



XLIII. On a new method for mapping the spectra of metals

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adjacent portion of the stem to be converted into a closed vessel by means of a flat disk of glass closing the bore, the effect on the change of the volume so enclosed could hardly differ appreciably from that occurring previous to the closure, supposing the bore to be fine. Also if the bulb be nearly spherical the pressure over its surface would seem, so far as change of volume is concerned, to be replaceable without serious error by a uniform pressure equal to that actually found at the level of the bulb's centre.

We should thus conclude that the change in the volume of a nearly spherical bulb follows approximately the same law as if the bulb were closed and subjected to uniform pressure equal in intensity to that occurring at the level of its centre of gravity. A relation equivalent to (3) thus seems likely to hold approximately for the bulb alone, at least when it is nearly spherical and the bore is fine. This is, I think, practically in harmony with the conclusion reached by Dr. Guillaume on his p. 111.

XLIII. *On a New Method for Mapping the Spectra of Metals.*

By Prof. HENRY CREW and Mr. ROBERT TATNALL*.

THE difference in physical character between the various lines in the spectrum of an element has recently assumed such importance that a table of wave-lengths is now, to some extent, incomplete unless accompanied by a photographic map. This is especially true for one who is seeking new relations among the wave-lengths. Thus, in the case of cadmium, the triplets overlap, but, "owing to the *physical similarity* of the lines forming any one triplet, it is a matter of perfect ease to select them"†.

Indeed, in many cases where series have been discovered, one might decide to what series a given line belongs quite as well by its appearance as by its wave-length. Rydberg has happily suggested, for these series, names which describe the appearance of their respective lines.

So far as we are aware, all photographs of metallic spectra which have hitherto been made are, with two exceptions, either of spark spectra or spectra of substances vaporized in the carbon arc. The two exceptions to which we refer are, *first*, the well-known spectrum of iron by Kayser and Runge, in which the arc employed is that between iron rods about one centim. in diameter; and, *secondly*, a copper arc with

* Communicated by the Authors.

† Ames, Phil. Mag. July 1890, p. 45.

which these same gentlemen have attempted to vaporize strontium, and thus obtain the strontium triplet * at $\lambda 3800$, free from the cyanogen band. They say, however, that the arc worked so badly as to give only one line out of the three.

The well-known difficulty with the spark spectrum is that it is almost as characteristic of the slight differences in physical condition under which it is obtained as of the chemical element from which it is obtained. Not only so, but owing to its streaks, as it were, of high temperature ("luminescence"?) there is obtained, at the same time with the spectrum of the metal, also the spectra of the gases in which the discharge takes place.

In the case of the carbon arc, nature has fortunately grouped its many thousand lines into bands, leaving here and there comparatively clear spaces in which the lines due to substances deliberately introduced into the arc can be studied and measured with a high degree of accuracy, as exemplified in the work of Rowland and of Kayser and Runge.

Fortunately also, in the case of some metals, especially the easily volatile ones, the metallic vapour acts as if it shunted off the current from the carbon vapour; and the metal comes out strong in comparison with the carbon.

At the same time, the carbon and cyanogen bands stretch practically through the whole spectrum from $\lambda 3500$ into the infra-red. Not only so, but many of these carbon lines have, as a rule, intensities quite comparable to those of the metallic lines. One ingenious effort has been made by Kayser and Runge (*l. c.*) to rid themselves of the cyanogen bands by working the carbon arc in a current of carbon dioxide. This is partially successful; but, at best, it only diminished the intensity of the band. Messrs. Lewis and Ferry †, speaking of the infra-red spectra of the metals, say:—"It seems as though little more could be done in the discovery of new metallic lines unless the carbon lines are first carefully mapped, or some means is devised for raising the substances investigated to sufficiently high temperature without placing them directly in the [carbon] arc."

We have, therefore, devised and used during the past year the following method for obtaining the arc spectrum of the metallic elements free from carbon, free from air-lines, and free also from any continuous spectrum.

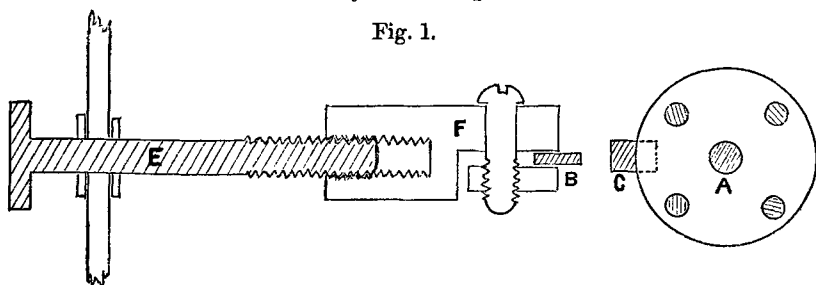
The idea is simply that of an arc in which one pole rapidly

* Kayser and Runge, *Wied. Ann.* lii. p. 115 (1894).

† Johns Hopkins University Circular, May 1894.

rotates or vibrates, thus preventing welding and destroying the coating of oxide which in some cases interrupts the current between ordinary metallic poles.

Fig. 1.



To accomplish this, a brass disk is fitted, by means of a collar and set-screw, to the shaft (or counter-shaft) of a small high-speed electric motor. Parallel to this brass disk, and upon it as a base, is screwed a similar disk. These disks are used as jaws in which to clamp small pieces of metal to be vaporized. One pole of the electric circuit which includes the arc is connected, by brushes, to the counter-shaft, shown in section at A (fig. 1). The other pole of the arc circuit is connected to another clamp F, which, by means of the screw E, can be made to approach or recede from the rotating disk. The clamp F is also fitted with parallel jaws, to receive a small piece of the metal (B) to be vaporized. This metal B is moved always parallel to itself, and the arc between B and C is maintained always at the same point. Both the rotating and the sliding jaws are mounted on the same base with the motor; and the whole is so light as to be easily carried about in one hand.

The disk is set in rapid rotation and the metal at B is slowly fed in, by the screw E, until the arc strikes. The incandescent vapour is then carried out by the disk into the form of an open fan, and is projected upon the slit of the spectro-scope by the "image" lens.

In the case of those elements which are easily obtainable in the form of a regulus, an entire disk may be made of the metal. With the rarer elements one needs to use only a small piece in the clamp, but the time of exposure is correspondingly lengthened. The disk once started, no attention is required except the feeding-in of the metal, B. Nearly all the wear is on this piece and very little on the disk, so that the latter will last for a comparatively long time, while the former has to be renewed with a frequency depending upon the amount of current employed. We have generally used

For the purpose of a comparison spectrum is used a second counter-shaft placed parallel to, and in the same horizontal plane with, the first. This shaft carries an iron disk, about an inch in diameter, against which is fed a piece of iron tubing. The spectrum of any one metal having been photographed, the whole instrument is translated laterally and the current switched on to the iron disk. While not so convenient as the sun in many ways, the iron spectrum has an abundance of sharp lines evenly distributed: it permits one to work in all kinds of weather and at night.

The plates whose measures follow will illustrate the method. They were taken with a Rowland concave grating of ten feet radius and ruled with fifty thousand lines. The portion of the plate measured, in each case, covers a part of the spectrum where the carbon bands are strong. Knowing of no adequate method of reproduction, except silver printing, which is too expensive, we have selected three typical plates and simply measured on a dividing-engine all the lines visible, including "ghosts" and recognized impurities. The tables explain themselves. They include all the lines certainly visible through the reading-microscope of the dividing-engine; but a still lower-power microscope shows a number of weaker lines between those measured. The wave-lengths were determined not with the highest accuracy possible, but well within a tenth of an Ångström unit, which is usually ample for purposes of identification. The method was interpolated between two of Rowland's standard iron lines, except in the case of copper, where, for convenience, the interpolation is between two of Kayser and Runge's copper lines.

Plate No. 178. *Tin.*

[illegible]

Plate 177. *Copper.*

| Element. | Plate 177. | Kayser and Runge. | Intensity. | Remarks. |
|-------------|------------|-------------------|------------|---|
| Copper ... | 4003·18 | 4003·18 | 5 | |
| | 3998·08 | ..... | 6 | Hazy. |
| | 3979·97 | ..... | 6 | Hazy. |
| | 3976·14 | ..... | 6 | Extremely wide and hazy. |
| Calcium ... | 3968·55 | ..... | 4 | Fraunhofer's H. |
| | 3964·27 | ..... | 6 | Wide and hazy. |
| | 3961·64 | ..... | 6 | Very weak. |
| | 3951·63 | ..... | 6 | Very weak. |
| | 3947·00 | ..... | 6 | Hazy. |
| Calcium ... | 3933·76 | ..... | 4 | Fraunhofer's K. |
| | 3933·11 | ..... | 6 | Wide and hazy. |
| Copper ... | 3925·36 | 3925·40 | 5 | |
| Copper ... | 3821·32 | 3821·38 | 5 | |
| Copper ... | 3899·42 | 3899·43 | 6 | |
| | 3888·73 | ..... | 6 | { Very weak and hazy; caesium line at λ 3888·83. |
| | 3883·39 | ..... | 6 | { No resemblance to head of C band at 3883·47. |
| | 3881·75 | ..... | 6 | Hazy. |
| (Ghost) ... | 3865·97 | ..... | ... | Second order; belongs to Cu 3860·64. |
| Copper ... | 3861·90 | 3861·88 | 5 | |
| Copper ... | 3860·57 | 3860·64 | 2 | |
| Iron | 3860·03 | ..... | 6 | Fe 3860·03 (K. & R.). |
| (Ghost) ... | 3857·88 | ..... | 6 | First order; belongs to Cu 3860·64. |
| | 3844·57 | ..... | 6 | Wide and hazy. |
| | 3837·48 | ..... | 6 | Wide and hazy. |
| Iron | 3825·99 | ..... | 6 | Sharp trace of Fe 3826·04 (K. & R.). |
| Copper ... | 3825·17 | 3825·13 | 6 | |
| Copper ... | 3820·97 | 3821·01 | 4 | |
| | 3820·52 | ..... | 6 | Sharp; unlike Hg 3820·6 (K. & R.). |
| | 3817·57 | ..... | 6 | Hazy. |
| | 3813·60 | ..... | 5 | Probably not copper. |
| Copper ... | 3812·08 | 3812·08 | 6 | Wide and hazy. |
| Copper ... | 3805·29 | 3805·33 | 3 | |
| | 3803·64 | ..... | 6 | Wide and hazy. |
| | 3800·57 | ..... | 4 | Fairly sharp. |
| | 3799·99 | ..... | 5 | Rather sharp. |
| | 3797·34 | ..... | 6 | Hazy. |
| | 3785·74 | ..... | 6 | Wide and hazy. |
| | 3780·20 | ..... | 6 | Wide and hazy. |
| Copper ... | 3771·96 | 3771·96 | 4 | |
| | 3764·98 | ..... | 6 | Wide and hazy. |
| Copper ... | 3759·56 | 3759·53 | 4 | |
| Iron | 3758·36 | ..... | 6 | Fe 3758·36 (K. & R.). |
| Iron | 3749·61 | ..... | 6 | Fe 3749·61 (K. & R.). |
| | 3745·53 | ..... | 5 | Hazy. |
| | 3743·53 | ..... | 6 | |
| Copper ... | 3741·36 | 3741·32 | 3 | |
| Iron | 3737·27 | ..... | 6 | Fe 3737·27 (K. & R.). |
| Iron | 3734·96 | ..... | 6 | Sharp trace of Fe 3735·00 (K. & R.). |
| Copper ... | 3734·29 | 3734·27 | 3 | |

Plate 177. *Copper (continued).*

| Element. | Plate 177. | Kayser and Runge. | Intensity. | Remarks. |
|-------------|------------|-------------------|------------|--|
| | 3721·79 | ..... | 6 | Hazy. |
| | 3720·89 | ..... | 5 | Very sharp. |
| | 3720·09 | ..... | 6 | Sharp. |
| Copper ... | 3712·06 | 3712·05 | 4 | Hazy. |
| | 3707·31 | ..... | 6 | Exceedingly weak and hazy. |
| Iron | 3701·20 | ..... | 6 | Trace of Fe 3701·20 (K. & R.). |
| Copper ... | 3700·61 | 3700·63 | 3 | |
| | 3699·17 | ..... | 6 | Hazy. |
| | 3695·48 | ..... | 6 | Hazy. |
| Copper ... | 3688·38 | 3688·60 | 6 | Exceedingly wide and hazy. |
| | 3686·67 | ..... | 5 | Rather sharp. |
| | 3685·04 | ..... | 6 | Rather sharp. |
| Copper ... | 3684·77 | 3684·75 | 3 | |
| Lead | 3683·60 | ..... | 6 | Faint trace of Pb 3683·60 (K. & R.). |
| Copper ... | 3676·96 | 3676·97 | 5 | |
| Copper ... | 3672·04 | 3672·00 | 5 | |
| Copper ... | 3665·83 | 3665·85 | 4 | |
| | 3664·21 | ..... | 6 | Hazy. |
| Copper ... | 3659·44 | 3659·44 | 5 | |
| Copper ... | 3656·86 | 3656·90 | 6 | |
| Copper ... | 3655·99 | 3655·99 | 4 | |
| Copper ... | 3654·47 | 3654·6 | 6 | |
| Copper ... | 3652·48 | 3652·56 | 6 | |
| | 3650·97 | ..... | 6 | Hazy. |
| Copper ... | 3648·52 | 3648·52 | 5 | |
| Copper ... | 3645·31 | 3645·32 | 4 | |
| * | 3643·80 | ..... | 6 | |
| Copper ... | 3641·80 | 3641·79 | 5 | |
| Copper ... | 3636·01 | 3636·01 | 4 | |
| | 3632·67 | ..... | 5 | Shaded towards violet. |
| | 3629·90 | ..... | 6 | |
| Copper ... | 3627·40 | 3627·39 | 4 | |
| Copper ... | 3624·36 | 3624·35 | 5 | |
| Copper ... | 3621·32 | 3621·33 | 3 | |
| Copper ... | 3620·47 | 3620·47 | 5 | |
| | 3619·52 | ..... | 6 | Certainly not copper. |
| (Ghost) ... | 3618·88 | ..... | 6 | First order: belongs to Cu 3621·33. |
| (Ghost) ... | 3616·37 | ..... | 6 | Second " " " |
| Copper ... | 3614·31 | 3614·31 | 6 | |
| Copper ... | 3613·85 | 3613·86 | 4 | |
| | 3610·88 | ..... | 5 | Hazy. Strong Cd line at λ 3610·66. |
| | 3609·43 | ..... | 5 | Very sharp. |
| (Ghost) ... | 3607·22 | ..... | 6 | Second order: belongs to 3602·11. |
| (Ghost) ... | 3604·64 | ..... | 6 | First " " " |
| (Ghost) ... | 3604·30 | ..... | 6 | Second " " " |
| Copper ... | 3602·10 | 3602·11 | 3 | |
| Copper ... | 3599·20 | 3599·20 | 3 | |

* The iron line at 3643·80 (K. & R.) is much weaker than some of its neighbours which do *not* show as impurity lines. Hence this line is probably not iron.

Plate 169. Zinc.

| Element. | Plate 169. | Kayser and Runge. | Remarks. |
|---------------|------------|-------------------|--------------------------------|
| (Ghost) | 4828.26 | ..... | Fifth order. |
| " | 4824.21 | ... .. | Fourth " |
| " | 4821.10 | ..... | Third " |
| " | 4817.41 | ..... | Second " |
| " | 4814.18 | ..... | First " |
| Zinc | 4810.79 | 4810.71 | Intensity 1. |
| (Ghost) | 4807.36 | ..... | First order. |
| " | 4804.11 | ..... | Second " |
| " | 4800.84 | ..... | Third " |
| " | 4797.30 | ..... | Fourth " |
| " | 4793.99 | ..... | Fifth " |
| " | 4788.70 | ..... | Fifth " |
| " | 4735.52 | ..... | Fourth " |
| " | 4732.26 | ..... | Third " |
| " | 4728.89 | ..... | Second " |
| " | 4725.70 | ..... | First " |
| Zinc | 4722.34 | 4722.26 | Intensity 1. |
| (Ghost) | 4719.03 | ..... | First order. |
| " | 4715.79 | ..... | Second " |
| " | 4712.67 | ..... | Third " |
| " | 4709.36 | ..... | Fourth " |
| " | 4705.98 | ..... | Fifth " |
| " | 4693.27 | ..... | Fourth " |
| " | 4686.85 | ..... | Second " |
| " | 4683.50 | ..... | First " |
| Zinc | 4680.38 | 4680.38 | Intensity 1. |
| (Ghost) | 4677.04 | ..... | First order. |
| " | 4673.97 | ..... | Second " |
| " | 4670.66 | ..... | Third " |
| " | 4667.52 | ..... | Fourth " |
| " | 4664.26 | ..... | Fifth " |
| Zinc | 4630.06 | 4630.06 | Intensity 4. |
| Zinc | (4613.96) | 3075.99 | Intensity 6: Third order line. |
| Zinc | (4608.29) | 3072.19 | " " " |
| Zinc | (4553.83) | 3035.93 | " " " |

Out of 98 lines measured on the copper plate, it will be noticed that we are unable to identify 41. They are not to be found among Kayser and Runge's values for Ag, Au, Sn, Pb, As, Sb, Mg, Ca, Zn, Sr, Cd, Ba, Hg, Li, Na, K, Rb, Cs, or Fe.

It is probable that these 41 lines belong to impurities whose wave-lengths have not yet been determined (or, at least, not published) with an accuracy sufficient for identification. It is not impossible, however, that some of these are *new* copper lines. We have found very little difference between "com-

mercial " copper and that which is sold by chemical supply houses under the label "chemically pure."

From the tables it will be seen that the plates are practically clear except for the impurity lines, which are very weak, many of them not showing on a silver print. In any case a table of the impurity lines and "ghosts" might accompany each map. A few years hence, when the spectra of the metals are more completely measured, such a table will be easily made.

North-Western University,
Evanston, Illinois, U.S.A.
July, 1894.

XLIV. *On the Vibrations of a Loaded Spiral Spring.* By
L. R. WILBERFORCE, M.A., *Demonstrator in Physics at the
Cavendish Laboratory, Cambridge*.*.

IT has been pointed out by Profs. Ayrton and Perry † that, by comparing the axial elongation and the twisting produced in a spiral spring of finite angle by the action of an axial force, we can deduce the ratio of the torsional and flexural rigidities of the wire or strip of which the spring is made, and hence obtain the ratio of the rigidity to the Young's modulus of its material.

This method is very interesting and instructive; but as it is not easy to produce springs of convenient and yet sufficiently uniform angles, nor to determine accurately a small axial elongation, it seemed to me that it might be worth while to modify it by attaching a mass to the spring and observing the periods of the vibrations which it executes when displaced. In this case it will be found convenient to use a spring of an angle so small that its square may be neglected.

Apart from their use in comparing moduli of elasticity, the vibrations of such a system present some rather interesting features, of which a detailed consideration may not be out of place.

If we have a spiral spring made of a length l of wire, and wound on a cylinder of radius r , so that the distance between the ends of the spring is x , and if ϕ is the angle between the planes through the axis of the spiral and the two ends of the wire, the force and couple required to produce a deformation from the equilibrium state (x_0, ϕ_0) to the state

* Communicated by the Author.

† Proc. Roy. Soc. vol. xxxvi. p. 311.