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A PHOTOGRAPHIC STUDY OF ARC SPECTRA.

By CAROLINE WILLARD BALDWIN.

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A PHOTOGRAPHIC STUDY OF ARC SPECTRA. I.

BY CAROLINE WILLARD BALDWIN.

INTRODUCTION.

IN the course of his investigation of the Infra-Red Spectra of the Alkalies, Professor Snow¹ has shown the remarkable effect produced upon the arc spectrum when the alkalies were present in the carbons. He found that the curve obtained from his bolometric measurements was materially changed by the metals. While in the ordinary arc he had several very strong maxima in the ultra-violet and in the visible spectrum, he discovered that upon introducing the metals, these intense regions disappeared and strong maxima were now observed only in the infra-red.

The maxima in the violet and ultra-violet are the well-known characteristic, bright groups of the arc spectrum. These are produced by a peculiar crowding together of fine lines in the regions $\lambda = 3450$ to $\lambda = 3590$, $\lambda = 3700$ to $\lambda = 3885$, and $\lambda = 4030$ to $\lambda = 4211$. The disappearance of these and other similar groups would amount to a practical obliteration of the arc spectrum and substitution in its stead of the line spectrum of the particular metal used.

The phenomena seemed worthy of further study, and as the bright groups lie in the regions to which the photographic plate is most sensitive, it was thought worth while to try the application of photography to determine whether the disappearance noted was complete, or whether the bright regions were only so much reduced in intensity as to escape detection by bolometric observation.

As a matter of fact, the work was extended beyond its original limit, and in the end it assumed the form of a photographic study of the spectrum obtained from different regions of the arc under

¹ B. W. SNOW, PHYSICAL REVIEW, Vol. I., p. 28.

different conditions, and of the effect of the metallic spectra upon the original carbon arc spectrum.

APPARATUS.

The spectrum to be photographed was produced by means of a Rowland concave grating, which was arranged in the usual way upon a Brashear mounting. The latter consisted of a strong iron frame, which carried two tracks, SG and SC , Fig. 1, at right angles to one another. At their point of intersection S , the slit was placed. The carriage G , which contained the grating, moved on one track, and the carriage C , for the camera box, on the other. These two carriages were connected by an iron rod to which they

Fig. 1.

were clamped in such a position as to keep the rod in the common normal to the grating and photographic plate. A screw on the camera box permitted the finer adjustments of position to be made.

The width of the slit was adjusted by means of a micrometer screw, 0.1 mm. being the width ordinarily used. The length of the slit was gauged by means of a diaphragm having a wedge-shaped opening. A frame which held the slit could be turned by means of a screw and spring so as to place the slit accurately parallel to the lines of the grating.

The grating was of six-foot radius, and 14,000 lines to the inch.

Celluloid films were used, and, as these could be readily bent to

any curvature, the film holder was curved to conform to the focus of the concave grating. A fence work of horizontal and vertical bars placed back of the film kept it from curving longitudinally, and yet permitted the spectrum to be seen from the back, so that a cleared film could be used for focussing.

The light used was obtained from a Thomson and Houston arc lamp, which was hung so that the arc could be kept nearly in the horizontal plane in which lay the center of the grating and the central points of the slit and camera box. The carbons were 1. cm. in diameter, unplated, and were made with a soft core .3 cm. in diameter. To produce the arc spectra of the metals, the cores were removed and the space was filled with the metallic salt well pounded in.

In order to prevent fogging of the photographic plates, the lamp *L*, Fig. 1, was placed in the outer of two dark rooms, and the light was reflected into the inner room, which contained the grating, by means of a large concave mirror (*M*). This mirror was mounted so as to be adjustable about both a horizontal and a vertical axis. Its radius of curvature was twelve feet. The arc light was placed nearly at the center of curvature of the mirror, which was so adjusted that a real, slightly enlarged image was formed on the slit (*S*). This arrangement was also of advantage, inasmuch as it did away with the use of a converging lens. The arrangement of the apparatus is given in Fig. 1, to which reference has already been made.

The opening between the two rooms was closed on the outer side by a slide provided with a circular opening, and on the inner side by a solid slide, by means of which the light could be entirely shut out.

A screen near the lamp cut off the direct rays of the opening between the rooms; and another screen was placed a short distance in front of the slit, to intercept the scattered light.

OUTLINE OF THE WORK.

The image of the arc, as examined by the eye, shows sheaths of different colors. The arc is slightly cone-shaped, the apex

resting on the negative carbon. The central portion (1), which is of a violet tint, connects the two bright points of the carbons. Outside of this is a sheath of dull blue (2), which is most brilliant at the negative carbon, where it extends across in such a way as to hide the violet portion. The outer sheath (3) is yellow, shading into orange at the cooler outer edge; this last part includes the greater portion of the flame of the arc, and extends well up around the positive carbon. The different divisions are shown in Fig. 2.

Fig. 2.

The investigation may be considered as divided into four parts:

I. Photographs were taken with the slit extending vertically through the arc in six different positions: first, through the center of the violet portion; second, at the line of separation between

Fig. 3.

Fig. 4.

Fig. 5.

the violet and blue; third, in the blue; fourth, between the blue and the yellow; fifth, in the yellow; and sixth, at the extreme outer edge of the yellow (see Fig. 3).

II. Photographs were also taken with the slit extending horizontally through the image of the arc. Three positions were chosen

for these: first, near the tip of the negative carbon; second, half-way between the carbons; and third, near the positive carbon.

III. The flame was blown out from between the carbons by means of a horseshoe magnet. Under these circumstances the violet part does not change much in its position, but is slightly extended on the side away from the magnet; while the blue and yellow are blown out nearly three centimeters beyond the edge of the carbons. The appearance of the arc was as shown in Fig. 4. Photographs were taken with the slit extending vertically through this image in nine different places (Fig. 5): first, at the inner edge of the arc; second, in the center between the tips of the carbons; third, in the outer part of the violet; fourth, at the edge of the carbons; fifth, outside of the carbons through the blue and yellow; sixth, in the yellow; seventh, at the extreme end of the flame; eighth and ninth, at the edge of the carbons, giving the extent of the flame in the first place at the side toward the negative carbon, and in the second place at the positive carbon.

One hundred and thirty photographs were taken by these methods, from which the study of the ordinary arc spectrum has been made.

IV. Metals were introduced into the arc, and similar sets of photographs were taken.

The metallic salts used were lithium carbonate, sodium nitrate and chloride, potassium chloride, calcium chloride, strontium oxide, barium chloride, copper sulphate, silver nitrate, zinc chloride, and cadmium chloride. Sodium and zinc were studied by all three methods, the others only by the first two. This series included one hundred and fifty photographs.

All of these photographs were taken in the primary spectrum, as there was less confusion due to overlapping of spectra. The ultra-violet of the second spectrum, which extended to the green of the first, could be easily cut off by means of a glass plate placed in front of the slit. This gave a pure spectrum in the region to which the plates were sensitive.

In order to have the negatives evenly exposed, and the intensity as nearly as possible the same for different parts of the spectrum, four positions were chosen for photographing. *First*, the ex-

treme ultra-violet, including the first bright group ($\lambda = 2263$ to $\lambda = 3600$); *second*, the region of the three principal bright groups ($\lambda = 3450$ to $\lambda = 4211$); *third*, from the brightest of the groups to the *D* lines, or from $\lambda = 3800$ to $\lambda = 5900$; and *fourth*, with a very long exposure, the region between $\lambda = 4500$ and $\lambda = 6400$. The exposures varied in length from thirty seconds in the violet to five or ten minutes in the extreme ultra-violet, and fifteen to twenty minutes in the red of the spectrum.

On account of the motion of the arc it was necessary to have a movable screen, by means of which the light could be cut off whenever the arc moved so as to throw the wrong part of the image upon the slit. This movement of the arc caused so much trouble that it was difficult to obtain good photographs of the different sheaths in the regions of the spectrum which required long exposure. Hence the study of the spectra of different parts of the arc has been confined to the region between $\lambda = 3010$ and $\lambda = 5500$; and toward the ends of this region photographs were taken only in the violet, blue, and yellow sheaths of the image. A slightly longer exposure was given in the outer part of the arc than was needed in the violet and blue portions.

The length of the arc used was about 1.4 cm.

I.

RESULTS OBTAINED WITH THE ORDINARY ARC.

The distinctive features of the arc spectrum are the bright groups¹ from $\lambda = 3520$ to $\lambda = 3590$, $\lambda = 3800$ to $\lambda = 3885$ mentioned by Kayser and Runge, Drude and Nunst, Nichols and Franklin, etc.; one from $\lambda = 4400$ to $\lambda = 4604$; the carbon bands² given by Kayser and Runge and others, $\lambda = 4680$ to $\lambda = 4737$, $\lambda = 4746$ to $\lambda = 5165$, and $\lambda = 5530$ to $\lambda = 5635$; together with a host of periodically placed fine lines. The bright groups appear to be due to a crowding together of these numerous fine lines. The strong lines of the various metals, which are present

¹ Snow, PHYSICAL REVIEW, Vol. I., p. 28; Kayser and Runge, Wied. Ann., XXXVIII, p. 81, 1889; Drude and Nunst, Wied. Ann., XLV., p. 460, 1892; Nichols and Franklin, Am. J. (3), p. 106, 1889.

² Kayser and Runge, Ueber die Spectren der Elemente, Zweiter Abschnitt.

as impurities in the carbons, are superposed upon this under spectrum. The arc spectrum thus seems to consist of two spectra.

The general arrangement of the periodic lines is worthy of note. They are finer and nearer together toward the violet end of the spectrum; the bright groups are also nearer together in the regions of greater refrangibility. In each group, however, the lines are finer and nearer together toward the red of the spectrum, the maximum being toward the longer wave lengths, on which side the termination of the group is sudden. Each of the groups shows secondary maxima, and between each of these the same general law is followed, as in the case of the group as a whole. We shall speak of these groups hereafter under the general name of the band spectrum.

Many of the metallic lines are stronger near the negative carbon and are weak or invisible at the positive carbon,¹ while the lines of the band spectrum are strongest at the positive carbon.

As we pass from the center of the arc to the edge, the band spectrum grows fainter and finally disappears. This is also true of many of the metallic lines, while other metallic lines seem to be equally bright in all parts of the arc, and a considerable number are relatively stronger in the outer sheath. This effect is enough to change the entire aspect of the spectrum in many places. The lines which show the last effect do not belong exclusively to any one metal, neither do all the lines of a metal seem to act thus. In the case of the calcium lines, all the triplets of the 2d series given by Kayser and Runge² are strongest in the center, while the pairs

$$\left. \begin{array}{l} 3968.63 \\ 3933.83 \end{array} \right\} \text{ and } \left. \begin{array}{l} 3737.08 \\ 3706.18 \end{array} \right\}$$

and certain other lines as $\lambda=4226.91$ are much stronger in the yellow part of the arc flame. A few of the triplets of the first series are stronger toward the edge. Such are

$$\left. \begin{array}{l} 4318.80 \\ 4302.68 \\ 4299.14 \end{array} \right\} \text{ and } \left. \begin{array}{l} 3644.45 \\ 3630.82 \\ 3624.15 \end{array} \right\}$$

¹ Lockyer, Proc. Roy. Soc., XXVIII., 1879.

² Kayser and Runge, Ueber die Spectren der Elemente.

In the carbon band, ending at $\lambda=4735$, the maxima remain the same as we pass from center to edge of the flame, but the law seems to be changed. In the outer sheath the maximum intensity is toward the violet and the strongest maximum is $\lambda=4645$. The shading of the band is thus completely reversed. Another band with maxima toward the violet is seen in the outer sheath from $\lambda=4840$; the maxima being $\lambda=4840$, $\lambda=4865$ and $\lambda=4892$. The strongest part of the group at 3590 becomes the weakest in the outer part of the arc, and many groups have the faintest lines at the center, the strongest at the edge.

When the photographs are taken giving the spectrum of the flame as blown out from between the carbons by the action of a magnet, the slit extends across the different sheaths of the arc, and those lines which are stronger in the outer parts of the arc reach through the spectrum with their brightness undiminished or increased at the edges, while the bands and many of the metallic lines appear only in the central part.

When the slit is arranged to pass through the image of the arc horizontally, this effect is more marked, owing to the greater steadiness of the flame. In watching the developing of the negatives, it was observed that many of the lines, as 4226, 3583, 3571, were first visible at the edge and then gradually extended toward the center, while the fine lines of the band spectra and most of the other lines appeared first at the center and then extended part way to the edge. The photographs taken by the three methods thus show complete agreement in their results.

Since the spectrum of the arc has already been mapped with more powerful apparatus than that used in these experiments, only such points will be given as may serve to indicate the differences between the spectra of the different sheaths.

(A) *Region lying between 2263 and 3100.*

135 lines were mapped between 2263 and 3016, all of which belonged to the central violet sheath [(1) Fig. 2].

The first lines which could be detected in the blue and yellow sheaths lay between 3018 and 3099; eleven lines among the nineteen mapped were visible in the blue and four in the yellow.

(B) *Region lying between 3100 and 3440.*

72 lines were mapped, all of which were confined to the central blue sheath.

(C) *Region lying between 3440 and 3928.*

135 lines were mapped, of which

125 were present in the violet,
96 were present in the blue,
58 were present in the yellow.

Of those which were invisible or very faint in the central violet sheath, although strong in the outer sheaths, the following are readily placed in Rowland's Standard List:¹

3812.12	} C.	3832.45	Mg.
3812.20		3834.36	Fe.
3812.34		3838.43	Mg.
3815.98	Fe.	3841.19	FeMn.
3820.59	FeC.	3856.52	Fe.
3827.03	Fe.	3860.05	FeC.

(D) *Region lying between 3930 and 4550.*

Throughout this region photographs were taken in the five positions indicated in Fig. 3, as *a*, 2, 3, 5, and 6.

213 lines were mapped, of which

211 lines were visible in central violet sheath (*a*),
200 lines were visible in outer violet sheath (2),
179 lines were visible in blue sheath (3),
175 lines were visible in inner yellow sheath (5),
57 lines were visible in outer yellow sheath (6).

The two lines absent from the central violet appear to be

3960.05 Fe } Rowland's scale.
4076.96 Fe }

¹ Rowland, *Astrophysical Journal*, I., p. 29, 1895.

(E) *Region lying between 4550 and 4960.*

Photographs were taken in three regions (1, 2, and 3, Fig. 2).

129 lines were mapped, of which

129 lines were visible in the violet sheath,
103 lines were visible in the blue sheath,
95 lines were visible in the yellow sheath.

(F) *Region lying between 4960 and 6042.*

115 lines were mapped, of which

115 lines were visible in the violet sheath,
42 lines were visible in the blue sheath.

If we sum up these data, we find

Total lines mapped	799, ¹
Visible in central violet	787,
Visible in blue	431,
Visible in yellow	232.

Attempts to classify these lines according to their sources led to no satisfactory results. A study of the photographs, however, showed that the lines of the arc spectrum may be grouped as follows:

1. *a.* Lines which grow gradually weaker as we move from the center to the edge, and are usually invisible in the outer sheath.

1. *b.* Lines which preserve about the same intensity in the center and blue of the arc, but are suddenly much weaker or invisible in the yellow.

Forty lines of this class were counted. They were distributed throughout the spectrum from 3024 to 5616.

The lines of the band spectra grow fainter through the blue, but disappear quite suddenly there, not being seen in the yellow.

1. *c.* Faint lines which are only found in the first two positions (*a* and 2, Fig. 3). Invisible in the blue. One hundred and sixteen of these were counted.

¹ Exclusive of the fine lines of the band spectrum which were not counted.

II. *a.* Lines which appear equally strong in all parts of the arc. Seventy such lines were counted.

II. *b.* Lines which become stronger as we go out from the center. Seventy-nine of these lines were mapped.

II. *c.* Lines which are not visible or exceedingly faint at the center of the arc. There are eighteen of these, of which exact positions for twelve have been given in a previous paragraph.

II. *d.* Lines which have their maxima in other sheaths, 2 or 3, rather than in the center or at the edge of the arc. There are sixteen such lines upon the photographs.¹

II. *e.* Lines which have more than one maximum. Six such lines were noted.

The lines of division I. are as a rule *stronger at the positive carbon*, while the lines of II. are usually *stronger at the negative carbon*. II. *b.* and II. *c.* are especially strengthened at the negative carbon, II. *a.* to a less extent.

The calcium lines 4581.66 and 4586.12 appear as single lines at the negative carbon, but at the positive they seem to be double.

¹ There is reason to think that at least ten of these are titanium lines, but the evidence is not conclusive.

A PHOTOGRAPHIC STUDY OF ARC SPECTRA. II.¹

BY CAROLINE WILLARD BALDWIN.

II.

METALLIC SPECTRA.

CERTAIN metals when introduced into the arc tend to obscure the band spectrum, *e.g.* Na, Li, K, Sr, Ba, Ca ; while others, as Zn, Cd, Cu, Ag, give the band spectra with equal or increased brilliancy. In no case was the band spectrum entirely invisible, but it was so much weakened by the alkalis that it is not strange that in their presence the carbon bands were not detected by the bolometric measurements of Professor Snow.

In the ensuing paragraphs the results obtained by photographing the arc when cores of the carbons were filled with various alkalis are briefly described and tables of the lines are given.

Lithium Carbonate.

Lithium gives an almost homogeneous carmine-colored arc. The spectrum has much the same general appearance as the spectra from the outer sheaths of the arc, with the addition of the lithium lines, and at a very short distance from the center of the arc the band spectrum is entirely invisible. However, the bright groups are faintly visible in the photographs taken from the center of the arc.

Lithium does not materially affect the other metallic lines present in the ordinary arc spectrum. The lines which are most brilliant in the outer sheaths of the original arc are, with but few exceptions, the strong lines present when lithium is introduced. The carbon lines 3585.99, 3586.04, and 3590.52 are much fainter than in the yellow of the ordinary arc, and are not visible at

¹ Concluded from the PHYSICAL REVIEW, March-April, 1896.

all when the slit is at a little distance from the center of the image, while a line at 3583 is very sharp in all the photographs. The calcium lines 4299.14, 4302.68, 4318.80, 4425.61, 4435.86, and 4456.81 are stronger than in the yellow of the arc, being nearly as strong as 4307.91; but Ca 4527.17 is fainter in comparison to surrounding lines. Line 4527.17 is in fact hardly visible.

Lithium lines photographed.¹

$\lambda = 2741.39$	$\lambda = 3794.9$	$\lambda = 3985.94$	$\lambda = 4602.37$
3232.77	3838.3	4132.44	4972.11
3670.6	3915.2	4273.44	6103.77
3718.9			

Sodium Nitrate.

When sodium is in the arc the flame is homogeneous and quite dense; the band spectrum is not so faint as when lithium is present, still it is much reduced in brilliancy. All of the calcium lines are strengthened. Calcium seems to have been present as an impurity in a number of the salts used. The *D*-lines were reversed both when the nitrate and chloride were used.

Sodium lines photographed.

$\lambda = 2512.23$	$\lambda = 4343.7$	$\lambda = 4546.03$	$\lambda = 5153.72$
2543.85	4390.7	4665.2	5670.40
2593.98	4393.7	4669.4	5675.92
2680.46	4420.2	4748.36	5682.90
2852.91	4423.7	4752.19	5688.26
3302.47	4494.3	4979.30	5890.19
3303.07	4500.0	4983.53	5896.16
4325.7	4542.75	5149.19	

¹ The wave lengths of the metallic lines are taken from Kayser and Runge, Ueber die Spectrum der Elemente, with whose measurements the scale readings agreed quite accurately. These tables are not given to establish wave lengths, but to show which of the lines already catalogued were found in these photographs.

Potassium Chloride.

Potassium easily gives a long arc which is homogeneous and very clear, so as to be hardly visible between the carbons. It is of a less intense color than the arc of sodium or of lithium, and seems to be surrounded by a considerable mass of cooler vapor. The carbons are not at a very high temperature. The band spectrum is absent except very near the positive carbon. The strong metallic lines from the original arc are present. The metallic lines appear much as when sodium and lithium are used.

Potassium lines photographed.

$\lambda = 3217.76$	$\lambda = 4047.36$	$\lambda = 4956.8$	$\lambda = 5112.68$
3446.49	4870.8	4965.5	5782.67
3447.49	4943.1	5084.49	5802.01
4044.29	4952.2		

Calcium Chloride.

When calcium is in the carbons, they are as highly incandescent as carbons which contain no metallic salt. The heat of the arc does not seem to be so much diminished as in the preceding cases. The arc shows a more varied formation. There is a blue-violet center, which is decidedly blue near each carbon. This is surrounded by a dark part, while the outer sheath is of an orange tint. The dark part diminishes as the carbons become heated.

In the spectrum the strength of the bands is less affected than by the other metals yet studied; but their hazy appearance is removed, and the fine lines are more sharp. As soon as we pass into the outer sheath, the bands disappear with the exception of a slight indication of the one which terminates at $\lambda = 3885$. The calcium lines remain exceedingly sharp and brilliant in the outer sheath.

As in the ordinary arc, the calcium lines 4581.66 and 4586.12, also lines of unknown origin near 4603., 4586., and 4581., are clearly seen at the negative carbon only, while lines at 4604. and 4576. are visible only at the positive carbon. Line 4226.91 was strongly reversed.

Calcium lines photographed.

$\lambda = 2398.66$	$\lambda = 3630.82$	$\lambda = 4318.80$	$\lambda = 5189.05$
2995.06	3644.45	4355.41	5260.58
2997.42	3653.62	4425.61	5261.93
2999.76	3706.18	4435.13	5262.48
3006.95	3737.08	4335.86	5264.46
3140.91	3933.83	4454.97	5265.79
3150.85	3949.09	4456.08	5270.45
3158.98	3957.23	4456.81	5349.66
3179.45	3968.63	4508.04	5513.07
3181.40	3973.89	4509.89	5582.16
3209.68	4092.93	4512.73	5588.96
3215.15	4095.25	4527.17	5590.30
3225.74	4098.82	4578.82	5594.64
3344.49	4226.91	4581.66	5598.68
3350.22	4240.58	4586.12	5601.51
3361.92	4283.16	4685.40	5603.06
3468.68	4288.51	4833.85	5857.77
3474.98	4299.14	4847.22	6102.99
3487.76	4302.68	4878.34	6122.46
3623.15	4307.91	5041.93	

Strontium Oxide.

With strontium the arc has a pear-shaped purple center, the larger end of which rests on the positive carbon. The central part is bluish at each carbon. The outer sheath is of a brilliant red color, and the line between the two parts is very sharp and bright. The carbons are not very hot. They are, indeed, scarcely more than at a red heat. The effect on the spectrum is similar to that of calcium, and the same arrangement of lines at the positive and negative carbon is emphasized. The band spectrum is about as strong as when calcium is present, but it does not disappear quite so completely as in the outer sheaths of the arc.

The number of strontium lines in the vicinity of the bands tends to obscure their character.

Strontium lines photographed.

$\lambda = 2931.98$	$\lambda = 3547.92$	$\lambda = 4319.39$	$\lambda = 4784.43$	$\lambda = 5156.37$
3199.1	3628.62	4326.60	4812.01	5222.43
3200.4	3653.22	4338.00	4784.43	5225.35
3301.81	3705.88	4361.87	4812.01	5229.52
3307.64	3940.91	4412.82	4832.23	5238.76
3322.32	3969.42	4438.22	4855.27	5257.12
3330.15	3970.15	4480.96	4868.92	5451.08
3351.35	4030.45	4531.54	4869.41	5481.15
3366.43	4032.51	4607.52	4872.66	5486.37
3380.89	4077.88	4678.39	4876.35	5504.48
3464.58	4161.95	4722.42	4892.20	5522.02
3475.01	4215.66	4729.93	4962.45	5535.01
3477.33	4305.60	4742.07	4968.11	5540.28
3499.40	4308.49	4755.59	4971.85	5543.49
3504.70				

Barium Chloride.

When barium is present, the arc has a large round center, which shades from rose pink through lemon yellow to lime green at the edge. Next to each carbon it is of a brilliant lemon yellow color. The carbons are not very highly heated.

The barium lines come out easily, and are very strong; but the bands and all but the strongest lines in the original spectrum are so weak that they are almost invisible.

Barium lines photographed.

$\lambda = 2304.32$	$\lambda = 3662.62$	$\lambda = 4085.35$	$\lambda = 4407.10$	$\lambda = 4636.80$
2335.33	3664.76	4087.90	4413.96	4642.38
2596.89	3689.28	4110.46	4432.13	4673.69
2702.78	3701.87	4130.88	4467.36	4691.74
3281.96	3794.77	4132.60	4489.50	4700.64
3357.00	3861.87	4166.24	4493.82	4724.98
3420.48	3889.45	4179.57	4506.11	4726.63
3501.29	3891.97	4224.11	4523.48	4877.99
3525.23	3892.97	4239.91	4525.19	4900.13
3544.94	3900.54	4242.83	4554.21	4903.11
3577.79	3906.20	4264.45	4574.08	4934.24
3579.97	3910.04	4283.27	4579.84	4947.50
3586.64	3917.42	4323.15	4589.82	5424.82
3588.33	3935.87	4325.38	4591.88	5437.66
3593.58	3938.09	4333.04	4600.02	5519.37
3599.60	3993.60	4350.49	4605.11	5535.69
3611.17	3995.92	4359.80	4620.19	5777.84
3637.10	4079.56	4402.10	4628.45	5853.91

Zinc Chloride.

The band spectrum is better than was obtained under any other circumstances. The bands are greatly extended and very distinct. The arrangement of lines in different parts of the arc is especially marked in the flame spectra. All of the calcium and aluminium lines are very clear in the outer sheath of the arc and near the negative carbon. The bands cling closely to the positive carbon, but the zinc lines cross the arc with nearly equal brilliancy in all parts. Only the carbon bands are seen in the region having a wave length greater than $\lambda = 4862$.

The "grating effect" is continuous from $\lambda = 3400$. to $\lambda = 5635$. The effect of the zinc seems to be to obscure all but the strongest of the other metallic lines, and to increase the intensity of the band spectrum.

Zinc lines photographed.

$\lambda = 2802.11$	$\lambda = 3072.19$	$\lambda = 3515.26$	$\lambda = 4293.02$
2823.27	3075.99	3572.90	4298.54
2833.13	3282.42	3671.71	4630.06
2863.43	3302.67	3683.63	4680.38
2873.39	3303.03	3740.12	4722.26
2913.63	3345.13	4019.75	4810.71
3018.50	3345.62	4058.02	5182.20
3035.93	3346.04	4101.94	

Cadmium Chloride.

The spectrum obtained when cadmium is present in the arc is similar to that with zinc.

Cadmium lines photographed.

$\lambda = 2677.65$	$\lambda = 2961.64$	$\lambda = 3466.33$	$\lambda = 3981.92$
2712.65	2980.75	3467.76	4306.98
2733.97	2981.46	3500.09	4413.23
2763.99	3081.03	3595.64	4662.69
2775.09	3133.29	3610.66	4678.37
2837.01	3252.63	3613.04	4800.09
2868.35	3261.17	3649.74	5086.06
2880.88	3299.11	3729.21	5154.85
2881.34	3403.74		

Copper.

Copper gives an arc which has a bluish-green center with bright green near the carbons. This is surrounded by a dark part, which is again enclosed by a yellow outer sheath.

The spectrum appears almost like that obtained from the center of the original arc, with the addition of the lines due to copper. The variation in brightness of certain lines at the positive and negative carbons is very noticeable, and is more easily observed owing to the fact that the copper lines are all strongest *about half-way between the carbons*, at which point they show a decided enlargement. In the band spectrum only the fine, grating-like lines are seen. The indications of the strong lines are seen at the negative carbon, while the lines of the band spectrum are strong for the whole width of the arc.

Copper lines photographed.

$\lambda = 3771.96$	$\lambda = 4123.38$	$\lambda = 4378.40$	$\lambda = 4674.98$
3860.64	4177.87	4397.42	4697.62
4003.18	4242.42	4415.79	4704.77
4010.96	4249.21	4480.59	5105.75
4015.80	4253.53	4507.62	5144.35
4022.83	4259.63	4509.60	5153.33
4056.80	4267.48	4513.39	5218.45
4062.54	4275.32	4531.04	5220.25
4063.50	4329.00	4539.98	5292.75
4073.28	4336.17	4587.19	5700.39
4080.70	4354.91	4651.31	5782.30

Silver.

The appearance of silver in the arc, and its effect upon the spectrum, are almost identical with that of copper.

Silver lines photographed.

$\lambda = 3280.80$	$\lambda = 3841.30$	$\lambda = 4055.44$	$\lambda = 4616.03$
3383.00	3907.63	4212.10	4668.70
3542.67	3914.47	4311.28	4678.04
3557.30	3940.30	4379.45	5209.25
3681.80	3943.10	4396.49	5465.66
3710.10	3981.87	4476.29	5471.72
3810.60	3991.90	4556.13	

REMARKS.

As has been noted in a previous paragraph, the lines of the ordinary arc which are strongest at the negative carbon increase in intensity in the outer sheaths, while the reverse is true with the lines from the positive carbon. When the metals K, Na, Li, Ba, Sr, and Ca are introduced, the lines from the positive carbon are weakened. The effect is most marked in the case of potassium. Barium reduces the carbon bands the most.

The metals Cu and Ag, from the group I. *b*, give the spectrum in about its normal condition, with the lines due to the especial metal added; while the metals Cd and Zn increase the intensity of the bands and diminish the strength of the metallic lines originally present near the negative pole.

It has been frequently observed by others who have worked with metallic spectra by this method, that it is necessary to have added resistance in the circuit which supplies the arc, when metals are used, in order to maintain a constant length of arc. The amount that had to be added in the course of these experiments varied very much with the different metals.

In a circuit of such electromotive force that 3 ohms resistance were necessary to give the ordinary arc its normal voltage (48 v), it was found that the following resistances would restore the arc to its proper condition:

Metal.	Resistance.	Metal.	Resistance.
Silver	3.1	Cadmium	5.8
Copper	3.8	Potassium	9.1
Zinc	5.6	Sodium	9.5
Barium	5.6	Lithium	9.7
Strontium	5.8	Calcium	9.9

When the metals were used, the temperature of the carbons was apparently much less than with the pure carbon points. The temperature of the positive carbon was most affected, and it did not waste so rapidly in proportion to the negative as when no metallic salt was in the core.

It might be thought that the changes observed were due to the fact that the temperature is not high enough to render all the lines visible. This view would be strengthened if the lines of metals which require the highest temperature for fusing and vaporization were strongest in those parts of the arc which are hottest. But this does not seem to be the case, for although K, Na, and Li, metals of low melting points, are strengthened at the negative carbon, so also are Ba, Sr, and Ca, which have relatively high melting points. The Cu and Ag lines extend across the arc with nearly even intensity, and the same is true of Zn and Cd.

It does not seem that the diminished intensity of the carbon bands in the presence of certain metals can be wholly due to the density of the gases of the flame; as there is no direct relation between the amount of weakening of the bands and the density of the metallic vapor. Neither does the change seem to depend in any simple way upon the atomic weight of the metals. Barium and potassium obscure the bands most; and they are respectively the highest and lowest in atomic weight of the metals studied.

There are many reasons for believing that there is an electrolytic action in the arc. This belief is strengthened by the fact that the metallic lines appear at the negative carbon, and the carbon bands are strongest at the positive. It is also true that the metals K, Na, Li, Ba, Sr, Ca, which are highly electropositive, are more strengthened at the negative carbon than are Cd, Zn, Cu, Ag, which are less positive.

In studying the effect of the metals upon the lines of the original spectrum, we may consider the need of increased resistance in the outer circuit to be due to diminished resistance of the arc, or to a change in the counter electromotive force. In the former case, the list of resistance given should have the same order as the resistance of the various metallic vapors. The arrangement, however, is not that of the respective metals as we know them at ordinary temperatures.

SUMMARY.

(1) The spectrum obtained from the electric arc is not the same for all parts of the arc and the surrounding flame. On the contrary, there is a decided difference in the spectrum of the several sheaths. The difference is largely due to a fading out of the carbon bands and of all lines from the positive carbon, and an increase of intensity in the outer sheath of those lines which are most brilliant near the negative carbon. Certain lines and bands which are invisible in the center are seen in the outer part of the flame.

(2) The total number of metallic lines diminishes rapidly, as we explore the arc from the center outwards.

(3) When the spectrum is changed by the introduction of metals into the carbons, it is observed that the more positive metals, such as K, Na, Li, and Ba, Ca, Sr, greatly weaken, but do not destroy, the characteristic band spectrum of the arc. The lines which are most affected by these metals are those which in the ordinary spectrum are strongest near the *positive carbon*.

Certain metals, as silver and copper, do not materially alter the original arc spectrum, while others, as zinc and cadmium, affect the lines near the *negative carbon*, and thus give the band spectrum, which is no longer obscured by the metallic lines usually present, an unwonted brilliancy.

The causes of the phenomena are not easily discovered, but it is hoped that the points brought out in this paper may throw some light upon the intricacies of this complex problem.

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