XXXVIII. The series law of resonance spectra

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The separation of the components of the doublets excited by the 5790.7 line varied in an irregular manner from 2.1 to 5.6 ÅU. In the case of the excitation by the 5769.6 line we have also a series of doublets, though the companion line is missing at the zero order, in other words the R.R. line has no companion. The separation of the components of the doublets is less irregular in this case, varying from 4.8 to 5.4 ÅU. The table of wave-lengths will be given in the communication following this one.

XXVIII. *The Series Law of Resonance Spectra.* By Prof. R. W. WOOD, *Johns Hopkins University*, and Prof. M. KIMURA, *University of Kyoto**.

IN the previous communication a general account of the results which have been obtained, up to the present time, on the resonance spectra of iodine has been given.

The present paper will deal with the measurements of wave-length of the lines in the groups, and the subject of the series law which governs their spacing.

The wave-lengths in the lines in the groups of 0 and +1 order were determined from plates made in the fourth order spectrum of a large plane grating with a telescope of 3 metres focus. They are correct probably to 0.01 ÅU. The groups +2, +3, and +4 were made in the second order spectrum, and the higher order groups in the first order spectrum.

The series which has been most definitely determined, and to which the greatest amount of study has been given, is the series of strong doublets excited by the Cooper-Hewitt lamp.

The two components of each doublet appear to be of equal intensity, although, in the case of two or three, a different ratio appears in the photograph as a result of absorption. It was found, as has been stated in earlier papers, that the first order group, which is usually recorded with the component of shorter wave-length three or four times as intense as the other, comes out with its lines of nearly equal intensity if the lateral branch of the iodine tube is cooled to zero, while the right hand component disappears entirely if the light from the tube is passed through a large glass bulb containing iodine vapour before it enters the spectroscope.

In studying the series law it has been found necessary to

* Communicated by the Authors.

reduce all wave-lengths to vacuum, and convert them into frequencies.

We will take up first the study of the doublets, the wave-lengths of which and their reciprocals are given in the following table, on the International Scale and reduced to vacuum.

Doublets excited by Green Line of Cooper-Hewitt Lamp.

Group Order.		$\frac{1}{\lambda}$ (Obs.)	Freq. Dif.	$\frac{1}{\lambda}$ (Cal.)	Difference between Obs. & Cal.
0.....	5462.23 (Hg or R.R. Line) 5463.74	183075 183025	50	183075	0
1.....	5526.55 5528.10	180945 180894	51	180942	+3
2.....	Missing				
3.....	5658.71 5660.38	176719 176667	52	176715	+4
4.....	5726.59 5728.25	174624 174573	51	174621	+3
5.....	5795.79 5797.51	172539 172488	51	172539	0
6.....	5866.14 5867.85	170469 170420	49	170470	-1
7.....	Missing				
8.....	6010.66 6012.50	166371 166320	51	166370	+1
9.....	Missing				
10.....	6160.63 6162.48	162321 162272	49	166322	-1
11.....	6237.68 6239.56	160316 160268	48	160316	0
12.....	6216.16 6218.14	158324 158270	50	158324	0
3.....	6396.08 6398.05	156346 156297	49	156344	+2
14.....	Missing				
15.....	6560.56 6562.68	152426 152377	49	152423	+3
16.....	6645.0 6647.0	150489 150443	46	150481	+8
17.....	6731.12 6733.28	148564 148516	48	148552	+12

From this point on values determined from plates made with telescope of 1 metre focus. They are correct only to about 0.1 ÅU.

18.....	6618.63 6820.01	146657 146608	49	146636	+21
19.....	Faint and masked	by mercury line			
20.....	6998.96 7001.39	142878 142828	50	142842	+36
21.....	Missing				
22.....	7186.23 7188.68	139155 139107	48	139099	+56
23.....	7282.39 7284.92	137318 137270	48	137247	+71
24.....	Missing				
25.....	7480.4 7482.9	133682 133638	44	133580	+102
26.....	Missing				
27.....	7685.7 7688.5	130110 130060	50	129964	+146

The first point established by this table is that, while the separation of the components of the doublets increases progressively from 1.51 ÅU. at 0 order to 2.5 ÅU. at the twenty-seventh order, THE FREQUENCY DIFFERENCE BETWEEN THE COMPONENTS IS A CONSTANT, 50. The extreme low values 46 and 44 found in the sixteenth and twenty-fifth orders are undoubtedly due to the fact that the lines were extremely faint, and the wave-lengths could not be very accurately determined. The last doublet (the twenty-seventh order) was fairly strong, and the frequency difference in this case is exactly the same as in the case of the 0 order.

We will now consider the law governing the spacing of the doublets along the spectrum, applying the calculations to the first member of each doublet (shorter λ component). If we confine our attention to the first few orders, it seems as if the distance between the doublets increased by a constant small increment. This would mean a constant second difference of wave-lengths. It was found, however, that this condition held only for the first few orders. The reciprocals of the wave-lengths were next examined, and it was found that a constant second difference existed, at least over a considerable range of the spectrum.

If this condition held rigorously the series would be represented by the formula

$$\frac{1}{\lambda_m} = 183075 - 2132m + 13 \frac{m(m-1)}{2},$$

in which λ_m is the wave-length of the doublet of the m th order, 2132 is the frequency difference between orders 0 and +1, 13 the constant second difference of frequency, and m the order of the doublet. The most accurate value of the second constant would be obtained by calculating it from a doublet of high order, as a small error would be enormously magnified by the term $\frac{m(m-1)}{2}$, the value of which is 351 for the twenty-seventh order.

Calculating the constants 2130 and 12.2 from orders 0 and 5 gave calculated values of $1/\lambda$ which differed from the observed by the following amounts:—

Doublet Order.	Difference.	Doublet Order.	Difference.
1	0	7	+ 2
3	+1	10	+ 4
4	-1	13	+ 14
5	-1	18	+ 65
5	0	23	+166
6	-1	27	+284

The large discrepancies in the higher orders are due to incorrect determination of the constants. In spite of this, though, the series is well represented up to the seventh order. The following formula gave the best results over the entire range:—

$$\frac{1}{\lambda_m} = 183075 - 2131.414m + 12.734 \frac{m(m-1)}{2}.$$

The values given in the table were calculated by this formula and, as will be seen, the agreement is good up to the doublet of the fifteenth order. There is a small discrepancy in the orders 1, 3, and 4, which appears to be inevitable if the constants are so chosen as to make the formula cover a wide range. Of course, the formula is not correct for the entire series, and though we have tried formulæ involving higher powers of m than the square, we have been unable to develop anything superior to the one given. The discovery of the fact that the frequency difference between the components of the doublets is a constant, has been of assistance

in picking out other series of doublets in the series of complicated groups excited by the quartz arc.

For example, we may take the wider doublets shown united by dotted lines in the previous paper (fig. 4).

The frequency differences for these doublets are given in the following table:—

Order.	Freq. Dif.	Order.	Freq. Dif.
0	161	8	158
1	159	10	157
3	159	12	157
5	158	15	152
6	157	17	156

It will be remembered that the frequency difference of the first series of doublets considered was 50.

The spacing of this series along the spectrum is only fairly well represented by the formula

$$\frac{1}{\lambda_m} = 183075 - 2119m + 13 \frac{m(m-1)}{2}.$$

The observed and calculated values of $1/\lambda$ for the components of longer wave-length (the companion line is to the left in this case) are given in the following table. It will be observed that the doublets are missing in the fourth, eleventh, and thirteenth orders, as well as in the orders in which the doublets of the first series failed to appear.

Order.	$\frac{1}{\lambda}$ (Obs.)	$\frac{1}{\lambda}$ (Cal.)	Dif.
0	183075	183075	0
1	180956	180956	0
3	176754	176757	3
5	172599	172600	1
6	170543	170556	13
8	166470	166487	17
10	162448	162470	22
12	158479	158505	26
15	152621	152655	34
17	148786	148820	34

In the following table are given the wave-lengths and their reciprocals, on the International Scale and reduced to vacuum, of all of the lines in the groups between 0 and 17, in the case of iodine vapour excited by the quartz mercury arc operating at 115 volts.

The doublets excited by the Cooper-Hewitt lamp are marked thus * and the other doublets which we have studied thus †. This table corresponds to the diagram in the previous paper. In the fourth order group lines A and B were added from an old series of measurements. The line between them is the only one which appears on our recent plates, and this line only is given in the table.

0 Order.		
No. of Line.	λ .	$\frac{1}{\lambda}$
1	5	
†2	5457·43	183236
3	5458·33	183189
4	5460·88	183121
5	5461·07	183114
†*6	5462·23	183075
*7	5463·74	183025
8	5464·05	183014
9	5466·04	182948

First Order.

1	5520·30	181149
2	†5521·33	181115
3	5522·92	181064
4	5525·17	180989
5	5525·38	180983
6 {	†5526·20	180956
	22	955
	47	47
	*5526·55	45
	71	39
	80	36
7	*5528·10	180894
8	5528·39	180884
9	5530·06	180830

Second Order.

5585·08	179048
86·33	179008
86·81	178992
89·05	921
89·42	909
91·02	858
91·17	853
91·38	847
93·33	784
93·77	770

Third Order.

1	5651·06	176958
2	†5652·49	176913
3	5654·55	176849
	†5657·57	176754
6	*5658·71	176719
7	*5660·38	176667
9	5661·97	176617
	5663·15	176580

and, in addition, faint lines as follows:

5656·87
57·17
57·35
57·98
58·24
58·96
59·27
59·50
60·70
61·02

Fourth Order.

No. of Line.	λ .	$\frac{1}{\lambda}$
†5719·62		174837
5722·05		174763
22·55		4747
24·47		4688
24·72		4681
†5725·13		4668
25·35		4661
*5726·59		4624
26·84		4616
*5728·25		4573
28·56		4564
28·95		4552

Fifth Order.

†5788·45	172757
91·03	2681
†5793·77	2599
94·48	2578
94·88	2566
*5795·79	2539
*5797·51	2488
98·70	2452

Sixth Order.

†5858·23	170700
60·8	625
63·2	555
†5863·6	543
64·75	510
64·9	505
*5866·14	469
*5867·85	420
68·1	413
68·1	395

Eighth Order.

5998·6	166704
†6001·38	628
04·88	531
†6007·07	471
09·32	411
09·40	406
*6010·66	371
10·91	364
*6012·50	320
12·80	310

Tenth Order.

†6149·87	162605
54·07	494
†6155·81	448
57·52	403
58·31	382
59·14	360
*6160·63	321
*6162·48	272
63·65	241

Eleventh Order.

λ .	$\frac{1}{\lambda}$
6228.79	160545
31.44	477
36.12	356
*6237.68	316
*6239.56	268
42.0	205

Twelfth Order.

6294.87	158859
99.40	745
+6303.71	636
08.57	514
+6309.99	479
*6316.16	324
*6318.14	274
19.6	237

Thirteenth Order.

λ .	$\frac{1}{\lambda}$
6388.24	156538
92.14	442
92.82	425
94.54	383
*6396.08	346
*6398.05	297

Fifteenth Order.

+6545.65	152773
+6552.19	621
59.05	461
*6560.56	426
*6562.64	378

Seventeenth Order.

+6714.00	148923
+6721.03	787
*6731.09	564
*6733.27	516

Excitation by the Yellow Lines.

We have measured the wave-lengths of the lines in the resonance spectrum excited by the yellow lines of the Cooper-Hewitt arc, and the quartz arc operating at 115 volts. The values given in the following table are on the International Scale and reduced to vacuum. They were determined from plates made with the plane grating and Cooke lens of 1 metre focus, and can be considered correct only to about 0.1 ÅU. We have, however, made some measurements of the doublets photographed with the 3-metre lens, which are correct probably to 0.02 ÅU., and as the same irregularities were found in the spacing, we have not thought it worth while to measure the complete spectrum to the highest degree of accuracy.

The wave-lengths are given in the following table. The lines or doublets excited by the Cooper-Hewitt lamp are marked thus *.

The series excited by the Cooper-Hewitt lamp in the case of the 5769 line differs from that excited by the green line in a number of respects.

In the first place, at the point of excitation we have only the R.R. line with no companion. At orders 1, 2, 3, 6, and 9 we have doublets, 4 and 8 are missing, and at 5, 7, and 10 we have single lines.

Excitation by Hg 5769·6 (5771·2) Reduced to Vacuum).

-1 Order.		Fifth Order.	
	$\frac{1}{\lambda}$		$\frac{1}{\lambda}$
5701·8	175383	6139·0	162893
5705·2	278	41·0	839
		*43·1	784
0 Order.		Sixth Order.	
5766·0	173430	6215·1	160898
67·8	376	17·0	849
*5771·2	274	18·9	800
75·2	154	*22·1	717
		*27·1	588 } 129
+1 Order.		Seventh Order.	
5834·4	171397	6294·9	158858
38·5	277	99·6	740
*5842·5	159	*6303·5	641
*5847·2	022 } 137		
Second Order.		Eighth Order.	
5911·2	169170	6374·3	156879
14·7	070		
*5915·8	039		
*5920·2	168896 } 143		
Third Order.		Ninth Order.	
5985·2	167078	6459·7	154806
88·3	166992	63·7	710
*90·0	945	*67·9	609
*95·1	803 } 142	*73·2	483 } 126
Fourth Order.		Tenth Order.	
6060·4	165006	6544·1	152809
64·6	164891	48·7	702
69·1	164769	*53·0	602

The $1/\lambda$ difference, in the case of the components of the doublets, is not constant, as in the previous case, but varies from 143 to 126.

As to the spacing of the doublets along the spectrum, we find that in this case the $1/\lambda$ difference is very nearly constant, as is shown by the following table:—

Order.	$\frac{1}{\lambda}$	$\frac{1}{\lambda}$ Dif.	Order.	$\frac{1}{\lambda}$	$\frac{1}{\lambda}$ Dif.
-1	175383		5	162784	
0	173274	2109	6	160715	2069
1	171159	2015	7	158641	2074
2	169039	2120	8		
3	166945	2094	9	154612	2014
4		2080	10	152602	2010

The variation is irregular, and it is obvious that the series is of a different type from the one excited by the green line, a portion of which at least was well represented by a formula.

In the case of the excitation by the 5790·7 line, we obtained different values of λ in the case of the Cooper-Hewitt lamp, consequently these values only are given in the table. It is probable that in the case of the quartz lamp at 115 volts reversal of the line causes the disappearance of the doublets excited by the lamp running at a lower temperature :—

Excitation by Cooper-Hewitt 5790·7 (5792·3 Reduced to Vacuum.)

λ .	$\frac{1}{\lambda}$	$\frac{1}{\lambda}$ Dif.	λ .	$\frac{1}{\lambda}$	$\frac{1}{\lambda}$ Dif.
— 2 Order.			Fourth Order.		
5658·6	176722 }	53	6084·3	164357 }	108
5660·3	669 }		88·3	249 }	
— 1 Order.			Fifth Order.		
5722·1	174761 }	34	6163·9	162235 }	58
5723·2	727 }		66·1	177 }	
0 Order.			Sixth Order.		
5792·3	172644 }	168	6242·3	160197 }	69
5797·9	476 }		45·0	128 }	
First Order.			Seventh Order.		
5871·3	170320 }	61	6325·8	158083 }	86
5873·4	259 }		29·2	157997 }	
Second Order.			Eighth Order.		
5936·8	168441 }	61	6404·0	156152 }	66
38·9	380 }		06·7	086 }	
Third Order.					
6010·8	166367 }	69			
13·3	298 }				

In the case of the series excited by this line the doublets are present in all orders, but the $1/\lambda$ difference between their components varies in a very irregular manner from a minimum value of 34 to a maximum value of 168.

The spacing of the series along the spectrum is more regular, however, the $1/\lambda$ differences being as follows (the last significant figure is omitted):

196	205
211	211
232	193
188	212
207	200
203	209
209	

It does not appear to be worth while at this stage of the investigation to give the wave-lengths of the lines in the more complicated groups excited by the quartz arc operating at various voltages, as the simpler series excited by the Cooper-Hewitt lamp does not appear at the present time to conform to any law. The cause of this may appear when the relation of this spectrum to the band spectrum developed when the iodine is in helium has been studied. This will require exposures of many days, however.

XXIX. *On the Pressure Effect in Corona Discharge.*

By A. M. TYNDALL, D.Sc., and Miss N. S. SEARLE, B.Sc.*

SEVERAL papers have been published within the past few years on what has been termed "the ionization pressure in corona discharge." When a glow or "corona" discharge starts between a cylinder and an axial wire in a closed tube at atmospheric pressure, a sudden rise in pressure is observed. Farwell† and Kunz‡ have contended that this pressure effect is quite distinct from that produced by the heating effect of the discharge, and have suggested that it is due to the increase in the number of gas particles resulting from ionization in the tube.

Kunz also has deduced the following formula connecting the rise in pressure " $p_1 - p_0$ " with the current " i ," potential difference " e ," and the volume of the tube " v_0 ":—

$$i = \frac{v_0}{e} (p_1 - p_0).$$

In support of this formula Warner§ has shown experimentally in a number of gases that, if the potential difference is constant, " i " is proportional to " $p_1 - p_0$." Arnold||, however, has suggested that the pressure effect can be accounted for by thermal considerations alone, and has pointed out that the small magnitude of the current excluded the possibility of any appreciable contribution to pressure by ionization. Recently Warner¶ has replied to this criticism. He has described a number of experiments on the pressure

* Communicated by the Authors.

† Farwell, Proc. A. M. I. E. E. vol. xxxiii. p. 1717 (1914).

‡ Kunz, Phys. Rev. vol. viii. p. 28 (1916).

§ Warner, Phys. Rev. vol. viii. p. 285 (1916).

|| Arnold, Phys. Rev. vol. ix. p. 93 (1917).

¶ Warner, Phys. Rev. vol. x. p. 483 (1917).