ON THE SPECTRUM OF X-RAYS FROM AN ALUMINIUM TARGET.[1]

By William Duane and Takeo Shimizu.

Synopsis.

Aluminium Spectrum.—The object of the research has been to investigate the question whether or not the frequencies of the K series are the highest X-rays frequencies characteristic of a chemical element. Several investigators have found experimental evidence, which they interpret as indicating the existence of characteristic emission or absorption of frequency higher than those in the K series. For aluminium the wave-lengths corresponding to these frequencies are stated to be .37 x 10^{-8} cm. and .49 x 10^{-8} cm. The authors of this paper have examined the emission spectrum of aluminium between the wave-lengths .1820 x 10^{-8} cm. and 1.259 x 10^{-8} cm. Four small peaks appear on the curves, indicating characteristic radiation at wave-lengths .622 x 10^{-8} cm., .705 x 10^{-8} cm., .975 x 10^{-8} cm. and 1.18 x 10^{-8} cm. The first two belong to the K series of molybdenum, and undoubtedly come from the metallic molybdenum in the Coolidge carthode in the X-ray tube. The last two belong to the L series of lead, and undoubtedly come from the lead screens containing the slits through which the X-rays passed before they reached the X-ray spectrometer.

No other peaks appear on the curve, and this leads to the conclusion that, within the range examined, aluminium has no emission lines the intensities of which amount to as much as 2 per cent. of the general radiation in the neighborhood.

SEVERAL investigators[2] have obtained experimental evidence, which they interpreted as indicating the existence of the emission or the absorption of X-radiation characteristic of a chemical element (the J-series), and of higher frequency than those in its K-series. Barkla and white (*l.c.*) measured the coefficient of absorption of X-rays in copper, aluminium, paper, water, and paraffin-wax. On platting these coefficients against the wave-lengths, and also on platting the coefficients for one substance against those for another (copper) certain breaks in the curves appeared, similar to, but very much smaller than the breaks that occur at the critical absorption wave-lengths associated with the K and L series of characteristic X-rays. From these breaks they inferred the existence of X-radiation characteristic of aluminium, oxygen and carbon at the wave-lengths .37 x 10^{-8} cm., 39 x 10^{-8} cm. and .42 x 10^{-8}

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[1] A paper read at the New York meeting of the American Physical Society, March 1, 1919.

[2] C. G. Barkla, Roy. Soc. Phil. Trans., 217, pp. 315–360, Aug. 29, 1917. C. G. Barkla and Margaret P. White, Phil. Mag., 34, pp. 270–285, Oct., 1917. C. M. Williams, Roy. Soc. Proc., 94, pp. 567–575, Aug. 1, 1918.

cm. respectively. In these experiments the X-rays were not homogeneous, and the wave-lengths were not measured by means of an X-ray spectrometer. They were calculated from the relation between the wave-length and the mass coefficient of absorption in aluminium. At a meeting of the American Physical Society in December, 1914, one of us proposed the equation

$$\frac{\mu}{\rho} = 14.9 \times \lambda^3 \text{ (}\lambda\text{ in ångströms)}$$

for this purpose, and it has been used to measure the wave-lengths of the general radiation.[1] It gives the effective wave-length, which may be defined as the wave-length of the homogeneous radiation that would have the same coefficient of absorption as the general radiation in some standard substance.

Williams (*l.c.*) measured the coefficient of absorption of *homogeneous* X-rays in aluminium and in copper. The homogeneous beam of rays was produced and its wave-length measured by means of an X-ray spectrometer. He took the precaution of so regulating the voltage applied to the X-ray tube that no X-rays in spectra of higher order than the first should be reflected by the crystal at the grazing angles used.

He found a small break in the coefficient of absorption wave-length graph for aluminium at $\lambda = .49 \times 10^{-8}$ cm., which is 30 per cent. longer than the wave-length determined by Barkla and White.

Williams also found a break in the corresponding graph for copper, but the break is in a direction opposite to that occurring at the characteristic absorption wave-lengths in the K and L series.

On account of the great importance in the theories of radiation and the structure of matter of knowing exactly what the highest X-ray frequency characteristic of a chemical element really is we decided to investigate the spectrum of the X-rays *emitted* by an aluminium target.

The Wave-lengths of the X-rays we have examined lie between $.1820 \times 10^{-8}$ cm. and 1.259×10^{-8} cm. This is the portion of the spectrum usually obtained from an ordinary X-ray tube excited by a difference of potential of 71,200 volts, and includes with ample margins the region in which the above mentioned scientists found the breaks in the absorption curves, and in which, therefore, the J characteristic radiation is supposed to lie.

As the shortest wave-length in the K series of aluminium is 7.98×10^{-8} cm. the range of frequencies in our experiments extends from 6.34 to 43.8 times the highest frequency in this K series.

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[1] Duane & Hunt, PHYS. REV., Vol. 6, No. 2, p. 169, Aug., 1915.

To produce X-rays of higher frequency than the upper limit in our experiments requires a difference of potential greater than 71,200 volts. At this difference of potential the X-ray tube began to show signs of weakening, and we did not push the research further for fear of destroying it.

The thickness of the glass walls of the X-ray tube fixes the lower limit of frequency. X-rays longer than about 1.26×10^{-8} cm. are almost completely absorbed by the glass.

In making the measurements we used the apparatus described in the Physical Review for December, 1917, p. 624. This consisted of an X-ray spectrometer with a calcite crystal, the beam of X-rays being defined by two slits in lead blocks, which lay between the X-ray tube and the spectrometer. The electric current through the tube came from a high tension transformer connected to a system of kenotrons and condensers, which produced approximately a constant voltage.

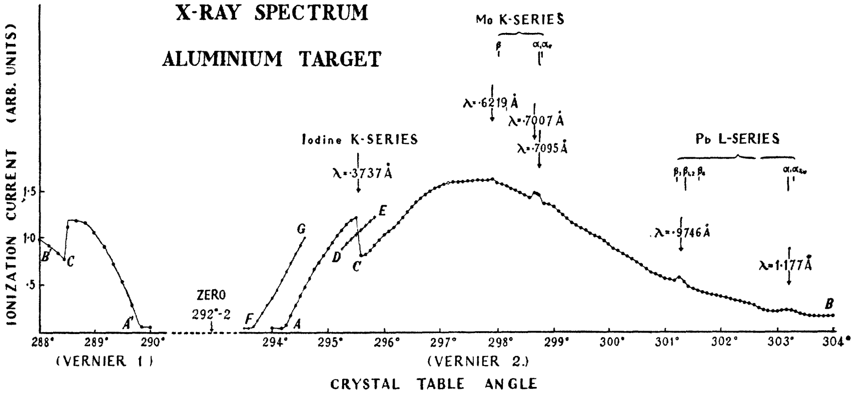

Fig. 1.

The X-ray tube (kindly sent us by Dr. W. D. Coolidge) was similar to the ordinary Coolidge tube, except that an aluminium target replaced the usual tungsten target. The cathode in these tubes consists of a hot tungsten wire coiled in the form of a circular disk and surrounded by a shield of metallic molybdenum.

The figure contains the curves obtained by platting the currents in the spectrometer's ionization chamber against the readings of the verniers attached to crystal table.

We took readings at intervals of 5 minutes of arc, having purposely regulated the breadths of the slits so as to eliminate the possibility that a peak representing characteristic radiation might lie between two such readings.

Curves AB and $A'B'$ represent an experiment in which the difference of potential applied to the tube amounted to about 53,200 volts. The points A and A', where the curves begin to rise above the natural ionization leak of the instrument, correspond to the frequency which, when multiplied by Planck's action constant, h, equals the energy acquired by an electron in the X-ray tube as given by the product of the difference of potential into its electric charge.[1]

The position of the zero on the scale was estimated from these two points A and A'. A correction of 45″ of arc must be subtracted from the double grazing angle of incidence 2θ on account of the scale's eccentricity, when calculating the wave-lengths from the usual formula $\lambda = 6.056 \times \sin\theta \times 10^{-8}$ cm.

At the points marked C and C' occur sharp breaks in the curves. These are due to the fact that the ionization chamber contained methyl iodide. The critical ionization wave-length of iodine is $.3737 \times 10^{-8}$ cm.,[2] and X-rays of shorter wave-length than this ionize the gas much more strongly than X-rays of longer wave-length do.

As the break in the absorption curve obtained by Barkla and White (*l.c.*), from which they inferred the existence of characteristic J radiation occurs at wave-length $.37 \times 10^{-8}$ cm., and as the break in our curve at C might completely mask a peak representing characteristic emission lines, we repeated our measurements over wave-lengths in this neighborhood using ethyl bromide in the ionization chamber instead of methyl iodide. The curve DE represents this experiment, and no peak appears in it that can be interpreted as indicating characteristic emission lines.

Further no peak appears on the curve AB in the neighborhood of wave-length $.49 \times 10^{-8}$ cm. at which Williams (*l.c.*) found a break in the absorption curve.

There are, however, two small peaks at wave-lengths $.6219 \times 10^{-8}$ cm. and $.7051 \times 10^{-8}$ cm. Within the limits of experimental error these are the wave-lengths of the β and α lines in the K series of molybdenum, and it is reasonable to suppose that these peaks are due to the presence of the metallic molybdenum in the Coolidge cathode. It is uncertain whether they are to be ascribed to primary radiation from a thin film of molybdenum deposited on the target during the excessive heating process to which these X-ray tubes are subjected during their exhaustion, or to tertiary, etc., rays excited in the target by secondary rays from the molybdenum in the cathode.

At wave-lengths $.9746 \times 10^{-8}$ cm. and 1.177×10^{-8} cm. appear two

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[1] Duane & Hunt, PHYS. REV., August, 1915, p. 169.

[2] Duane and Hu, PHYS. REV., June, 1918, p. 491.

more small peaks indicating characteristic radiation. These peaks correspond exactly with the β and α lines in the L series of lead, and, doubtless, are due to secondary rays from the lead blocks containing the slits through which the X-rays passed before they reached the spectrometer.

In order to extend the research to X-rays of shorter wave-length than those produced by a difference of potential of 53,200 volts, we took a series of readings with a difference of potential of 71,200 volts. The curve *FG* represents these measurements, and it contains no peak.

Molybdenum and lead are much more efficient radiators of X-rays than aluminium is, for their atomic numbers are higher, 47 and 82 respectively, instead of 13 for aluminium. Further, if the voltage applied to the X-ray tube lies considerably above that required to produce the characteristic rays of its target (as is the case with molybdenum and lead in our experiments), the characteristic radiation is many times more intense than the general radiation in its neighborhood. It is not surprising, therefore, that secondary or tertiary characteristic radiation from molybdenum and lead can produce effects amounting to a few per cent. of the general primary radiation from aluminium, upon which it is superposed, as indicated by our curves.

No peaks representing the emission of characteristic X-rays appear on our curves other than those corresponding to the K series of molybdenum and the L series of lead, and we conclude, therefore, that aluminium has no characteristic lines in its emission spectrum, between the wave-lengths $.1820 \times 10^{-8}$ cm. and 1.259×10^{-8} cm. that amount to as much as 2 per cent. of the general radiation in the neighborhood and that can be produced by the voltages we employed.

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