THE CAUSE OF THE SO-CALLED POLE-EFFECT IN THE ELECTRIC ARC

By T. ROYDS

Differences of vapor-density were first suggested in *Kodaikanal Observatory Bulletin*, No. 38, as the cause of the displacements of certain lines in different parts and conditions of the electric arc, and of the abnormal sun-minus-arc displacements of the same lines. Since, however, direct experimental proof is wanting, and has been said to give negative results, it seems desirable to discuss the evidence and experiments at the point at which work here on the subject has to be abandoned.

The cause of the displacements in the electric arc has also been treated by St. John and Babcock,[1] Gale and Whitney,[2] and Whitney,[3] none of whom discusses the evidence and conclusion in *Kodaikanal Observatory Bulletin*, Nos. 38 and 40.[4]

In the last two papers on experiments with a calcium arc, the pole displacement is ascribed to the greater amplitude of vibration of the electrons, and is said to depend on the intensity-gradient along the arc. The latter phrase is unfortunate, as, so far as I understand them, the authors do not mean the rate of change of intensity, but intensity-differences.

It must be obvious to every experimenter that the intensity of lines is great in those regions of the arc where displacement occurs; but, as it is equally true of lines which do not undergo displacement and of those which are displaced to the red and to the violet, one fails to see how the displacement can be said to depend on the intensity-differences. One might with equal or more truth say that the displacement depends on the width of the spectral lines, or on their diffuseness, but for reasons which have already been

[1] *Astrophysical Journal*, **42**, 231, 1915.

[2] *Ibid.*, **43**, 161, 1916.

[3] *Ibid.*, **44**, 65, 1916.

[4] Both these bulletins appeared in 1914.

elaborated,[1] I believe that the displacement depends on the unsymmetrical character of the spectral lines. I have not met with a single case where lines whose character was known were not displaced, either not at all, to the red, or to the violet, according as they were symmetrical, unsymmetrically widened toward the red, or unsymmetrically widened toward the violet, *except under those conditions, e.g., in reversals, where the vapor-density has been kept low.* Of course these phenomena—unsymmetrical character, intensity, etc.—are not the *cause* of the displacement, but are attendant effects due probably to the same cause.

Increased amplitude of vibration of the electrons is suggested by Gale and Whitney[2] as the cause of the displacement in the electric arc, but it is easy to see that this cannot be. The most effective and probably the only certain way known to me of increasing the amplitude of vibration of the electrons in the atom is to raise the temperature, but the displacements in the arc are not an effect of temperature, for many reasons, among which the three following seem sufficient.

1. Little is known of the variation of temperature along the arc, but it is certain that the positive pole is much hotter than the negative, whereas under normal conditions the displacement is greatest near the latter. The enhanced lines, which are high-temperature lines, appear stronger at the positive pole than at the negative,[3] also indicating that the temperature is higher there than at the negative pole.

2. The experiments described in *Kodaikanal Observatory Bulletin*, No. 40, and here, show that the displacement at the negative pole can be varied to any desired extent without reason for believing that the temperature of the arc is altered in any appreciable degree.

3. In the sun's reversing layer, where the temperature exceeds that attainable in the arc, the displacement of lines unsymmetrical in the arc is in the direction *opposite* to that of the displacement at the poles of the arc.

[1] Royds, *Kodaikanal Observatory Bulletin,* Nos. 38, 40.

[2] *Loc. cit.*

[3] A. Fowler, *Monthly Notices,* **67,** 154, 1907.

Although the evidence given in *Kodaikanal Observatory Bulletin*, Nos. 38 and 40, is strongly in favor of density as the cause of the displacements, there are many difficulties in the way of direct experimental proof, due primarily to the difficulty of controlling the vapor-density in a source of light. Experiments with different quantities of material, such as those giving Gale and Whitney's Tables III and IV, fail; or at any rate are inconclusive, because there is no reason to believe that the atoms have been separated a greater distance with the smaller amount of material. If the atoms are vaporized in clusters, they may not be removed from each other's influence any more than when a larger amount has been used. Exposure-times are not a sufficient test of vapor-density, but only an indication of the total amount of material consumed.

On account of this difficulty it was thought better to use alloys as electrodes. Presumably the molecules in an alloy are so intimately mixed with another metal that each would be surrounded by molecules of another kind, and would be removed from the influence of those of the same kind. Even so, the experiments gave negative results. The best alloys available were the coins of the Indian coinage, the silver coins containing 10 per cent of copper, and the nickel coins containing 20 per cent. As the silver coins, and the money they represent, melt away rapidly and do not give a steady arc, the experiments were conducted mostly with nickel coins (value one anna). With a nickel coin as one electrode, and the other another coin, iron, or carbon, the wave-lengths and displacements of the three copper lines $\lambda\lambda$ 4480, 4509, and 4531 were compared with those in the arc between copper electrodes with the same length of arc and current-strength. The maximum displacement of the first and last was about $+0.05$ A and of the second about $+0.025$ A. The wave-length at the center of the alloy arc was identical with that at the center of the pure copper arc, but it was found that the wave-length at the negative pole could be varied at will by varying the material of the negative electrode. With carbon as negative electrode and the nickel coin or copper as the positive, the displacement of the copper lines at the negative electrode could be made very small, especially with those conditions when the green luminosity surrounding the positive electrode did not reach up to the negative which showed the characteristic blue of the carbon arc. When the nickel coin is negative, and the positive pole a coin, iron, or carbon, there is on the other hand not the slightest difficulty in obtaining displacements at the negative quite as large as those at the negative pole of the arc between two copper electrodes.

The results with the alloy were therefore, in the main, disappointing, especially the fact that the wave-length at the center of the alloy arc was identical with that at the center of the pure metal arc. There is, however, one case, the sodium pair $\lambda\lambda$ 5682, 5688, where it is possible to obtain a displacement in the same direction as that in the sun and opposite to that usual at the negative pole. The data are given in *Kodaikanal Obersvatory Bulletin*, No. 40. The solar displacement of these lines, comparing the center of the sun's disk with the center of a very long arc, is -0.14 A (i.e., to the violet), the displacement of the unreversed line at the negative pole is $+0.36$ A, while the displacement of the *reversal* which occurs at the negative pole is -0.019 A. The sodium pair is very sensitive to displacement, and is only a case more extreme than many others, found in the bulletin referred to, for which the displacement at the negative pole is much smaller if the line undergoes reversal there than if the line remains unreversed. A new example of this has turned up in the first subordinate triplet of calcium near λ 4450. If the lines are reversed at the negative pole, the displacement is quite small or zero[1] and the lines appear almost, if not quite, symmetrical.[2] If, however, the lines are obtained unreversed at the negative pole, the displacement amounts to about -0.012 A and the unsymmetrical widening toward the violet is evident.

I have not met with cases such as that recorded by Whitney, where the displacement of the reversal was identical with that of the unreversed lines (it is not so for these lines on my photographs), but there is nothing impossible in it on the density hypothesis.

[1] Royds, *Kodaikanal Observatory Bulletin*, No. 40.

[2] Royds, *Astrophysical Journal*, **41**, 154, 1915, and *Kodaikanal Obseratory Bulletin*, No. 43.

The only way in which the results with the alloy and pure metal can be reconciled with the density hypothesis is to suppose that the density-differences effective in producing the displacements are of a much higher order than those obtained using the alloy containing 20 per cent of the metal investigated. It would seem that the atoms influence each other only soon after they are torn off from the electrode, as if they occur there in compact clusters which are soon dissipated so that when they reach the center of the arc the atoms are removed out of each other's influence. In the sun the density is supposed to be so small that a farther separation and displacement takes place. If the density-effect is due to the mutual electrical fields of the atoms, it is conceivable that fields of atoms of a different kind would also have an influence, thus explaining the considerable displacement at the poles of the alloy arc compared with the pure metal arc.

The considerations of the last paragraph would also explain the negative results of St. John and Babcock, but it cannot be conceded without further information that increasing the quantity vaporized increases the vapor-density in the furnace in the same ratio. One would have thought that the greater the quantity of material vaporized the greater would be the rate of its removal by condensation on the cooler parts of the tube.

The really interesting result of Gale and Whitney's and of Whitney's experiments is that they have, apparently, succeeded in obtaining arc conditions which bring the normal displacement at the negative pole of the arc down to zero, and even, for the more sensitive lines in the direction opposite to the usual one, i.e., in the same direction as the sun-minus-arc displacement.

I agree with Duffield's remarks on the influence of density- and temperature-gradients in light-scources on the displacement of spectral lines,[1] but I should like to make clear that the gradients cannot have any influence unless density and temperature are themselves causes of displacement.

Although direct experimental proof has not been obtained, I cannot find any hypothesis other than density to explain the displacement of certain spectral lines in different parts and conditions

[1] W. G. Duffield, *Philosophical Magazine*, 30, 385, 1915.

of the arc and the abnormal sun-minus-arc displacement of the same lines which have been discussed in *Kodaikanal Observatory Bulletin*, Nos. 38 and 40. Whether some additional conditions are necessary, or whether the density-differences effective in displacing lines are larger than those hitherto attempted, are points for further experiment. It is hoped that a source of light may be constructed where the vapor-density can be varied over a large range when it is possible to resume these experiments.

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