XXIV. *Spectrum of the Radium Emanation.* *By* Prof. E. Rutherford, *F.R.S., and* T. Royds, *M.Sc., Beyer Fellow, University of Manchester* *.

[Plates X. & XI.]

THE first determination of the spectrum of the radium emanation was made in 1904 by Ramsay and Collie †, who obtained visual observations of the wave-lengths of eleven lines. They stated that the emanation was a bright line spectrum similar in general character to that observed for other monatomic gases. Since that time, no further information on this important subject has been forthcoming. In a previous paper ‡, one of us has given an account of methods employed in purification of the emanation and determination of its volume. In order to test the purity of the emanation, an electrodeless discharge was passed in the capillary tube in which the volume of the emanation was measured, and visual observations of the wave-lengths of the main lines were made by means of a direct reading Hilger spectroscope. We have observed the spectrum of the radium emanation in this way on four different occasions during the past two months. It was evident that a number of new lines were present, which were not recorded in the initial observations of Ramsay and Collie. As soon as the measurements of the volume had been completed, arrangements were made to photograph the emanation spectrum in order to determine the wave-lengths of the lines with more accuracy than is possible with visual observations. For this purpose, a quantity of radium emanation was purified as completely as possible by the methods outlined in the last paper. The emanation was first condensed in a U-tube surrounded by liquid air, and the uncondensed gases completely pumped off. The emanation was then left for three hours in contact with a tube coated with caustic potash to remove the last traces of carbon dioxide. Finally, the U-tube was surrounded by a pentane bath cooled down by liquid air, and the uncondensed gases pumped off at a temperature above that of liquid air. In order to obtain the spectrum, a small vacuum tube of capacity about

* Communicated by the Authors. A preliminary account of this work was published as a letter in 'Nature,' July 8, 1908.

† Proc. Roy. Soc. lxxiii. p. 470 (1904).

‡ See Rutherford, "Volume of Emanation," Phil. Mag. Aug. 1908.

50 c.mms., provided with fine platinum electrodes, was used. This was sealed to the connexion leading to the pump and completely exhausted, a discharge being passed to free the electrodes of hydrogen. When the emanation had been purified as completely as possible in the manner outlined, it was condensed in the spectrum-tube by dipping a side tube connected with it in liquid air. When the greater part of the emanation had been condensed, the spectrum-tube was sealed off and removed for observation.

Measurements of the γ ray activity showed that the amount of emanation in the tube corresponded to 130 milligrams of radium. Now the volume of the emanation per gram of radium is ·57 cubic mm. Consequently, the volume of the pure emanation in the spectrum tube was ·074 cubic mm. Since the volume of the spectrum-tube was 50 cubic mms., this would give a pressure of emanation in the tube of 1·1 mms. of mercury. In order to photograph the spectrum, a spectrograph with a glass prism of two inches base was used. The length of the spectrum on the plate between λ 5000 and λ 4000 was 1·5 cms. Arrangements were made so that visual observations of the wave-lengths could be made by the Hilger spectroscope while the plate was being exposed. Two photographs were taken before the emanation spectrum ran out. The first (photograph 1) showed about thirty of the more intense emanation lines. The second (photograph 2), which had a much longer exposure, showed over a hundred lines. A helium tube was used for comparison purposes, and its spectrum obtained above and below the emanation spectrum. The plates were measured up with the aid of a Kayser's measuring machine. The wave-lengths were deduced with the aid of the Hartmann dispersion formula.

Remarks on Spectrum.

The colour of the discharge through the emanation was bluish and not so intense as the helium tube. The spectrum observed visually was a brilliant one of bright lines. The most noticeable lines were a number of strong lines in the green and another group in the violet. The mercury and hydrogen lines were also observed. In order to be sure that the lines were due to the emanation, the side tube attached to the spectrum-tube was immersed in liquid air. At the moment of condensation, which was readily noticed by the increased brilliancy of the phosphorescence of the glass, practically all the lines except those due to hydrogen vanished. The colour of the discharge then completely changed to a pale rose, and the tube became harder. At the moment of volatilization the emanation lines flashed out again.

The hydrogen lines came out more strongly when the emanation was condensed. In previous experiments with the electrodeless discharge, the hydrogen lines had been absent. Their occurrence in the present experiment was without doubt due to the liberation of hydrogen from the platinum electrodes when a strong discharge was passed. This is borne out by the results of another experiment recorded later. The emanation was momentarily condensed at intervals during the experiment in the side tube. From observations of the brilliancy of the phosphorescence at condensation, it was noted that the amount of the free emanation in the tube gradually diminished with increasing time of discharge, while the intensity of the emanation spectrum decreased relatively to that of hydrogen. The emanation lines, however, persisted to the close of the experiment, when practically all the emanation had been driven into the walls of the tube. From observations of the phosphorescence, it was evident that the emanation was approximately uniformly distributed along the line of discharge. As the discharge had been reversed at intervals during the experiment, it was difficult to be certain whether there had been any considerable absorption of the emanation by the electrodes. The occlusion of the emanation had been observed previously on several occasions in the capillary tube using the electrodeless discharge (see previous paper). It seems probable that the emanation is in some way driven into the walls of the tube by the discharge. This effect is no doubt similar to that recorded by Campbell Swinton for ordinary gases. It is difficult to remove such occluded emanation even by strongly heating the glass.

After three days, the tube was very much darkened by the emanation, and it was necessary to get rid of the blackening by heat in order to observe the spectrum. The main helium lines were observed, but were faint in comparison with the hydrogen lines.

After a week's interval, the spectrum-tube was again attached to the pump and thoroughly heated above the temperature of thermo-luminescence in order to make the glass as transparent as possible. The spectrum-tube was exhausted, care being taken by heating the tube and by passage of a strong discharge to get rid of most of the hydrogen from the electrodes. About the same quantity of pure emanation as in the first experiment was condensed in the tube. After sealing off the tube, the spectrum was photographed, visual observations being made at the same time.

The same general effect as in the first experiment was observed when the emanation was condensed on the side tube. In this case, however, the hydrogen spectrum was relatively much feebler. On condensing the emanation, the tube became very hard and showed the characteristic green coloration of the cathode-ray vacuum. It was thus clear that the methods employed had been fairly successful in getting rid of the hydrogen from the electrodes. The photograph of the spectrum in this case (photograph 3) showed only the hydrogen line H_β, although H_α also was observed visually. In the second photograph, already referred to, the stronger lines of the compound line spectrum of hydrogen had been photographed*. The photograph 3 is reproduced in Plates X. and XI., magnification 3·7 times. Plate X. was exposed to bring out clearly the strong lines of the spectrum only. It will be seen that the stronger lines in Plate XI. are somewhat overexposed in order to bring out some of the less intense lines in the spectrum. This photograph is somewhat better for reproduction purposes than photograph 2, but does not show quite the same number of faint lines.

The measurements of the wave-lengths of the lines common to the two plates agreed within the limits of experimental error. We shall consequently only give the measurement of photograph 2, since the hydrogen lines present in this spectrum serve as an indication of the accuracy of the measurements. It will be seen that the error of measurement is certainly not greater than half an Ångström unit. The lines given in the Table are common to both photographs. It has not been thought necessary to give the weaker lines observed, for the identity of these with the emanation spectrum requires further confirmation.

In the Table the lines observed visually are given in a separate column. In photograph 3, when the hydrogen was far less prominent, the relative intensity of some of the emanation lines differed from that observed in photograph 2.

* No trace of the carbon-dioxide spectrum was observed in either experiment. The occurrence of this spectrum in the electrodeless discharge in nearly pure emanation (see paper, *loc. cit.*) was without doubt due to a trace of organic matter on the surface of the mercury.

Wave-lengths of the Emanation Lines.

Visual.		Photograph.		Remarks.	Visual.		Photograph.		Remarks.
Inty	λ.	Inty	λ.		Inty	λ.	Inty	λ.	
0	6079				0	4439	8	4435·7	Inty 2 in photo. 3.
1	5976						3	4384·0	
1	5945						4	4372·1	
1	5829				3	4351	15	4350·3	
1	5765						7	4340·9	Hγ 4340·66. Absent
3	5718	1	5715·0		1	4310	10	4308·3	from 3rd photo.
5	5582	8	5582·2				2	4225·8	
0	5395	0	5392·4		1	4202	10	4203·7	
0	5372						5	4188·2	
1	5257				1	4169	20	4166·6	
2	5120						7	4114·9	
10	5087	4	5084·5				6	4102·2	Hδ 4101·85. Absent
2	5060						2	4088·4	from 3rd photo.
10	4985	4	4979·0				1	4055·7	
1	4964	0	4965·6				2	4051·1	
1	4955	00	4949·4				4	4045·4	
1	4917	00	4914·6				1	4040·2	
1	4895	0	4889·5				10	4018·0	
	4865		4861·3	Hβ 4861·49			12	3982·0	
0	4831	1	4827·8				9	3971·9	Not Hε 3970·25.
2	4820	4	4817·2				7	3957·5	
0	4798	1	4796·7				3	3952·7	
1	4772	3	4767·9				3	3933·3	
1	4726	5	4721·5	Inty 1 in photo. 3.			1	3927·7	
0	4705	2	4701·7				2	3905·7	Inty 0 in photo. 3.
5	4685	10	4681·1	Does not quite dis-			4	3867·6	
		1	4671·8	appear when emana-			2	3818·0	
		1	4659·3	tion condensed.			0	3811·2	
5	4650	10	4644·7				10	3753·6	Inty 3 in photo. 3.
6	4631	8	4625·9				1	3748·6	
1	4614	7	4609·9	Inty 4 in photo. 3.			7	3739·9	„ 1 „
3	4608	4	4604·7	„ 6 „			2	3690·4	
1	4581	7	4578·7	„ 4 „			1	3679·2	
0	4550	1	4549·9				10	3664·6	
1	4511	9	4509·0	„ 4 „			0	3650·0	„ 3 „
		2	4504·0				2	3626·6	
0	4460	10	4460·0	„ 2 „			1	3615·4	
		2	4440·6				6	3612·2	

None of the emanation lines have been identified in any stellar spectra.

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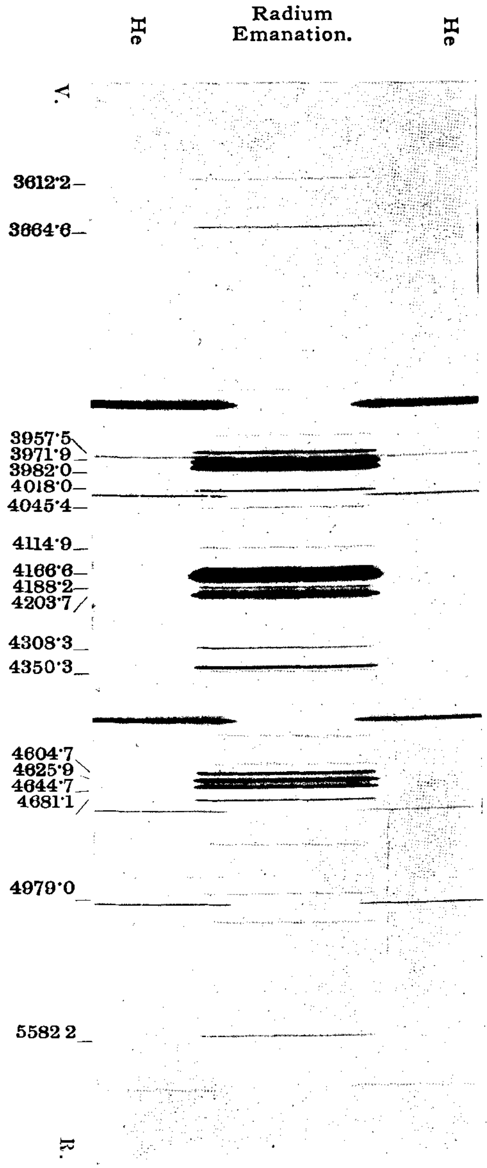
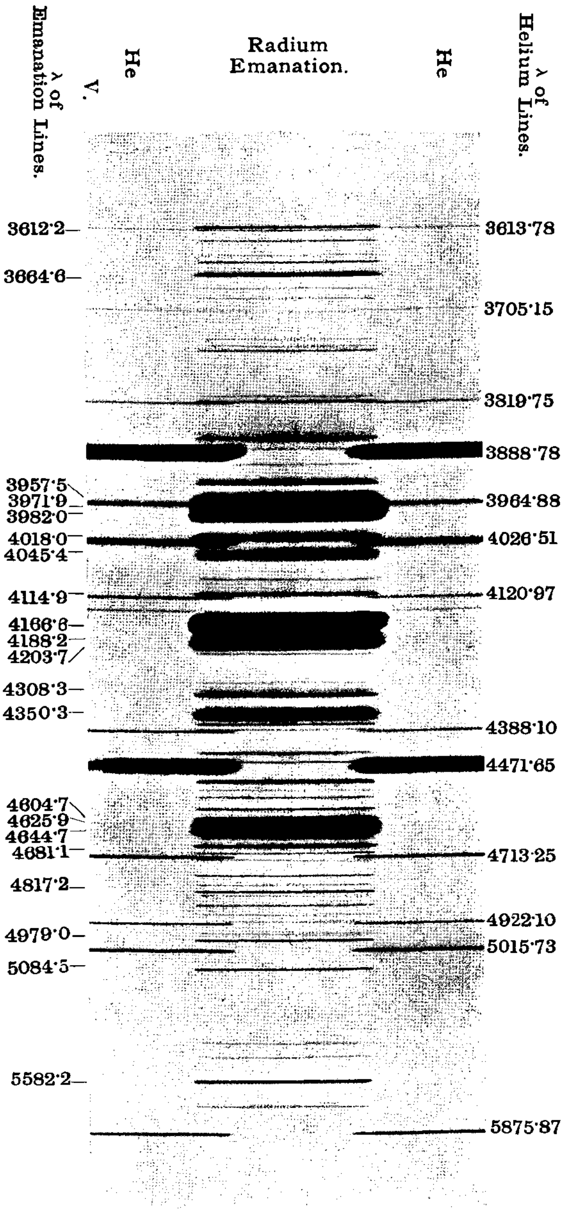


Strongest Lines in the
SPECTRUM OF RADIUM EMANATION.



SPECTRUM OF RADIUM EMANATION.

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