Moseley's Work on X-rays.

By Sir ERNEST RUTHERFORD, O.M., F.R.S.

TO the many friends of the late H. G. J. Moseley, who was killed in action at Gallipoli in 1915, it has always been a matter of regret that no reasonable portrait of him could be found. Apparently Moseley had an objection to placing himself in the hands of the professional photographer. Recently, Mr. N. Garrod Thomas kindly sent me the negative of a snapshot of Moseley taken probably in the Balliol-Lincoln Laboratories at Oxford in the summer of 1910, about the time of his graduation and before he took up a post as lecturer in physics in the University of Manchester. A part of this negative has been enlarged by Mr. W. H. Hayles, of the Cavendish Laboratory, and is here reproduced.¹ I think all will agree this is an admirable portrait of Moseley. It is difficult to be certain of the apparatus in his hands, but it may have been connected with a repetition of some of the expansion experiments of Prof. C. T. R. Wilson, which it is known he carried out about that time.

In an obituary notice in this journal (Sept. 9, 1915), and also in a special notice in the Proceedings of the Royal Society in 1916, I gave an account of Moseley's life and work, and directed attention to the fundamental importance of his two papers published in the *Philosophical Magazine* (Dec. 1913, April 1914), entitled "The High Frequency Spectra of the Elements." In these papers he formulated for the first time the law, now known as Moseley's Law, governing the X-ray spectra of the elements, and by its aid was able to fix definitely the number and order of the elements. While the importance of these brilliant researches was immediately recognised, now that a decade has elapsed we can appreciate even more clearly the significance and fundamental character of his discoveries and can estimate the extent to which his work has influenced the development of modern physics.

In this connexion it may not be inappropriate to recall briefly the theoretical position at the moment Moseley began his investigation and the subsequent developments. The nuclear theory of the atom had

been advanced in 1911, and from the results of experiments on the scattering of α rays, it had been suggested that the nuclear charge of an atom might be given by the atomic or ordinal number of the element. On the nuclear theory, the properties of an atom are defined mainly by its nuclear charge, since this controls the number and arrangement of the outer electrons.

Following the discovery in 1912 by Laue, Friedrich, and Knipping of the diffraction of X-rays by crystals,

W. H. and W. L. Bragg in 1913 had found evidence by the electric method of the presence of bright lines in the spectrum of platinum, using the method of reflection of crystal faces. These results were confirmed and extended by an investigation by Moseley and Darwin, published in the same year.

At this stage I remember well a discussion with Moseley, in which he proposed a research to test whether an examination of the X-ray spectra of a group of elements could give a decisive answer to the question whether the properties of an atom are defined by its atomic number, as suggested by the nuclear theory, or by its atomic weight, as indicated by the periodic law of the elements. As we know, his hopes were strikingly verified. He rapidly examined by the photographic method the *K* spectra of a group of the lighter elements and the *L* spectra of a number of

the heavier elements. The conclusions reached by Moseley are clearly given in the terse summary in his second paper, which for its interest is reproduced here.

1. Every element from aluminium to gold is characterised by an integer N , which determines its X-ray spectrum. Every detail in the spectrum of an element can therefore be predicted from the spectra of its neighbours.

2. This integer N , the atomic number of the element, is identified with the number of units of positive units of electricity contained in the atomic nucleus.

3. The atomic numbers for all elements from Al to Au have been tabulated on the assumption that N for Al is 13.

Henry Gwyn Jeffreys Moseley, 1887-1915.

¹ I have arranged with Mr. Hayles to provide copies of this enlargement at a small charge.

4. The order of the atomic numbers is the same as that of the atomic weights, except where the latter disagrees with the order of the chemical properties.

5. Known elements correspond with all the numbers between 13 and 79 except three. There are here three possible elements still undiscovered.

6. The frequency of any line in the X-ray spectrum is approximately proportional to $A(N-b)^2$, where A and b are constants.

Apart from (2), the conclusions drawn in Moseley's paper are a straightforward interpretation of the experimental facts and involve no theoretical assumption as to the nature of radiation or the structure of the atom.

Moseley's identification of the atomic number as a measure of the nuclear charge afforded an interpretation of the frequency law he had found in accord with Bohr's quantum theory of spectra, which had been published previously. The correctness of this identification has since been verified by Chadwick by direct measurement of the scattering of α rays by the nucleus.

As a result of these brilliant experiments of Moseley, a relation of unexpected simplicity is seen to hold for all the elements. The properties of an atom are defined by a whole number which represents the ordinal or atomic number of the element and, at the same time, its nuclear charge and the number of electrons external to the nucleus. The atomic weight turns out to be in a sense a secondary property and the periodic law of the elements is put on a wider and more philosophical basis by the substitution of the atomic number or nuclear charge for the atomic weight of the atom.

The work of Moseley has formed a solid and indispensable foundation for the subsequent attack by an army of researchers of the great problem of the constitution of the outer atom. His frequency law has proved an invaluable aid in interpreting the intricacies

of X-ray spectra and their relation with atomic constitutions—a subject on which so much fine work has been done in recent years.

We have seen that Moseley showed that all possible elements, disregarding isotopes, had been discovered up to number 79 except three,² numbers 43, 61, and 75, and he stated "as the X-ray spectra of these elements can be confidently predicted, they should not be difficult to find." The study of the X-ray spectra affords a powerful and unique method of chemical analysis of a mixture of elements; subsequent research has shown that the presence of an element can be detected with certainty and its amount estimated by its X-ray spectrum even if it be present only to the extent of one part in a thousand. The first of these missing elements found by this method, namely, number 72, was called hafnium by Hevesy and Coster. In this case the method of X-ray analysis was all-important since hafnium is always found with zirconium, with which it is chemically so closely allied that separation is very difficult.

If the other missing elements existed in appreciable amount in minerals, their detection seemed certain. A few weeks ago it was announced by Dr. Noddack and Fräulein Tacke that the missing elements 43 and 75 had been identified by their X-ray spectra in material separated from certain platinum minerals. A preliminary account of their investigations has been given in this journal of July 11. One element, 61, in the rare earths remains unidentified; but for this, Moseley's list of numbers is complete from 1 to 84.

Moseley had the spirit and courage of the true pioneer in science, coupled with great original ability and powers of work. It is rare in the history of science that so young a man has achieved so much.

² In making this statement, Moseley assumed that number 72 had already been filled by a rare earth element cerium. As we now know, number 72 had not been isolated at the time Moseley wrote. There were not three but four gaps.

Concerning the Rate of Man's Evolution.¹

By Sir ARTHUR KEITH, F.R.S.

BEFORE proceeding to discuss my subject—"The Rate of Man's Evolution"—it may be well to ask the question: Is evolution at work in England to-day? Are the Londoners of to-day taller than those of two, ten, or twenty centuries ago? Any one who sets out to answer this simple question is brought face to face with the difficulties which encompass the inquiries of the student of man's evolution. His difficulties are those of variability. The men and women we meet on the streets are of varying height; to strike a true average for the stature of Londoners we must measure hundreds of individuals in every district of this great city. Nor would our average for London hold for the men and women of Birmingham, Manchester and Newcastle, nor would the averages for these cities hold for their surrounding districts. To know the average stature of men and women now living in England entails the measurement of many thousand individuals.

Until the War we believed that the average Englishman stood 5 ft. 8 in. in height; figures gathered then compel us to reduce our estimate by nearly 2 in. When we search the ancient graveyards and burial-places of

England to ascertain the average stature of the men and women buried in them, our difficulties are even greater. The people buried in ancient tombs differed in height just as much as we do; the numbers available for measurement are limited; we have to estimate stature from the length of their limb bones. If we are uncertain of our modern stature, we are still less certain of that of former times. Still, if for the moment we dispense with the precision of the biometrician, we may say that there has been no great change in the stature of the inhabitants of these islands since the close of the Ice Age, some 12,000 years ago. There have been "ups and downs," but the mean for modern Englishmen of 5 ft. 6 in. may be taken as the pivot on which the scales of stature have been balanced for thousands of years.

When we apply measurement to the size and form of head, and compare the dimensions of modern Englishmen with those of former times, we are again confronted with the perplexities of variability. In the third millennium B.C. the skulls of England were long and narrow. About the beginning of the second millennium the eastern and southern parts were settled by a people with short and wide skulls; in the first millennium,

¹ Discourse delivered at the Royal Institution on Friday, March 6.