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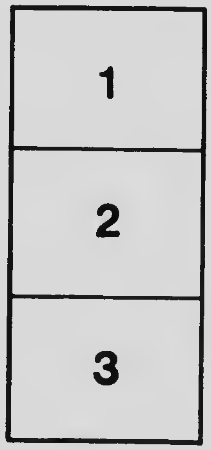

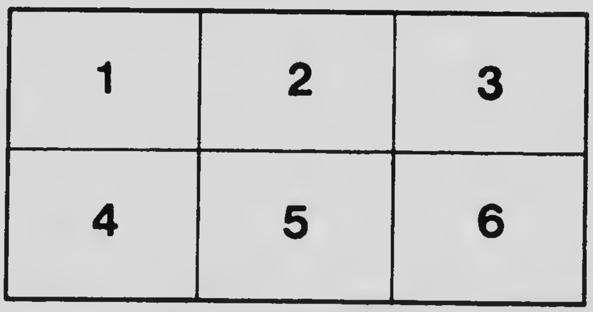

UNIVERSITY OF TORONTO STUDIES

PAPERS FROM THE PHYSICAL LABORATORIES

No. 48: ON THE ABSORPTION SPECTRA OF MERCURY, CADMIUM, ZINC, AND OTHER METALLIC VAPOURS, BY PROFESSOR J. C. McLENNAN AND EVAN EDWARDS

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On the Absorption Spectra of Mercury, Cadmium, Zinc and Other Metallic Vapours.

By PROFESSOR J. C. MCLENNAN, F.R.S., AND MR. EVAN EDWARDS, M.A., B.SC. UNIVERSITY OF TORONTO.

I. INTRODUCTION.

(Read May Meeting, 1915.)

In 1907 it was pointed out by R. W. Wood[1] that in the absorption spectrum of non-luminous mercury vapour there is a heavy band at $\lambda = 2536\cdot72$ A°.U., and a less sharply-defined one at $\lambda = 2350$ A°.U. In a later paper by Wood and Guthrie[2] dealing with the same subject, no mention is made of the absorption band at $\lambda = 2350$ A.°U.; but it is stated that with dense mercury vapour there is a fairly strong band at $\lambda = 2338$ A°.U. and another very broad one at $\lambda = 2140$ A°.U. From the work of Kirschbaum[3] and others it is known that light of wave-length $\lambda = 1849\cdot6$ A°.U. is strongly absorbed by mercury vapour.

The absorption band at $\lambda = 2536\cdot72$ A°.U. has been shown by Wood to be asymmetrical. It is sharply defined on the shorter wave-length side; but with increasing vapour density it gradually spreads out towards the red end of the spectrum. With low vapour densities it consists of two bands the one at $\lambda = 2536$ A°.U. and the other at $\lambda = 2539$ A°.U. The band at $\lambda = 2338$ A°.U., which is probably the same one as that originally given by Wood at $\lambda = 2350$ A°.U., does not appear to have been examined in detail. In regard to the band noted by Wood at $\lambda = 2140$ A°.U., especially as it was obtained with high vapour densities, it appeared to the writers that it might be connected with the absorption observed by Kirschbaum at $\lambda = 1849\cdot6$ A°.U. Some experiments were made by us to test this view and also to study the character of the absorption band at $\lambda = 2338$ A°.U. and these will be described in what follows.

II. ABSORPTION SPECTRUM OF MERCURY.

In the first experiments the light from a quartz mercury arc lamp was projected through an evacuated clear fused quartz tube containing

[1] R. W. Wood. Ast. Phys. Jl. Vol. XXVI, p. 41. 1907.
[2] Wood and Guthrie. Ast. Phys. Jl. Vol. XXI[illegible] No. 1, p. 21[illegible], 1909.
[3] Kirschbaum. Electrician. Vol. 72, p. 1[illegible], 1914.

a little mercury. The mercury was gradually heated and a series of photographs was taken with a small Hilger quartz spectrograph. A reproduction of one of these photographs is shown in Fig. 1. The upper spectrum is that of the mercury arc alone, the second is that obtained when the quartz tube was moderately heated and the third is that obtained when the mercury vapour density was considerably higher. The asymmetrical character of the absorption band at $\lambda = 2536 \cdot 72$ A°.U. is clearly brought out by the photograph.

In the second experiments a photograph was first taken of the spark spectrum of mercury in air in a manner already described in a previous communication by one of us.[1]

Photographs were also taken of the spectrum of the light from the spark between terminals of cadmium in air after it passed through the mercury vapour in the exhausted quartz tube mentioned above. These were taken with gradually increasing vapour density and are shown in Fig. 2. In this photograph the mercury spectrum is shown at the top well down into the ultra-violet and the strong lines at $\lambda = 1942 \cdot 1$ A°.U. and $\lambda = 1849 \cdot 6$ A°.U. are clear and distinct. The succeeding four spectra show that even with small vapour density the absorption was such as to cut off the light of wave-lengths in the region of $\lambda = 1942$ A°.U. and $\lambda = 1849 \cdot 6$ A°.U. In the second last spectrum, absorption at $\lambda = 2536 \cdot 72$ A°.U. can just be detected but in the last one it is well marked. The absorption band at $\lambda = 2338$ A°.U. also comes out in this spectrum and that at $\lambda = 1849$ A°.U. has widened out so that on the side of longer wave-lengths it has reached $\lambda = 2144 \cdot 0$ A°.U. From the general appearance of the photograph it will be seen that the absorption at $\lambda = 1849 \cdot 6$ A°.U. develops symmetrically with increasing vapour density. This photograph also shows that light of wave-lengths near to $\lambda = 1849 \cdot 6$ A°.U. was the most strongly absorbed by mercury vapour. That in the neighbourhood of $\lambda = 2536 \cdot 72$ A°.U. came next, while high vapour densities were required to bring out the absorption at $\lambda = 2338$ A°.U.

In the third experiment a large Hilger quartz spectrograph was used. With this instrument the arc spectrum of mercury from a quartz lamp was first taken, then the spark spectrum between aluminium terminals in water after the manner devised by Henri[2] and the the spectrum of the light from the spark between these aluminium terminals in water after it had passed through a heated clear fused quartz evacuated tube containing mercury vapour of high density. These three photographs are shown in Fig. 3. The spark from

[1]McLennan. Proc. Roy. Soc. A. Vol. 91. p. 26, 1914.
[2]Henri. Phys. Zeit. No. 12. p. 516. June 15th, 1913.

aluminium terminals in water as will be seen from the second spectrum in the figure gives a continuous spectrum of remarkable extent. It can be obtained with ease down to $\lambda = 2150$ A°.U.

The arrangement for producing the Henri spark is shown in Fig. 4. The terminals of the induction coil AB were joined to the spark gap at CD and to the inside coatings of two one-gallon Leyden jars

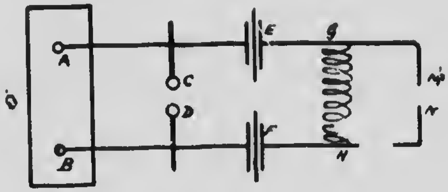

Figure 4

EF. The outside coatings of these jars were joined to two rods of aluminium MN. These rods constituted the terminals of the spark gap which was the light source and they were short circuited by a coil of small self-induction GH. The aluminium terminals MN were rods about 1 cm. in diameter. They were conically pointed and were held clamped in a vertical plane inclined at 45° to each other. The clamps in which they were held were provided with threads which enabled one to readily alter the distance between the sparking points. When the spark was in action the terminals MN were immersed to a depth of about 5 cms. in a vessel of water. The light from the spark passed through the water and out of a quartz window sealed into the side of the vessel. It was then focussed with a cylindrical quartz lens upon the slit of the spectrograph. The third spectrum in Fig. 3 is the mercury vapour absorption spectrum taken with the light from the Henri spark. In the region below $\lambda = 2150$ A°.U. it will be seen there is complete absorption. The asymmetrical nature of the absorption at $\lambda = 2536 \cdot 72$ A°.U. is also brought out. At $\lambda = 2338$ A°.U. it will be seen that the absorption is complex, and consists of four bands, one extending from $\lambda = 2313$ A°.U. to $\lambda = 2320$ A°.U., one at $\lambda = 2322$ A°.U. another at $\lambda = 2326$ A°.U. and a wider one between $\lambda = 2330$ A°.U. and $\lambda = 2338$ A°.U. The absorption moreover is strong and sharply edged on the longer wave side but it weakens out and is less clearly defined on the side of the shorter waves.

It will be noted the third spectrum in Fig. 3 also shows a narrow absorption band at $\lambda = 2288$ A°.U. As cadmium vapour has an absorption band at this point its occurrence in this photograph was ascribed to the presence of a trace of cadmium in the mercury.

From these results it will be clear that between $\lambda = 6000$ A°.U. and $\lambda = 1800$ A°.U. there are but three regions of absorption in the absorption spectrum of non-luminous mercury vapour, viz., in the neighbourhood of $\lambda = 1849 \cdot 6$ A°.U. of $\lambda = 2338$ A°.U., and of $\lambda = 2536 \cdot 72$ A°.U. It should be noted that $\lambda = 1849 \cdot 6$ A°.U. is the first line in the series of the mercury arc spectrum given by n = 1.5,S—m, P and $\lambda = 2536 \cdot 72$ A°.U. is the first line in the series n = 2, p_2—m, S[1] of the same spectrum. The line $\lambda = 2338$ A°.U. has not been shown as yet to belong to any series.

III. The Absorption Spectrum of Cadmium Vapour.

In the experiments with cadmium vapour the spectrum of the light from the spark between terminals of cadmium in air was first of all photographed directly and then after it had passed through cadmium vapour of different densities contained in a heated, highly exhausted tube of clear fused quartz. A photograph taken in this way with the small quartz spectrograph is shown in Fig. 5. The upper spectrum is the spark spectrum taken directly and the lower two are absorption spectra. They show as will be seen, strong and symmetrical absorption at λ 2288 A°U. The experiments were repeated with the larger spectrograph and one of the photographs taken with the instrument is shown in Fig. 6. The second spectrum is the spark spectrum taken directly and the third is the absorption spectrum. This photograph shows a sharply defined narrow absorption band at $\lambda = 3260 \cdot 17$ A°.U. as well as a wide symmetrical band with centre at $\lambda = 2288$ A°.U. Although numerous experiments were made with vapour of varying densities, no trace of any other bands was found. This confirms the observations of Wood and Guthrie.[2]

In this connection, however, it should be noted here that in a number of the photographs of the absorption spectrum of cadmium vapour a narrow, tolerably well defined absorption band came out at $\lambda = 2536 \cdot 72$ A°.U. This was no doubt due to absorption by mercury vapour which either came back, during the process of exhaustion, from the mercury pump into the tube containing the cadmium vapour or else was present as an impurity in the metallic cadmium originally. This absorption band was clearly shown in the original photograph from which the reproduction shown in the third row of Fig. 6 was made but as will be seen it is scarcely detectable in the reproduction.

It is interesting to note that the lines at $\lambda = 2288$ A°.U. and $\lambda = 3260 \cdot 17$ A°.U. are respectively the first numbers of the series

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[1]Dunz. Inaugural Dissertation. Tubingen 1911, pp. 67 and 68.

[2]Wood and Guthrie. *loc cit.*

in the arc spectrum of cadmium given by n = 1·5, S—m, P and n = 2, p_2—m, S, *i.e.*, they are analogous to the lines in the mercury arc spectrum at λ = 1849·6 A°.U. and λ = 2536·72 A°.U.

Some photographs were also taken of the spectrum of the cadmium arc. In taking these the form of arc used is that shown in Fig. 7.

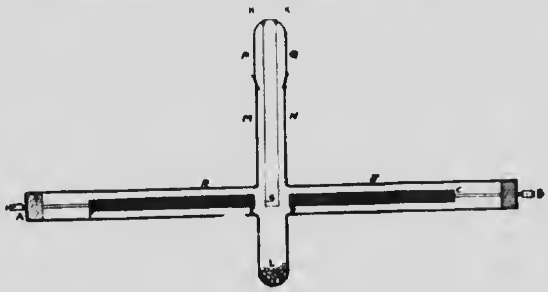

Figure 7

The apparatus consisted of a tube of fused quartz possessing three arms, R, S and MN together with a receptacle L. The metal to be used in the arc was placed in the receptacle, L, and two rods of the same metal FE and DC were attached to two wires and these latter were in turn fastened to two brass plugs A and B which were sealed into the tubes R and S with mastic wax. A small sheet of platinum was attached to two wires which constituted a heating circuit and these were sealed with platinum wire into a glass tube PQ at H and K. The open end of the glass tube was ground so as to fit exactly into the end of the quartz tube MN as shown in the diagram. The arms MN, R and S were each about 40 cms. long and it was found with this length that when the receptacle L was strongly heated with a Bunsen burner the wax joints at A and B and the ground one at the end of the tube MN remained quite cool.

In the experiments the plate G was coated with a thin layer of either calcium oxide or barium oxide. When the tube was in operation the terminals of an auxiliary heating circuit were attached at H and K, B and K were joined by a wire and the arcing voltage was applied between B and A, the latter being the positive terminal. With this arrangement G and D constituted a double cathode. The tube was highly exhausted with a Gaede mercury pump through a glass tube sealed into an opening in the brass end piece at A.

In taking the photographs the plate G was brought to incandescence by means of the auxiliary heating circuit; the metal in it was strongly heated with the flame of a Bunsen burner so as to keep the plate G surrounded with the vapour of the metal, and the collimator of the quartz spectrograph was directed at the incandescent plate G. A short tube of asbestos cloth was attached to the quartz tube directly in front of this plate so that the radiation from the arc passed through it to the slit of the spectroscope. This arrangement was found necessary to cut off the radiation from the Bunsen flame itself.

With the arrangement just described, it was found that when the direct current 110-volt circuit with suitable resistance in series was applied to the terminals A and B, and the plate G brought to incandescence strong arcs could be maintained for hours with both cadmium and zinc. With the 220-volt circuit applied the arcs of these two metals could be made most intense and could be maintained for long periods. With the 220-volt circuit it was found that when the arc was once struck it could be easily maintained for a considerable time without the continued use of the oxy-cathode G. With low voltages, however, it was always necessary to maintain the plate G at incandescence in order to keep the arc established.

A photograph of the cadmium arc spectrum taken with a lamp of this form is shown in the upper row of Fig. 6. As the illustration shows, there is a marked difference between the arc and spark spectra of cadmium, numerous lines coming out in the one which do not appear in the other. Another point of interest in connection with these spectra is that in the arc spectrum there was a reversal at $\lambda = 2288 \cdot 79$ A°.U. and also another though less clearly marked at $\lambda = 3100$ A°.U. In the arc spectrum no reversal at $\lambda = 3260 \cdot 17$ A°.U. was observed.

IV. The Absorption Spectrum of Zinc Vapour.

Although a number of observers had looked for absorption bands in the absorption spectrum of zinc vapour none was observed until a short time ago, when a well defined band was noted by one of us at $\lambda = 2139 \cdot 3$ A°.U.[1] The reason that this band had not been found before was that it was far down in the ultra-violet beyond the range examined by the other investigators. It is shown in Fig. 8. The upper spectrum is that of the zinc spark in air and the lower two are the spectra obtained when the light from the zinc spark in air was passed through zinc vapour in a heated evacuated quartz tube. It will be seen that with increasing vapour density the band developed symmetrically. Photographs of the absorption spectrum of zinc vapour were also taken with the larger spectrograph. One of these is shown in Fig. 9. The upper spectrum is that of the zinc spark in air taken directly after it had passed through zinc vapour. The absorption corresponding to $\lambda = 2139 \cdot 3$ A°.U. as will be seen is extensive and clearly defined. It will also be seen that there is a narrow band at

[1]McLennan, *Phil. Mag.*, Vol. XXVIII, Sept. 1914.

λ = 3075·99 A°.U. In the emission spectrum of the spark taken directly there are two lines close together at λ = 3075·99 A°.U. while in the lower photograph only one line is seen. In order to bring out the absorption at this point more clearly, a series of photographs was taken with gradually increasing vapour density. One of these is shown in Fig. 10. The upper spectrum shows the line at λ = 3075·99 A°.U. to be double. In the second and third spectra the line is single and in the fourth and fifth spectra a narrow dark band is seen close to and to the left of the single line. An enlargement was taken of this portion of the absorption spectrum and it is shown in Fig. 11. This photograph it will be seen brings out very clearly the absorption band at λ = 3075·99 A°.U.

If the absorption spectrum in Fig. 9 be examined it will be seen that absorption bands are also shown at λ = 2288 A°.U. and λ = 2536·72 A°.U. These were no doubt due to the presence of mercury and cadmium vapours in the tube containing the zinc vapour. As this tube was a new one and had not been used previously it would seem that the mercury and the cadmium must have been present in the zinc as impurities. It is of interest to note this, for the zinc had been purchased as being doubly distilled and specially pure. The mercury vapour absorption band is also shown in Fig. 10 at λ = 2536·72 A°.U.

The zinc lines at λ = 2139·3 A°.U. and λ = 3075·99 A°.U. are respectively the first members of the series given by n = 1·5, S—m,P and n = 2, p_2—m, S in the spectrum of the zinc arc. There is therefore a complete analogy in so far as the first members of these two series are concerned in the absorption spectra of mercury, cadmium, and zinc vapours. In the absorption spectra of cadmium and zinc vapours no absorption was observed corresponding to that obtained with mercury at λ = 2338 A°.U. It will be remembered, however, that with mercury this absorption band required high vapour density to bring it out clearly. It may very well be that with cadmium and with zinc vapours, the densities used were not sufficiently high to produce noticeable absorption at points in their spectra corresponding to the band at λ = 2338 A°.U. in the mercury spectrum.

V. Absorption Spectra of Gold and Silver Alloys.

In the course of the experiments described above and in view of the relationships which have been established above between the absorption spectra of mercury, cadmium and zinc vapours, it was thought well to make an attempt to see if the absorption spectra of gold, silver and copper vapours revealed similar relationships. Small quantities of gold, of silver and of copper were in turn heated as highly as possible in evacuated quartz tubes, and although these tubes were heated to softening, the vapours obtained of all three metals were not very dense. Moreover, when the light from the spark in air between gold, silver, and copper terminals was sent through their respective vapours, no trace of absorption was in any case obtained.

Through the kindness of Mr. C. D. Heycock our attention was drawn to some alloys of gold and of silver which have low melting points. One of these which contained 96·2% gold and 3·8% aluminium had its melting point at 52(·5°C and another which has the composition represented by Ag_3Cu_2 contained 28% of copper and 72% of silver and had its melting point at 777·3°C. The light from the Henri spark was projected in turn through evacuated quartz tubes containing these alloys and though the tubes were heated as highly as was practicable, no absorption was detected in the region between λ = 6000 A°.U. and λ = 1800 A°.U.

VI. On the Structure of Fine Lines in the Mercury, Cadmium and Zinc Arc Spectra.

When working with the particular form of metallic arc lamp described above, it was found that when the 220-volt circuit was applied, cadmium and zinc arcs of extraordinary brilliancy could be obtained. This made it possible to make a close examination of the structure of some of the finest lines in the arc spectra of these metals. Two of them in particular were carefully studied, viz., the cadmium red line λ = 6439·3 A°.U. and the red zinc line λ = 6364 A°U. Light of the former wave-length it will be remembered was used by Michelson[1] in his determination of the length of the metre. In studying its structure with his own type of interferometer, it was found by him to be simple and not to possess any satellites. This was confirmed by Janicki[2] who, at a later time, investigated it with an echelon grating. In our investigation with a Lummer plate interferometer it was also found to be simple and a reproduction of one of the Lummer plate patterns of it is shown in Fig. 12.

The zinc line λ = 6364 A°.U. is also given by Janicki[3] as a simple line without satellites. In our study of it with the Lummer plate this line appeared visually at times to be accompaned by two faint satellites. These came out only when high currents were passing in the arc; but although numerous attempts were made to obtain photographs of them they did not appear on any of the plates. We are not

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[1]Michelson. Phil. Mag. 34 pp. 280—299, 18·..

[2]Janicki. Ann. der. Phys. (4) 29, p. 833, 1909.

[3]Janicki. loc. cit.

able, therefore, to decide whether the satellites have a real existence or not. The Lummer plate pattern of this line showing just the one simple component is reproduced in Fig. 13. For purposes of comparison the Lummer plate pattern of the mercury green line $\lambda = 5461$ A°.U. taken by one of us with the same Lummer plate interferometer is shown in Fig. 14. The structure of this line has been discussed elsewhere by McLennan and McLeod.[1] In so far as this photograph goes it shows the line to consist of a wide main component accompanied by five satellites.

V. The Ultra-violet Spark Spectrum of Cadmium.

While the experiments which have been described above were in progress, a spectroscope provided with a fluorite train, made for us by the Adam Hilger Co., was added to the equipment of the Physical Laboratory at Toronto. With this instrument some preliminary photographs were taken of the spark spectrum of cadmium in air in the region below 2100 A°.U. As the plates showed a number of lines in addition to those given by Eder and Valenta the experiments were carefully repeated. Rods of the purest cadmium obtainable were used as terminals for the spark gap. Photographs of the spark spectra of zinc and aluminium were taken on the same plates and in measuring up the wave-lengths of the lines in the cadmium spectra the following well-known lines were used as standards.

Zinc lines[2]	Aluminium lines[3]
λ = 2138·66 A°.U.	λ = 1990·57
02·35	35·9
00·06	31·15
2064·32	1862·81
62·08	58·2
25·51	54·8

From the measurements it was easy to identify certain lines on our spectra with those given by Eder and Valenta which appear to be the only ones recorded for the spark spectrum of cadmium in the region investigated by us. The wave-lengths of the lines found by us were determined on the assumption that those given by Eder and Valenta were correct. All the lines found by us together with their

[1] McLennan and McLeod. Proc. Roy. Soc., A. Vol. 90, p. 243, 1913.
[2] Eder and Valenta. Atlas Typischer spectren, Wien.
[3] Handke. Inaugural Dissertation, Berlin, 1909, p. 18.

relative intensities are given in Table I. The lines found by Eder and Valenta[1] with their relative intensities are also given in the same table.

Table I.

Ultra-violet spark spectrum of cadmium			
McLennan and Edwards		Eder and Valenta.	
Wave-lengths in A°. U.	Intensity	Wave-lengths in A°. U.	Intensity
2096·1	1	2096·1	3
76·3	1	—	—
64·5	3	64·5	1
62·1	4	62·06	5
55·4	4	55·4	3
47·6	1	—	—
41·3	2	—	—
25·5	7	2025·53	5
21·2	1	—	—
19·4	5	2019·4	1
07·7	3	07·7	2
04·3	7	04·3	5
1995·1	5	1995·1	3
89·2	1	—	—
79 8	1	—	—
77·1	4	1977·1	2
70·4	1	—	—
65·4	4	1965·4	1
45·6	1	—	—
42·9	6	1942·9	2
39·2	4	39·2	4
21·9	4	1921·9	3
19·6	3	—	—
01·1	6	1901·1	1
1899·2	2	—	—
83·1	2	—	—
77·8	1	—	—
73·8	6	1873·8	5
56·4	6	56·4	4
54·8	6	—	—
50·6	7	—	—
44·1	7	—	—

VI. Summary of Results.

I. In the absorption spectrum of non-luminous mercury vapour there has been shown to be a strong symmetrically spaced band at $\lambda = 1849\cdot$ °.U., a diffuse complex band at $\lambda = 2338$ A°.U., and an asymmetrical band at $\lambda = 2536\cdot72$ A°.U. The complex band at $\lambda = 2338$ A°.U. consists of a band extending from $\lambda = 2313$ A°.U. to $\lambda = 2320$ A°.U. one at $\lambda = 2322$ A°.U. another at $\lambda = 2326$ A°.U. and a wider one between $\lambda = 2330$ A°.U. and $\lambda = 2338$ A°.U.

[1]Kayser's Handbook of Spectroscopy. Vol. V, p. 283.

II. In the absorption spectrum of non-luminous cadmium vapour there is a strong symmetrically spaced absorption band at $\lambda = 2288$ A°.U. and a narrow sharply defined one at $\lambda = 3260{\cdot}17$ A°.U.

III. In the absorption spectrum of non-luminous zinc vapour there is a strong symmetrically spaced absorption band at $= \lambda\ 2139{\cdot}3$ A°.U. and a very narrow, sharply defined one at $\lambda = 3075{\cdot}99$ A°.U.

IV. With the exception of the absorption band at $\lambda = 2338$ A°.U. all the absorption bands found for the vapours of the three metals are the first members of either the series represented by $n = 1.5, S-m, P$ or that represented by $n = 2, p_2-m_1, S$.

V. No absorption bands were found in the absorption spectra of gold, silver and copper vapours and in those of the vapours of alloys of these metals.

VI. A new form of metallic vapour arc lamp has been devised which gives arcs of exceptional brilliancy.

VII. In the arc spectrum of cadmium, reversals were found at $\lambda = 2288{\cdot}79$ A°.U. and $\lambda = 3100$ A°.U.

VIII. An examination of the cadmium arc line $\lambda = 6439{\cdot}3$ A°.U. with a Lummer plate interferometer showed it to be simple and without satellites. The zinc line $\lambda = 6364$ A°.U. photographically was found to be a simple one but visually it appeared at times to be accompanied by two faint satellites.

IX. A number of new lines have been found in the spark spectrum of cadmium between $\lambda = 2100$ A°.U. and $\lambda = 1840$ A°.U. These were brought out by the use of a fluorite spectroscope.

We desire to acknowledge our indebtedness to Mr. P. Blackman for assisting us in taking the photographs.

The Physical Laboratory,
University of Toronto,
May 1st, 1915.

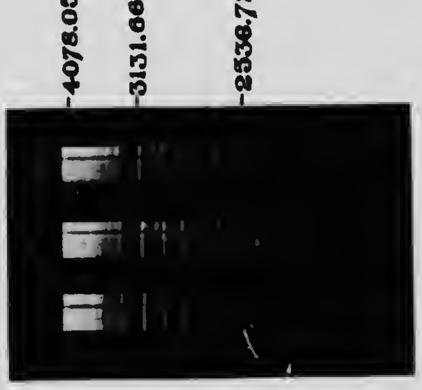


Fig. 1.

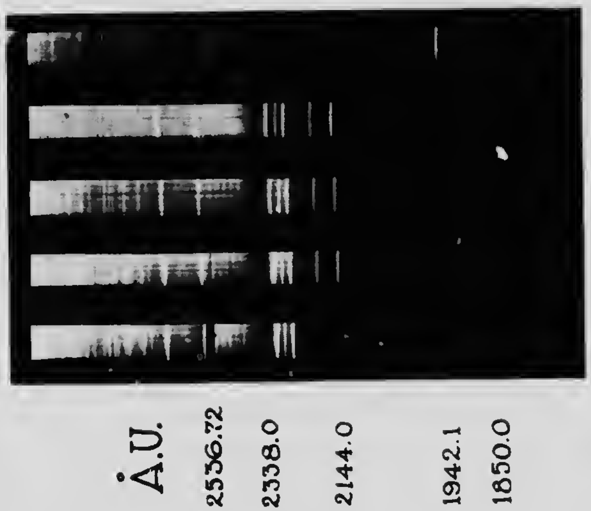


Fig. 2.

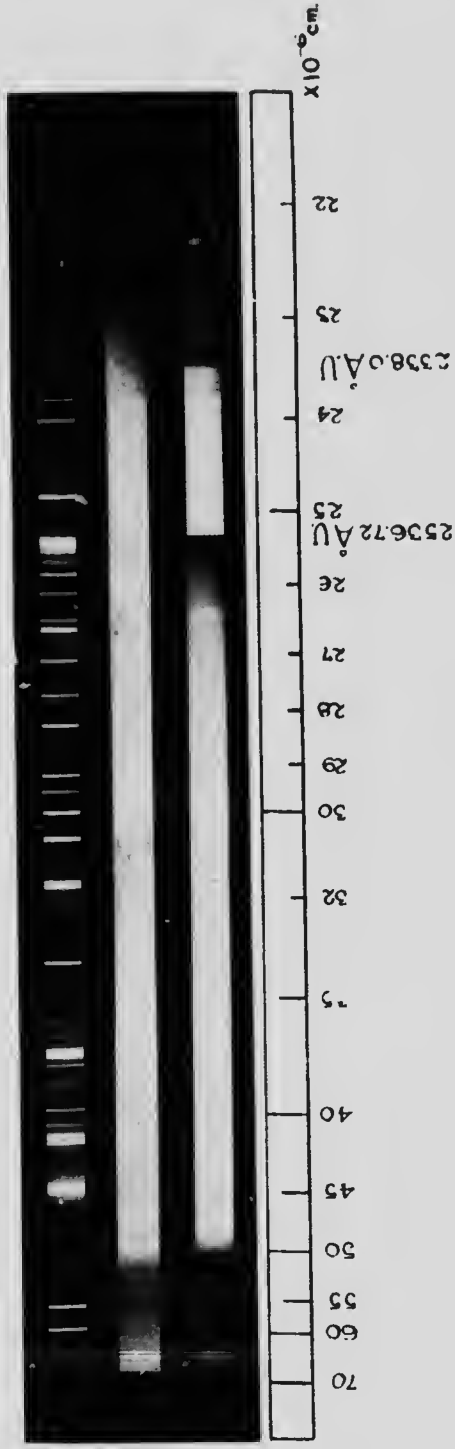

x10⁻⁶cm
22
23
2338.0 ÅU
24
25
2336.72 ÅU
26
27
28
29
30
32
35
40
45
50
55
60
70

Fig. 3.

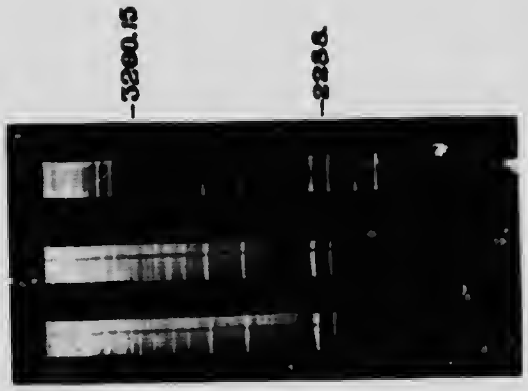


Fig. 5.

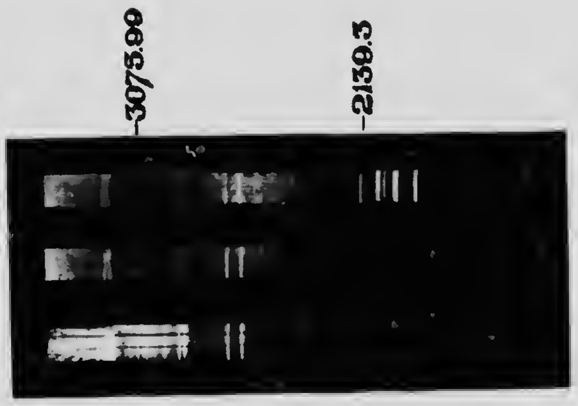
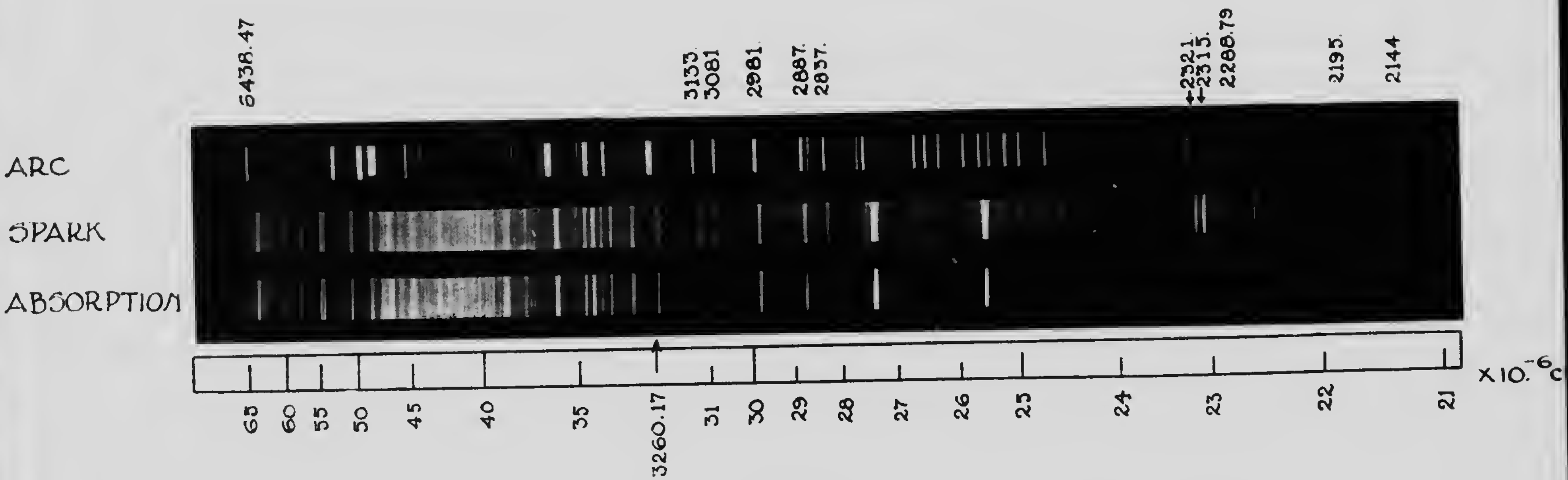


Fig. 8.



6438.47
3133
3081
2981
2887
2857
2321
2315
2288.79
2195
2144
ARC
SPARK
ABSORPTION
63
60
55
50
45
40
35
3260.17
31
30
29
28
27
26
25
24
23
22
21
$\times 10^{-6}$ c

Fig. 6.

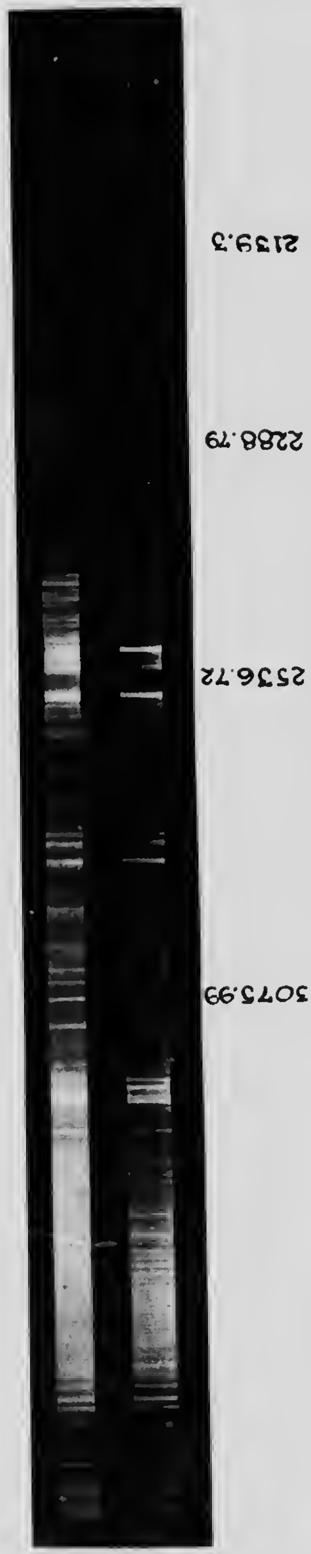
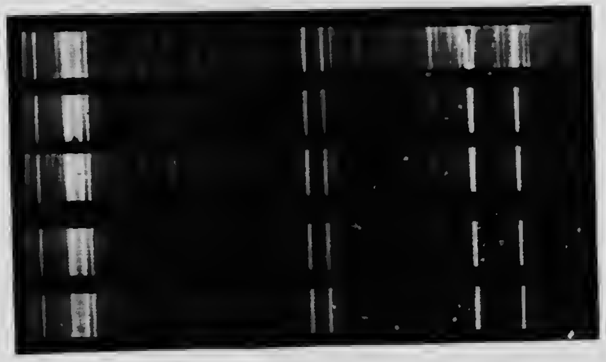


Fig. 9.



3075.99

2536.72

Fig. 10.

3075.99

Fig. 11.

Fig. 12.

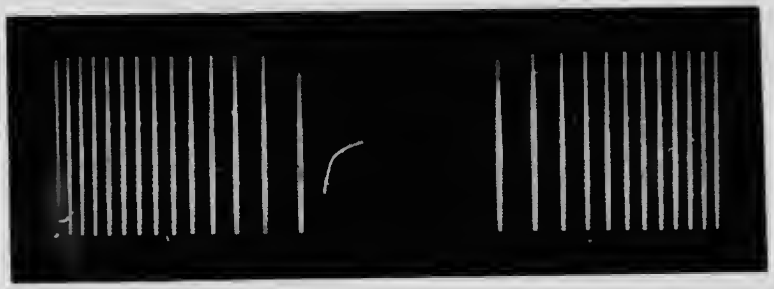


Fig. 13.

Fig. 14.