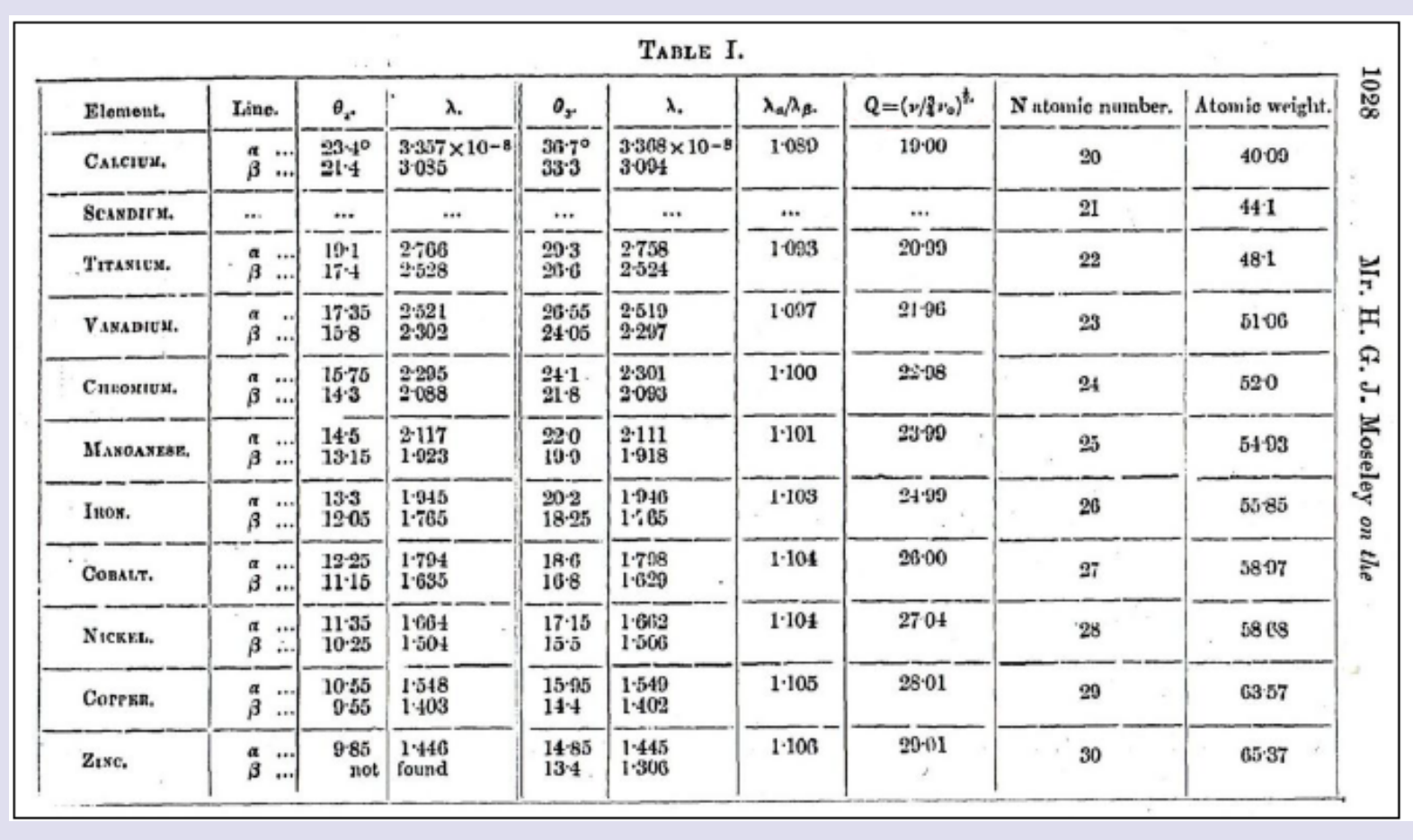

TABLE I.

Element.	Line.	θ_1.	λ.	θ_2.	λ.	$\lambda_\alpha/\lambda_\beta$.	$Q=(\nu/\frac{3}{4}\nu_0)^{\frac{1}{2}}$.	N atomic number.	Atomic weight.
CALCIUM.	α ... β ...	23·4° 21·4	3·357×10⁻⁸ 3·085	36·7° 33·3	3·368×10⁻⁸ 3·094	1·089	19·00	20	40·09
SCANDIUM.	...	...	...	...	...	...	...	21	44·1
TITANIUM.	α ... β ...	19·1 17·4	2·766 2·528	29·3 26·6	2·758 2·524	1·093	20·99	22	48·1
VANADIUM.	α ... β ...	17·35 15·8	2·521 2·302	26·55 24·05	2·519 2·297	1·097	21·96	23	51·06
CHROMIUM.	α ... β ...	15·75 14·3	2·295 2·088	24·1 21·8	2·301 2·093	1·100	22·98	24	52·0
MANGANESE.	α ... β ...	14·5 13·15	2·117 1·923	22·0 19·9	2·111 1·918	1·101	23·99	25	54·93
IRON.	α ... β ...	13·3 12·05	1·945 1·765	20·2 18·25	1·946 1·765	1·103	24·99	26	55·85
COBALT.	α ... β ...	12·25 11·15	1·794 1·635	18·6 16·8	1·798 1·629	1·104	26·00	27	58·97
NICKEL.	α ... β ...	11·35 10·25	1·664 1·504	17·15 15·5	1·662 1·506	1·104	27·04	28	58·68
COPPER.	α ... β ...	10·55 9·55	1·548 1·403	15·95 14·4	1·549 1·402	1·105	28·01	29	63·57
ZINC.	α ... β ...	9·85 not	1·446 found	14·85 13·4	1·445 1·306	1·106	29·01	30	65·37

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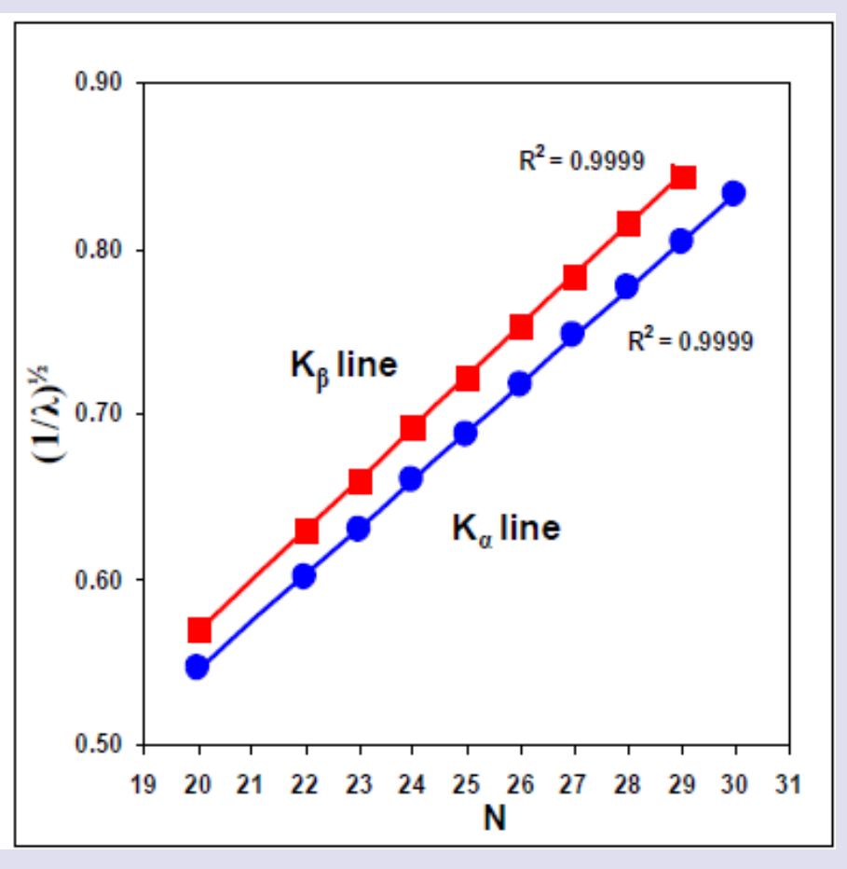
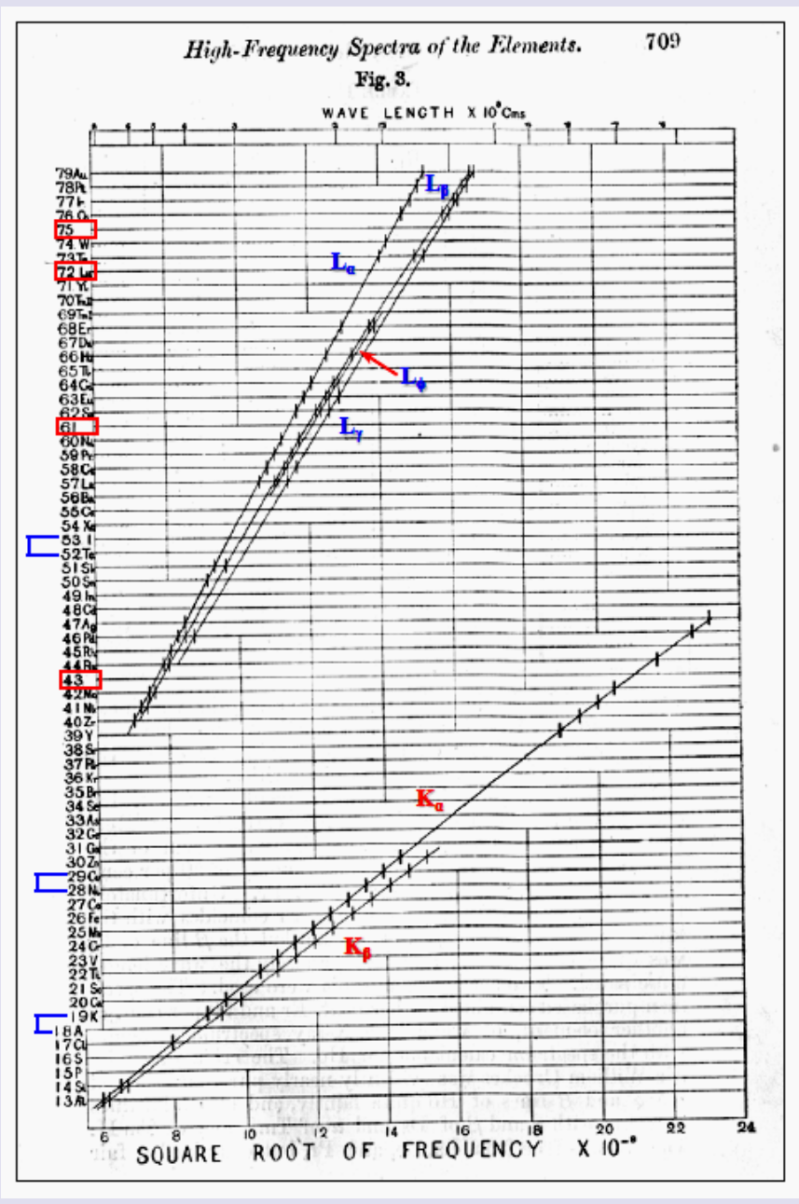




"From the approximate linear relation between $\nu^{\frac{1}{2}}$ and N for each line we obtain the general equation"

$$\boxed{\nu = A\,(N - b)^2}$$

For K_α line

$$A = \left(\frac{1}{1^2} - \frac{1}{2^2}\right)\nu_0 \quad \text{and} \quad b = 1$$

For L_α line

$$A = \left(\frac{1}{2^2} - \frac{1}{3^2}\right)\nu_0 \quad \text{and} \quad b = 7.4$$

Moseley's Law

$$\nu = \nu_0\left(\frac{1}{1^2} - \frac{1}{2^2}\right)(N-1)^2$$

$$\nu = \nu_0\left(\frac{1}{2^2} - \frac{1}{3^2}\right)(N-7.4)^2$$

Unfulfilled promise

Moseley's untimely death, at age 27 at the Battle of Gallipoli, occasioned appreciations from the scientific community, both at the time and later:

Ernest Rutherford:
"Moseley was one of the best of the young people I ever had, and his death is a severe loss to science."
"It is a national tragedy that our military organization at the start was so inelastic as to be unable, with a few exception, to utilize the offers of services of our scientific men except as combatants on the firing line. The loss of this young man on the battlefield is striking example of the misuse of scientific talent."

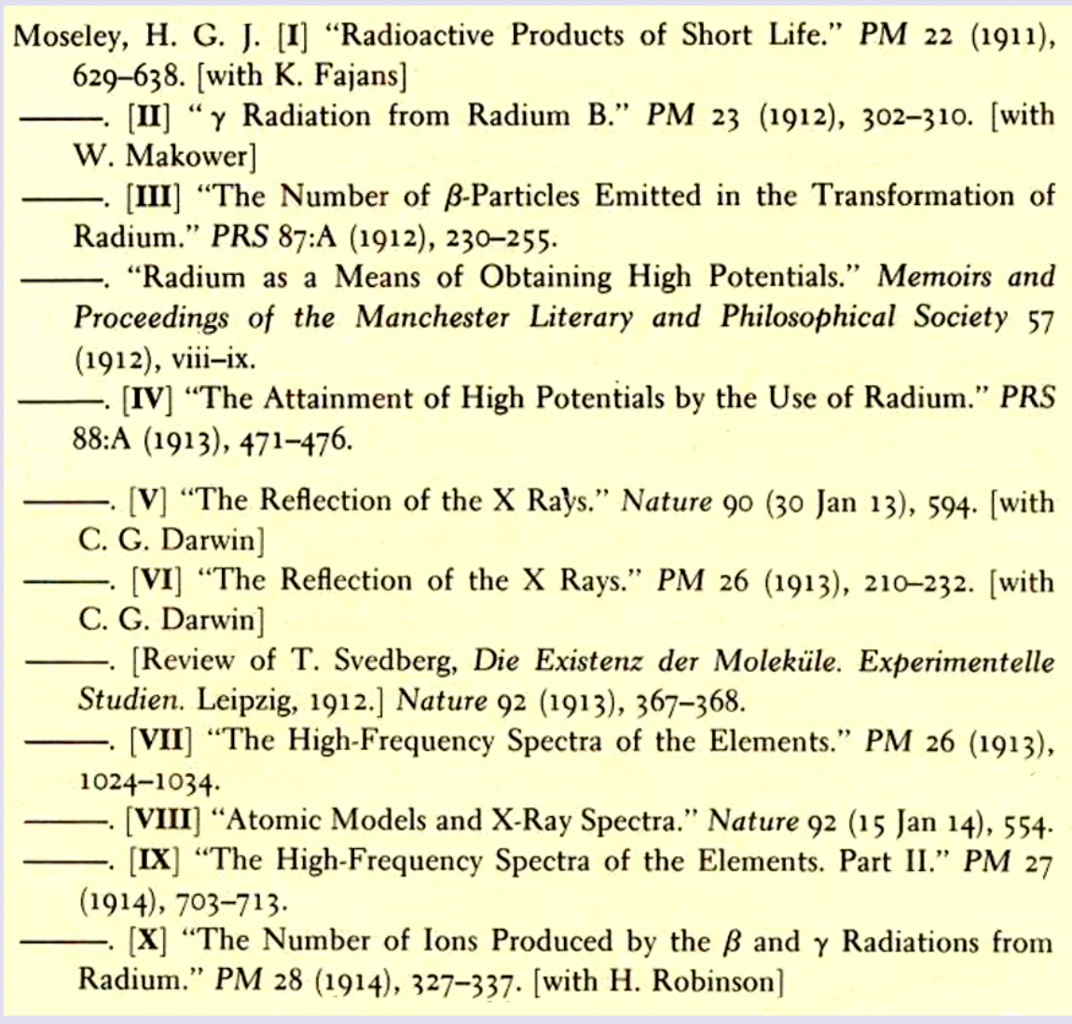
Georges Urbain of the University of Paris wrote to Rutherford:
"I had been very much surprised when I visited Moseley at Oxford to find such a very young man capable of accomplishing such a remarkable piece of work. The Law of Moseley confirmed in a few days the conclusions of my efforts of twenty years of patient work. His law subtituted for Mendeleev's somewhat romantic classification a complete scientific accuracy."

Nobel Laureate Robert A. Millikan:
"In a research which is destined to rank as one of the dozen most brilliant in conception, skillful in execution, and illuminating in results in the history of science, a young man twenty-six years old threw open the windows through which we can glimpse the sub-atomic world with a definiteness and certainty never dreamed of before. Had the European War had no other result than the snuffing out of this young life, that alone would make it one of the most hideous and most irreparable crimes in history."

Nobel Laureate Louis de Broglie:
"Moseley's law was one of the greatest advances yet made in natural philosophy."

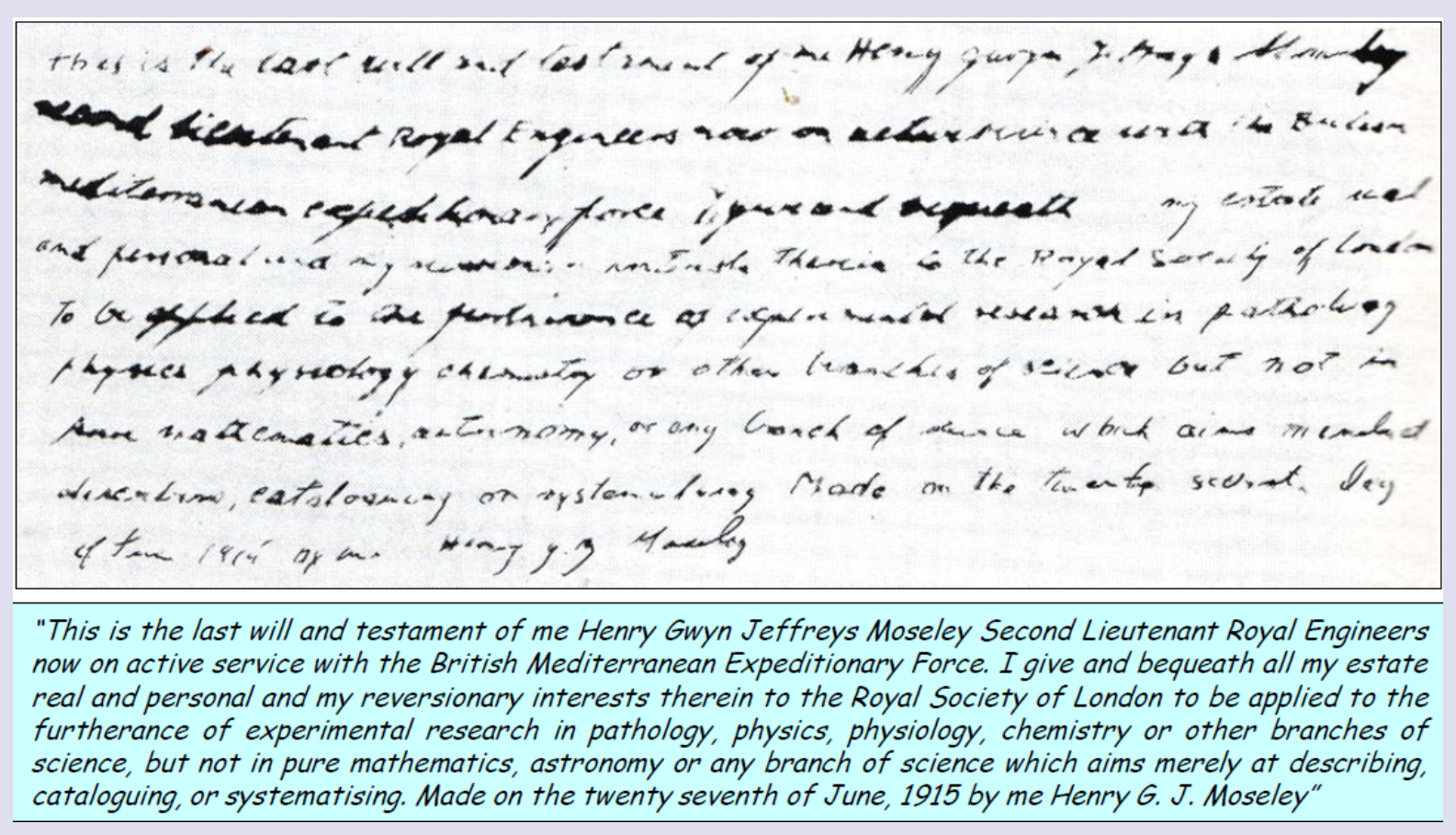
Nobel Laureate Niels Bohr:
"You see actually the Rutherford work [the nuclear atom] was not taken seriously. We cannot understand today, but it was not taken seriously at all. There was no mention of it any place. The great change came from Moseley."

Science writer Isaac Asimov:
"In view of what he might still have accomplished, his death might well have been the most costly single death of the war to mankind generally."



Moseley, H. G. J. [**I**] "Radioactive Products of Short Life." *PM* 22 (1911), 629–638. [with K. Fajans]
——. [**II**] "γ Radiation from Radium B." *PM* 23 (1912), 302–310. [with W. Makower]
——. [**III**] "The Number of β-Particles Emitted in the Transformation of Radium." *PRS* 87:A (1912), 230–255.
——. "Radium as a Means of Obtaining High Potentials." *Memoirs and Proceedings of the Manchester Literary and Philosophical Society* 57 (1912), viii–ix.
——. [**IV**] "The Attainment of High Potentials by the Use of Radium." *PRS* 88:A (1913), 471–476.
——. [**V**] "The Reflection of the X Rays." *Nature* 90 (30 Jan 13), 594. [with C. G. Darwin]
——. [**VI**] "The Reflection of the X Rays." *PM* 26 (1913), 210–232. [with C. G. Darwin]
——. [Review of T. Svedberg, *Die Existenz der Moleküle. Experimentelle Studien.* Leipzig, 1912.] *Nature* 92 (1913), 367–368.
——. [**VII**] "The High-Frequency Spectra of the Elements." *PM* 26 (1913), 1024–1034.
——. [**VIII**] "Atomic Models and X-Ray Spectra." *Nature* 92 (15 Jan 14), 554.
——. [**IX**] "The High-Frequency Spectra of the Elements. Part II." *PM* 27 (1914), 703–713.
——. [**X**] "The Number of Ions Produced by the β and γ Radiations from Radium." *PM* 28 (1914), 327–337. [with H. Robinson]

Moseley's entire publications list, showing that his great contributions were all made within in a short period of his brief life.



"This is the last will and testament of me Henry Gwyn Jeffreys Moseley Second Lieutenant Royal Engineers now on active service with the British Mediterranean Expeditionary Force. I give and bequeath all my estate real and personal and my reversionary interests therein to the Royal Society of London to be applied to the furtherance of experimental research in pathology, physics, physiology, chemistry or other branches of science, but not in pure mathematics, astronomy or any branch of science which aims merely at describing, cataloguing, or systematising. Made on the twenty seventh of June, 1915 by me Henry G. J. Moseley"

Moseley's will, written while on duty in Turkey.

Acknowledgements

This poster was a synthesis of two presentations made at the International Henry Moseley School and Workshop on X-ray Science June 14 - 23, 2012

Institute of Theoretical and Applied Physics (ITAP) Marmaris, Turkey

Presentation 1 by M. Dizdaroglu:
http://itap-tthv.org/moseley_2012/pdf/day.01_june.14.2012_m.dizdaroglu.pdf

Presentation 2 by M. Hart:
http://itap-tthv.org/moseley_2012/pdf/day.01_june.14.2012_m.hart.pdf