Kodaikanal Observatory.

BULLETIN No. XXVII.

ON THE PRESENCE OF RADIUM AND THE ELEMENTS OF THE INACTIVE GROUP IN THE CHROMOSPHERE.

A comparison of the wave-lengths of radium lines measured by Runge and Precht with Rowland's table of solar spectrum lines shows, as was pointed out by Runge, that the radium lines are not found in the absorption spectrum of the sun. A comparison of the emanation lines measured by Royds with the sun gives a similarly negative result

A comparison recently made by Dr. Dyson * of the lines of radium and the emanation with the bright line spectrum of the chromosphere as observed at eclipses indicates several apparent coincidences of wave-length which suggest that these elements may, after all, be revealed by their emission lines although not by their absorption lines, as is the case with helium in the sun.

In discussing the spectroscopic results of the eclipses of 1898 and 1900 I showed that the chromosphere or "flash" spectrum observed at eclipses is in truth a reversal of the Fraunhofer spectrum, notwithstanding the great differences in the relative intensities of the lines of different elements in the bright line and dark line spectra; and that the only bright lines of the flash spectrum which could not with reasonable certainty be identified with the dark lines of the Fraunhofer spectrum are those of helium in the visible region of the spectrum and of hydrogen in the ultra violet region, and the unknown line at 4685·7.†

In the absence of very accurate measures of the wave-lengths of the flash spectrum lines, it is not possible to say with certainty whether other elements may not also be recognised in the emission spectrum of the chromosphere although not in the absorption spectrum. If radium and the emanation can be so recognised it would be natural to suppose that in addition to helium, other elements of the inactive group (in which I include the emanation) might be expected to indicate their presence in this way.

In the year 1903 S. A. Mitchell announced the discovery of neon and argon in the flash spectrum,‡ but his conclusions appear to have been based on insufficient evidence, and the wave-lengths of the neon lines at that time were not known with sufficient accuracy to give a decisive result.

I propose to show that with the best eclipse material now available and the most recent measurements of the lines of the elements in question the evidence is of a distinctly negative character as regards radium and the emanation as well as neon and argon, and the probability is that not one of these elements can be recognised in the sun by a study of the emission spectrum of the chromosphere, any more than by a comparison with the solar absorption spectrum.

For comparison with the radium and emanation lines in the ultra violet region of the spectrum, I have taken the chromosphere wave-lengths from my measures of the "flash" spectrum obtained at the eclipse of 1900 for which the limits of accuracy may be estimated at about ±0·04Å for well-defined lines. In the less refrangible region between the limits λλ 4000 and 4800 no measures have hitherto been published which are sufficiently accurate for satisfactory comparisons. At the eclipse of 1905 Mitchell secured some grating spectra of the "flash" which are, I believe, the finest which have ever been obtained in the less refrangible region, and it is to be regretted that no wave-length measures have been published. I have in my possession

* Astronomische Nachrichten No. 4589. † Phil. Trans. A. **197**, 402; A. **201**, 463. ‡ Astrophysical Journal XVII, 224.

some positives on glass of these plates kindly sent me by Dr Mitchell, and at the risk of anticipating to some extent any results which he may subsequently publish, I have myself made a set of measures of all the lines which fall near to either radium or emanation lines.

The scale of the plates is 1 mm. = 10·8 Å and the definition is such that isolated lines of medium intensity can be measured with a probable error of ± 0·001 mm or ± 0·01Å. Many of the fainter lines or blends will however be subject to an error four or five times greater than this. As the spectra are almost perfectly normal the reduction process is the simplest possible; I have taken as standards sixteen lines well identified with lines in Rowland's table, mostly of titanium, and distributed over a range of spectrum extending from λ 4012 to λ 4924.

In tables I and II I have entered in columns 3 and 4 the results of these measures with estimates of intensity. The more refrangible chromosphere lines are from my 1900 eclipse results, these being of the same order of accuracy as the measures of Mitchell's plates In columns 5, 6, 7 I give the wave-lengths, intensities and origins of the nearest Fraunhofer lines from Rowland's table.

TABLE I—*Radium.*

Radium lines (Runge and Precht).		Chromosphere.		Solar lines (Rowland).			Remarks.
λ	Intensity	λ	Intensity.	λ	Intensity.	Origin.	
				3649·438	4	Fe.	
3649·75	50	3649·53 *	5	·476	3	Co.	
				·654	5	Fe-La	
				3814·671	4	Fe-C.	
3814·58	100	3814·73 †	7	·738	3	—C.	p Ti. Lockyer.
4340·83	50	Hγ interferes					
4436·49	20	4435·84	1	4435·851	4	Ca.	Chromosphere lines from Mitchell's 1905 spectrum.
				4682·088	3	Ti	
4682·36	50	4682·23	0	·295	1	Fe. ?	
		4682·57	0	·529	1	—Co.	
4826·12	20	4825·74	0			...	

TABLE II—*Emanation.*

Emanation lines (Royds.)‡		Chromosphere.		Solar lines (Rowland).			Remarks.
λ	Intensity.	λ	Intensity.	λ	Intensity.	Origin.	
3612·76	3	(3612·65)	(0)	.	...	...	
3664·96	5	3664·74	10	3664·760	2	Y	3664·78 in chromosphere, Dyson.
3957·80	8	..		..	. .	.	
3971·71	8	3972·1	0	3972·813	2	Ni	3972·02 ditto.
				3981·248	2	Fe	
		3981·3		3981·376	1	Cr	
3981·83	15		Band.				3981·87 ditto.
		3982·8		3981·917	4	Ti	
				3982·742	3	Y	
4017·90	6	4018·09	0	4018·251	7	Mn	
4114·71	6	4114·72	0	4114·606	4	Fe	
4166·59	20	4167·63	1	4167·438	8	. .	Wide line in chromosphere probably 2 lines.
4208·29	10	. .	...	..		...	
				4307·907	3	Ca	
(4308·3)	(10)	4308·01	3				
				4308·081	6	Fe	
4349·81	15	4348·01	0	4348·008	2	Fe	
(4460·0)	(10)	4460·46	1	..	.	..	
4508·68	7	4508·46	4	4508·455	4	Fe? —	4508·463 Hale & Adams
4577·77	8	4576·58	1	4576·512	2	...	4576·526 in chromos-
4604·46	6	4603·18	0	4603·126	6	Fe	4577·866 phere.
4609·40	10	.	...	...	...	...	
4625·58	15	4625·28	0	4625·227	5	Fe	
4644·29	15	4643·66	00	4643·645	4	Fe	
				4680·317	1	Zn	
4680·92	10	4680·50	0	4680·480	1	..	
				4680·658	1	Cr	

Note.—The emanation lines in brackets are from Rutherford and Soddy, and the chromosphere line in brackets from Dyson's catalogue.

* The wave-length according to Dyson is 3649·60.
† The wave-length according to Lockyer is 3814·7 and Dyson 3814·67.
‡ T. Royds. Phil. Mag. **17**., 202, 1908.

It is apparent from these tables that the chromosphere lines are in nearly every case matched by a solar dark line or group of lines within the limits of accuracy of the measures, and that in general the wave-lengths differ appreciably from those of the radium and emanation lines. Only one of the radium lines and three of the emanation lines fall within allowable limits of the chromosphere lines—a proportion which may well be ascribed to chance coincidences. The strongest radium line at 3814·58 and the strongest emanation line at 4166·59 are not represented in the chromosphere within allowable limits. Dr. Dyson suggests that the chromosphere line at 3814·73 may be partly due to radium. The line is well defined in my spectra and the error of measurement is almost certainly less than $\pm$ 0·05 Å. The wave-length, which is confirmed by the measures of Dyson and Lockyer, agrees well with the double solar line at mean wave-length 3814·70 of which the more refrangible component is due to Fe and the less refrangible to Ti—a line which is slightly enhanced in the spark. The intensity in my eclipse spectra is not greater than would be expected considering it to be due to Fe and Ti.

The two chromosphere lines 4508·46 and 4576·58 occur in a region that was photographed by Hale and Adams at Mount Wilson without an eclipse, and the very accurate measures made by them confirm my measures of Mitchell's spectra, but give an additional line at 4577·866 which is near to, but still not coincident with, the emanation line at 4577·77.

The improbability that radium or the emanation can ever be recognised in eclipse spectra seems the greater because of the high atomic weights of these elements, which would cause them to be confined to a very low level in the solar atmosphere, and as I have shown in discussing the results of the eclipse of 1898 "The apparent intensity of the radiation of any element in the chromosphere is determined by the extent to which that element is diffused above the photosphere." Gases confined to very low levels cannot give a conspicuous emission spectrum at eclipses.

Neon and Argon in the Chromosphere.

The great intensity of the helium lines in the chromosphere would lead one to expect some of the lighter elements of the inactive group to be represented, particularly neon with atomic weight 20 and possibly argon.

In table III I give in column 1 the principal neon lines measured by Baly * and including all those exceeding intensity 3. In column 3 are entered the chromosphere lines from my eclipse results of 1898 and 1900.

TABLE III—*Neon.*

Neon lines.		Chromosphere.		Solar lines (Rowland).			Remarks.
λ	Intensity.	λ	Intensity.	λ	Intensity.	Origin.	
3370·01	6	.	...	.	...	.	
3418·05	8	...	...	..	...	...	
3447·83	8	...	...	.	.	..	
3450·87	4	..	...	..	...	...	Chromosphere lines from eclipse of 1898.
3454·30	6	..	...	...	. .	.	Intensities increased eight-fold to make comparable with 1900 results
3460·67	6	3460·58	25	3460·460	4	Mn	
3464·48	6	3464·32	8	{ 3464·275 3464·608	1 1	Fe Sr ?	
3466·72	6	...	. .	...	...	..	
3472·70	8	3472·58	8	3472·68	5	Ni	
3498·19	6	...	...	...	..	..	
3501·84	6	..	..	...		..	
3515·30	6	3515·32	15	3515·206	12	Ni	Chromosphere line mean of 1898 and 1900 eclipses.

* E.C. Baly Phil. Trans. A **202**, 183.

TABLE III—*Neon*—cont.

Neon lines.		Chromosphere.		Solar lines (Rowland).			Remarks.
λ	Intensity.	λ	Intensity.	λ	Intensity.	Origin.	
3520·57	8	3520·33	20	3520·397	2	Ti	
3593·67	10	3593·65	30	3593·636	9	Cr	
3600·24	4	3600·89	30	3600·880	3	Y	
3633·78	6	(3633·62)	(1)		..	..	Chromosphere lines from eclipse of 1900.
3682·33	4	(3682·37)	(1)	..	.	..	The lines in brackets are from Dyson's catalogue.
3685·84	4	3685·36	60	3685·339	10	Ti	
3701·30	6	3701·28	3	3701·288	8	Fe	
4158·68	4			...		..	
4198·71	4	4198·9	5	4198·800	3	Fe	
4201·03	4				...		
4259·58	6		...		.	.	Mitchell gives a faint line at 4259·5 from eclipse of 1901
4704·56	4	..	.	.	.		
4709·00	4	.	.			.	

Of the twenty-five neon lines, seven fall so near to strong lines of Fe, Ni, Cr, Ti, and Y that they would be indistinguishable if present; these include the strongest neon line at 3593·67 which practically coincides with a very strong chromium line. Thirteen neon lines seem to be entirely unrepresented in the chromosphere and these include the two strong lines (intensity 8) at 3418·05 and 3447·83. Two lines, of intensity 6 and 4 respectively, coincide within allowable limits with faint lines measured by Dyson, and there remain also three lines, 3460·67, 3464·48 and 4198·71 which might reasonably be attributed in part to neon if the other neon lines of greater intensity were also present.

The absence of the thirteen neon lines above mentioned is confirmed by reference to Dyson's list of chromosphere lines, but one of these, 4259·5, occurs in Mitchell's list of flash spectrum lines photographed by him at the eclipse of 1901. On the whole, it seems certain that neon does not exist in appreciable quantities in the chromosphere.

In the red and blue spectra of argon there are, according to Kayser, 56 lines of intensity exceeding 4 between λ 3475 and λ 5190, of these thirteen may be ruled out because of their close proximity to strong lines of Fe, Ti, Sc, etc. The following twenty-eight lines seem to be unrepresented in the chromosphere; they are not found in the catalogues of Lockyer, Evershed, or Dyson.*

λ	Intensity.	Red or Blue spectrum	λ	Intensity.	Red or Blue spectrum.
3476·926	5	Blue	4228·310	5	Blue
3480·636	5	,,	4259·491	7	Red
3491·444	5	,,	4266·425	5	,,
3545·792	5	,,	4266·684	6	Blue
3559·695	8	,,	4272·304	6	Red
3561·213	7	,,	4277·718	6	Blue
3582·547	7	,,	4348·222	10	,,
3638·015	7	,,	4401·156	5	,,
3729·450	9	,,	4426·165	9	,,
3928·749	7	,,	4430·355	6	,,
4072·159	7	,,	4510·851	5	Red
4104·107	7	,,	4579·527	5	Blue
4190·841	5	Red	4736·065	5	,,
4191·162	5	,,	4806·173	6	,,

The line at 4348·222 intensity 10 is the strongest argon line: it falls near to a faint chromosphere line at 4347·8 of my list of eclipse lines, and 4348·06 of Dyson's list: a line which may probably be identified with the lines in Rowland's table at 4348·002 intensity 2 and 4348·130 intensity 1. I have remeasured this line on Mitchell's grating spectrum of the 1905 eclipse and get the value 4348·01, which proves that it does not coincide with the argon line.

* Phil. Trans. A. **197**, 208, A **201**, 478; A **206**, 408.

The remaining fifteen argon lines fall near to, or coincide with, faint chromosphere lines of which no origins can otherwise be assigned with certainty. They are given in the following list:—

Argon.			*Chromosphere.*		
λ	Intensity	Red or Blue spectrum.	λ	Intensity	Authority.
3491·723	7	Blue	3491·99	0	Dyson
3546 005	5	,,	3546·09	0	,,
3588·633	9	,,	3588 97	1	,,
3781 018	6	,,	3781·0	1	Lockyer
3850·715	8	,,	3850·15	2	Evershed (a group of lines).
			3851·90	0	
3868·718	6	,,	3868·7	2	Lockyer
3949·107	6	Red	3949 11	4	Evershed
			3949·08	3	Lockyer
4164 309	5	,,	4164·43	1	Dyson
4198·436	5	,,	4198 4	0	Evershed
4200 799	9	,,	4200 73	1	Dyson
			4200·8	00	Mitchell
			4200·9	1	Evershed
4331·354	6	Blue	4331·47	2	Dyson
4379·827	6	,,	4379·94	2	,,
			4379·7	0	Evershed
			4379·7	2	Lockyer
4545·220	5	,,	4545·33	2	Dyson
			4545·585	1	Hale and Adams
4609·742	6	,,	4609·71	0	Dyson
			4609 8	1	Lockyer
5188·46	5	Red	5188·38	0	Dyson
			5188·9	2	Lockyer

Perhaps the most important line of this list is the one at 4200·799 intensity 9 which agrees well with the mean of the three measurements of the chromosphere line. I have remeasured the lines in this region on Mitchell's grating spectrum of 1905 and find a clear space at 4200·8, the nearest lines being at 4198·92 and 4202·35. This is confirmed by Lockyer who gives no line between these two in the beautiful eclipse spectra obtained in 1898. There must remain some doubt therefore as to the reality of the line in the chromosphere. The last line in the table at 5188·38 according to Dyson, is certainly the bright line equivalent of the double solar line at mean wave-length 5188·94. It is beautifully defined in Mitchell's 1905 spectrum at 5188·93, and Lockyer's wave-length confirms this identification.

In a spectrum so rich in lines as that of argon a certain number of chance coincidences are to be expected, but the long list of absent lines, including those of both the red and blue spectra and the strongest line in the blue spectrum, seems to prove that argon does not exist in appreciable quantity in the chromosphere.

The spectra of Krypton and Zenon have also been examined but I can find no evidence of the presence of either of these elements in the chromosphere.

KODAIKANÁL,
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