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On the Constitution of the Electric Spark

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VI. *On the Constitution of the Electric Spark.*

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[Plates 8–12.]

1. *Object of Research and Description of Apparatus.*

When an electric spark passes between metallic electrodes, the spectrum of the metal appears not only in immediate contact with the electrodes, but stretches often across from pole to pole. It follows that, during the short time of the duration of the spark, the metal vapours must be able to diffuse through measurable distances.

The following investigation was undertaken primarily to measure this velocity of diffusion, with the special view of comparing different metals and different lines of the same metal.

Dr. Feddersen* published in the year 1862 an interesting research in which photographs of sparks were taken after reflection from a rotating mirror. He was able to draw some important conclusions from his experiments, but it was necessary for the more detailed examination we had in view, to analyse the light by a spectroscope, so as to distinguish between the luminous particles of air and those of the metal poles.

Attempts to measure the required velocity, using rotating mirrors either between the spark and the slit of a spectroscope or between the prism and telescope, were made by one of us at various times during the last fifteen years. They failed because the method requires that the spark should pass when the mirror is in the same position, and no satisfactory device could be found to secure this object, without at the same time complicating the spark circuit, which it was necessary to confine as much as possible to the electrostatic capacity and spark gap.

Instead of using a rotating mirror, it is possible to secure the same object by taking photographs in a rapidly moving film. An arrangement of this kind was employed by Professor H. Dixon in his experiments on explosions, and proved at once successful.

The principle of the method is extremely simple, and may be employed in all cases

* 'Pogg. Ann.,' vol. 116, p. 132 (1862).

where each spark is of sufficient intensity to give a good spectrum. A sensitive film is attached to a spinning wheel and the spark image formed on it. Were the spark absolutely instantaneous, the images taken on the rotating wheel would be identical with that taken on it when stationary, but on trial this is found not to be the case. The metal lines are found to be inclined and curved, and their inclination serves to measure the rate of diffusion of the metallic particles.

The interpretation of the photographs presents no difficulties if the velocity of the film is everywhere at right angles to the direction of the slit. Such is the case in Professor DIXON'S experiment, and our first wheel was nearly a copy of that used by him. Fig. 1 shows the section of this wheel; the axle bears at A and B against strong screws fixed in a cast-iron support, not shown in the figure. The rim of the

Fig. 1.

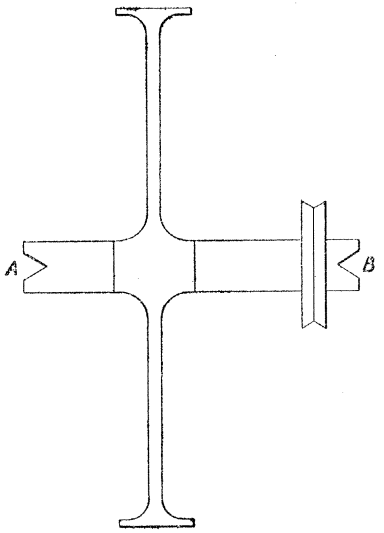
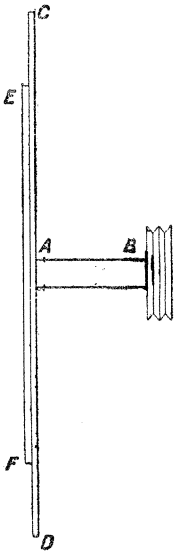


Fig. 2.



wheel had a width of 4 centims., its diameter was 30 centims. The photographic film was wound round the rim, and, although good results were obtained with this wheel, some difficulty arose from the tendency of the film to fly off. Several methods of fastening it to the rim were tried, but the only one which proved satisfactory was to tie it down by two strong steel wires, stretched tightly round the whole circumference. Velocities of about 80 revolutions a second could be obtained, but at the high speeds the film lifted up along the central line, just where the spark images fell.

A new apparatus was now constructed for us by the Cambridge Scientific Instrument Company, and is illustrated by figs. 3, 4, 5 (Plate 8), while fig. 2 shows a section of the moving parts. The film is placed flat against a steel disc, CD, and is kept in place by a second steel disc, EF, which presses against it, being secured by small screws,

shown in fig. 4. The ball-bearing, AB, consists of the hub and axle of a bicycle pedal, the hub being supported by two sets of three strong twisted cords, stretched and fixed as shown in fig. 3, which gives a back view of the apparatus. The same figure also shows a narrow vertical tube for oiling the bearing. The moving parts are surrounded by a circular cast-iron box, which can be covered both in front and at the back. The light forming the image of the spectrum passes through a rectangular aperture cut into the front cover. Fig. 4 (Plate 8) gives a front view with the smaller disc detached and placed in front of the cover. Fig. 5 (Plate 8) shows the whole apparatus ready for experiment. The driving power was a half h.-p. electric motor capable of revolving 33 times a second, and carrying a disc with three grooves. The disc was provided with two pulleys of equal size, so that at high speeds it might be driven from two motors at opposite sides, thus avoiding the side pull. The motor and spinning wheel were tightly clamped to the table of a lathe, in such a way that the apparatus could be dismounted and put together again, with all parts occupying the same position. This was of importance, the method of focussing adopted rendering the removal of the disc necessary during part of the operation. The diameters of the two steel discs were 33 and 22·2 centims., the photographs being taken in the annular space of 10·8 centims., left free when the smaller disc was placed on the larger one.

In all the experiments the driving cord was passed round the second pulley of the motor, which had a diameter of 21·7 centims., while the groove of the pulley on the spinning-wheel was cut to 2 inches, or 5·1 centims. The speed of the motor was measured by an indicator of Elliott Brothers, which was tested and found correct. The ratio of the angular velocities of motor and disc might be obtained approximately by calculation from the diameter of the pulleys, allowance being made for the thickness of the cord, or we might turn the motor slowly by hand, counting the number of turns of the disc at the same time. For our purpose this would have been sufficient, as the other uncertainties of the experiments do not at present allow a very great accuracy, but in order to avoid any doubt, and on account of the interest which attaches to the amount of slipping which takes place at high speeds, an independent stroboscopic method was employed to determine the ratio of the angular velocities. We were surprised to find no measurable slip, except at the highest speeds, such as were never used by us in our experiments.

In our experiments the disc revolved generally about 120 times a second, giving a linear velocity of between 90 and 100 metres per second for that part of the film on which the photograph was taken. When the cord was passed over the largest pulley of the motor we could spin the disc over 160 times a second; this was tried and the speeds were tested, but no photographs were taken, as the smaller velocities gave us sufficiently good results.

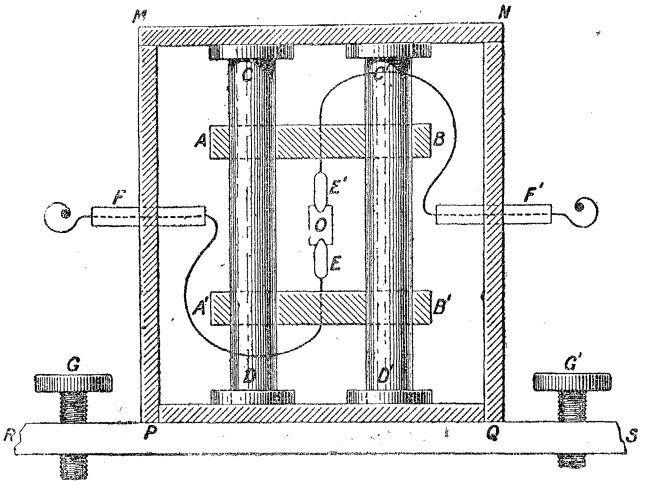
Our first successful experiments were made with a single-plate Voss machine, the discharge being taken from four Leyden jars in the circuit, but the beauty

of the photographs was considerably increased when a much more powerful battery was introduced, and charged from an induction machine constructed for us by Mr. H. C. Wimshurst. This machine has 12 plates, of 62 centims. diameter, and gives, without jars, sparks which are 13 inches long. In the majority of our experiments six large jars of flint glass were used, each jar having a coating of tinfoil, of about 2000 sq. centims. surface. The capacity of each jar was measured separately for us by Mr. J. R. Beattie, and found to vary from ·0049 to ·0060 microfarad, the capacity of the complete battery being ·033 microfarad. The jars, which had not been used for years, were found to be in bad condition. They were carefully cleaned, by soaking first in caustic soda and then in nitric acid. After coating with tinfoil to within 10 centims. from the top, the uncovered parts were heated in front of a fire to over 60° C., so as to secure complete dryness, and then, whilst hot, varnished. After this treatment the jars gave no trouble.

Great care is necessary in handling a battery of this capacity, especially as the experiments are conducted in the dark.

Fig. 6.

Fig. 7.



The whole battery was placed together on an insulated table, and Mr. Wimshurst's recommendation to keep one hand always in the pocket while handling the jars also proved useful.

The metal electrodes were fitted inside a box having an opening towards the collimator of the spectroscope. Perhaps the greatest source of trouble at first consisted in the uncertainty of the position of the points on the electrodes, from which the sparks set out. Successive sparks did not always leave the poles at the same points, so that the spark images did not always fall centrally on the slit. This was remedied to a great extent by giving careful attention to the shape of the electrodes and to their polish. The form adopted after a few trials was conical, and is shown in fig. 6. The metal having first been turned in the lathe to the required shape, was

polished by means of emery paper, and finally by wash-leather. Good polish was found necessary to prevent sharp projections, which, though they may be small, cause premature discharges before the jars are sufficiently charged.

A section of the electrode box is shown in fig. 7. It is made of wood and is fixed to a board, RS, capable of being levelled so as to make the spark path as nearly as possible parallel with the slit. The electrodes are fixed to two wooden plates, AB and A′B′, which are attached to flint-glass tubing, CD and C′D′, the glass being carefully varnished. The electrodes, E, E′, are connected to the Leyden jars by means of gutta percha-covered wire (No. 18) which passed, as shown in the figure, through apertures in the plates, AB, A′B′, and finally through glass tubes, F and F′. The leads from the jars were hooked to loops formed by the wires attached to the poles, the sharp ends of all wires being protected by means of small spheres of sealing-wax. We used in the experiments a standard distance of 1 centim. between the electrodes. The electrodes having been fixed to the plates, their distance was adjusted and the plates secured to the glass rods by means of sealing-wax.

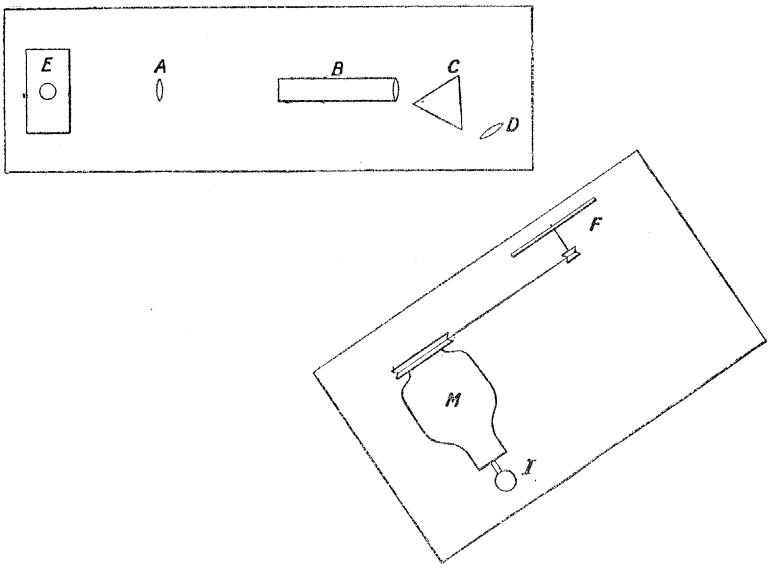
A few words should be said about the optical arrangements. It was for our purpose most important to have a good image of the spark in coincidence with the slit. As we confined our investigation principally to that part of the spectrum which, with glass prisms and lenses, is photographically most intense, the lenses were specially made for us by Messrs. Zeiss at Jena, the chromatic and spherical aberrations being corrected for the region F to H of the solar spectrum. When it is required to form a spark image on the slit, sufficient attention is not always given to the fact that lenses are generally constructed to be used with a parallel beam of light. The aberrations introduced when objects at small distances are to be focussed, are sometimes considerable, and had to be avoided in our experiments. We asked Messrs. Zeiss therefore to make a lens of 4 centims. aperture and 25 centims. focus, which when placed at a distance equal to twice its focal length from the spark, should give an image equal in size to the object within the required limits of the spectrum, free from chromatic and spherical aberrations. The lens sent to us answered all our requirements perfectly. Both collimator and camera lenses had apertures of 4 centims., and focal lengths of 46·3 and 39·9 centims. respectively. The prism used was made of old flint glass by Steinheil, having a refracting angle of 59° 28′ and a refractive index of 1·6227 for sodium light. The extent of the spectrum between F and H on the revolving disc was about 1·5 centim.

The general arrangement of the apparatus is shown in a diagrammatic form in fig. 8. E represents the electrode box, A the lens forming the image of the spark on the slit of the collimator B, through which the light passes before it is dispersed by the prism C and focussed by the camera lens D. The parts A, B, C, D were mounted on a slate slab secured to the wall by means of strong brackets. The lathe support which carried the motor M and spinning disc F, was placed so that the image of the

spectrum should fall near the top of the disc vertically above the axle. I represents the indicator which shows the speed of the motor.

The adjustments which it is necessary to carry out with accuracy consist in the focussing of the spark image on the slit, the proper centering of the apparatus, and the focussing of the camera lens. In addition to this, it was found convenient to place the lens A as nearly as possible half-way between the spark and slit, so that the spark image on the slit should be of the same magnitude as the spark. This rendered the interpretation of the photographs more easy, as the linear dimensions measured in the direction of the spark discharge were reduced in that case by the optical arrangement in the fixed ratio of the focal lengths of the camera and collimator lenses, viz., ·86. One millimetre in length of the slit images therefore always corresponded to 1·16 millim. in length of the spark path.

Fig. 8.



The adjustment of collimator and lens A is most easily carried out if the prism C and lens D are removed, so that a clear view can be obtained through the collimator towards the spark box. The collimator was adjusted in the usual way for infinite rays. As it was separately supported on a tripod stand, it could be accurately levelled, and the centre of the slit placed, by means of a cathetometer, accurately at the same height as the centre of the spark gap. The focal length of the lens A being known, the distance between the spark and slit was adjusted by measurement to be equal to a little more than four times that focal length, and the lens A was placed at the right height, and exactly half-way between the slit and spark gap. Sparks from an induction coil were now allowed to pass between the electrodes, the slit being opened wide, and a telescope adjusted for infinite rays placed in front of the collimator, so that the observer obtained a clear view of the slit. If the adjustment is good, the

electrodes illuminated by the spark are in perfect focus. By a few successive trials, in which the electrode box and lens A alone were moved, and in such a way that the latter was shifted through half the distance of the former, this could always be secured, and at the same time the lens kept half-way between spark and slit.

The lens A had now to be temporarily removed, to make sure that the axis of the collimator pointed to the centre of the spark gap. For this purpose the collimator lens was covered by a piece of cardboard with a central slit about 2 millims. wide, and the electrode box shifted sideways until the maximum amount of light passed through this slit. Replacing the lens A into its previous position, it is easy to ascertain that the adjustment of distances has not been disturbed. The adjustment being complete, the correct position of collimator was permanently secured by pouring melted paraffin wax round the tripod screws which carry it. The lens A was fixed in the same way, but a lateral motion of the electrode box must be allowed, so as to correct the small displacements which necessarily occur when one set of electrodes is replaced by another.

The prism is placed in the usual way in its proper position in front of the collimator; we worked in a position of minimum deviation for a wave-length of about $4{\cdot}3\ 10^{-5}$.

The only remaining adjustments are those of the camera lens and disc. The lens D was fixed to a brass tube which could be made to slide in a collar by means of a screw. The lens was placed so that it was completely illuminated by light passing through the collimator and prism; this is easily tested by an eye placed at the focus of the lens.

When the position of the disc had been accurately fixed, so that the spectrum was formed at the proper place, a film, which had to be sacrificed for the purpose, was placed on the disc just as during an experiment. A pointed rod was now brought into contact with the film and against some prominent spectrum lines like the blue triplet of zinc. The rod was fixed in this position, slightly touching the film, so that the disc could be rotated without appreciable friction. The disc was now removed for the final adjustment of focus, an eye-piece being put in position, so that the pointed end of the rod was in its focal plane. If the lines of the spectrum were not in focus, the lens D were moved until that was the case. The wheel being then replaced into contact with the rod, a perfect focus was secured.

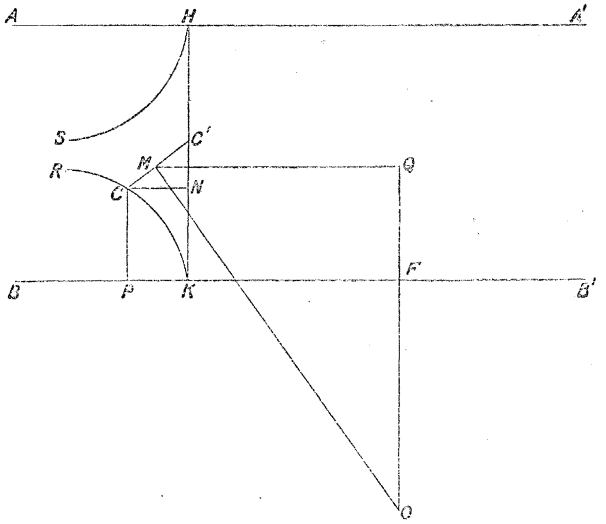
The different parts of the spectrum were not situated at equal distances from the axis. A slight correction which may in consequence be necessary in the reduction of the observations, requires the knowledge of the point of the spectrum which lies at the minimum distance from the axis, *i.e.*, if the spectrum is horizontal, we want to know the wave-length lying vertically above the axis. This may readily be ascertained by suspending a plumb-line close to the disc passing in front of its centre. The shadow of the string will then show on any photograph of the spectrum which is taken.

2. *Interpretation of Photographs.*

With the wheel which was first used, the film was placed round the rim (fig. 1

and the velocity of the film being everywhere at right angles to the image of the slit, the interpretation of the photographs was obvious. But with the film on the face of the disc, as in our final experiments, the linear velocity is not the same for different portions of the slit image, or different parts of the spectrum, nor is it everywhere perpendicular to the slit image. The following investigation shows how the velocity of the particles may be deduced from the measurement of the photographs.

Fig. 9.



Let AA′ (fig. 9) represent the upper, and BB′ the lower, edge of the spectrum, as it would be formed on a stationary film. KH represents the monochromatic image of the slit at the instant of the beginning of the discharge, and KR, HS the curved edges of a spectroscopic line as they appear on a photograph taken with a moving slit. The displacements are most easily determined by measuring the coordinates $PC = y$ and $NC = x$ parallel and at right angles to HK. If O be the centre of the disc, a point, C′, of the slit image will describe a circular arc, C′C, on the moving film, and the time taken by the moving particle to go from K to C′ is the same as that which the point C of the disc takes to describe the arc CC′, which may for our purpose be taken as equal to the length of the chord. From the middle point of CC′ draw the lines MQ perpendicular to HK, and QO parallel to HK. Then

$$C'N : NC = MQ : OQ,$$

or if $KC' = z$, $OF = a$, $FK = b$, and if the squares of y and z and their products are neglected, compared to a^2,

$$z - y = bx/a.$$

For the line HS we should similarly find $z - y = -bx/a$. Also from the figure

$$CC' : CN = OM : OQ,$$

or writing s for CC′ and r for OM,

$$s : x = r : a + \tfrac{1}{2}(y + z).$$

Again neglecting the square of small quantities,

$$s : x = r : a + y.$$

It is convenient to introduce in place of a the distance (c) between O and the *centre* of the spectrum, so that $a = c - h$, where h represents half the width of the spectrum. To the required degree of accuracy it is then found that

$$\frac{s}{x} = \frac{r}{c}\left(1 \pm \frac{h - y}{c}\right),$$

where the minus sign refers to measurements taken along HS.

The time (t) taken for the description of the arc CC′ is $s/r\omega$, ω denoting the angular velocity of the disc, and if v be the linear velocity at the centre of the spectrum

$$t = \frac{sc}{rv} = \frac{x}{v}\left(1 \pm \frac{h - y}{c}\right).$$

As y and x are obtained by measurement of photographs, and h and c have been practically constant in the experiments (though also measured in each case), the above equations allow us to calculate

$$z = y \pm \frac{bx}{c}, \qquad t = \frac{x}{v}\left(1 \pm \frac{h - y}{c}\right).$$

If x_1, y_1, and x_2, y_2 are the measured coordinates of two points lying near each other on the curved images of the spectroscopic lines, the velocity of the luminous particles at the corresponding point of the spark will be $\mathrm{K}\frac{z_2 - z_1}{t_2 - t_1}$, where K is the ratio of the length of the spark gap to that of its image on the film, which in our case was simply the ratio of the focal lengths of the camera and collimator lenses, *i.e.*, 1·16. If both poles are made of the same material, so that both the lines which appear at the top and bottom of spectrum can be measured and the mean taken, the correction disappears, and the velocity of the particles is given directly by $\mathrm{K}v\frac{y_2 - y_1}{x_2 - x_1}$. Even when a line can only be measured on one side, this may approximately be taken to be the velocity, for in our experiments c was equal to 14, the distance b was seldom greater than 1 and never greater than 2, while the ratio x/y was always less than $\frac{1}{3}$, so that z and y only differed at the maximum by 5 per cent. from each other. The uncertainty of our experiments, for reasons which will be given, was greater than that amount. Similarly may the quantity $\frac{h - y}{c}$ be neglected for the present.

3. *Method of Conducting Experiments and Measurement of Photographs.*

The method of conducting an experiment is obvious from the preceding descriptions. The apparatus being in adjustment, a photograph was taken of the spark spectrum, on the stationary disc. This is for the sake of reference, chiefly for the purpose of identifying the lines. The disc was then set spinning and when the desired speed was attained and found to be uniform the Wimshurst machine was set going by hand until about six sparks had passed. We thus obtained a number of images on each film, some of which sometimes were found accidentally to overlap. The images are not found to be equal in clearness, the spark not always passing parallel to the slit; the two best were selected for measurement. For this purpose the film, after the images had been developed and fixed, was cut up, each image being carefully marked for future reference.

The measurements were made by means of a "comparator," a very beautiful instrument, made by ZEISS, of Jena. The instrument consists essentially of two microscopes at a fixed distance from each other. A sliding table underneath serves to carry the photograph to be measured under one microscope and a scale under the other. A photograph having been fixed to the table by means of soft wax, a fine adjustment screw allows a certain relative displacement between it and the scale, so that when any desired line is in the centre of the field of view of one microscope the scale may be read with the other, and adjusted to give any desired reading. This adjustment is of great convenience in the comparison of different spectra with each other, as some air line, common to all, may always be placed so that the reading is in every case the same. The scale is divided into $\frac{1}{5}$ millims., and a micrometer eye-piece allows readings to $\frac{1}{1000}$ millim.

Speaking for convenience sake of the slit images as "vertical," the photograph must be placed so that when the sliding table is moved the trace of the centre of the field of view on the photograph is horizontal, and the measurements consist in measuring the horizontal displacements of each spectrum line at different distances from the edges of the spectrum.

Our first method of conducting the measurement was to take contact prints on glass of the selected images. On these copies horizontal equidistant lines were ruled by a fine needle point fixed to a dividing engine. The displacements could then be measured along each of these lines. The disadvantage of this method consists in the labour of taking copies and ruling lines, and also in the loss of definition, which, however small, was always noticeable in the contact print. At a later stage, therefore, the method of measurement was changed to the following:—A brass frame was made in which the film could be clamped so that it lay perfectly flat under the microscope. Underneath the photograph was placed a transparent scale, made of a portion of a film from which the sensitive layer had been removed, and on which horizontal lines at a distance of about ·55 millim. had been ruled. These lines could

be seen in the instrument traversing the spectrum horizontally. They served as reference lines along which the displacements could be measured.

Accurate measurements of wave-lengths were not necessary for our purpose as long as we could identify the different lines. As the prism was not disturbed during the principal series of our experiments, the air lines were found to be sensibly at the same distance from each other in all our photographs. Making use, therefore, of a few of these air lines, which are sharp, and of the lines of zinc and cadmium, which are easily identified, a curve may be drawn from which the wave-lengths corresponding to any reading of the comparator may be determined in the usual way with quite sufficient accuracy.

4. *Preliminary Experiments.*

Before entering into the main subject of our research, we desired to become familiar with the appearance of the spark itself, and with such other phenomena connected with it as could be elucidated by photographs of the spark itself. We describe the results obtained, selecting out of a number of plates those which seem to present distinctive features of interest.

Fig. 11, Plate 9, November 10, 1897.—Image of spark taken between zinc and brass electrodes; 5 Leyden jars were used, their total capacity was not measured, but the jars were smaller than that of the battery of six used in the later experiments, and the total capacity was estimated to be about half, *i.e.*, about ·015 microfarad. The chief feature of this photograph is a slightly curved very luminous column, containing, as was subsequently ascertained, the first discharge breaking through the air. This is surrounded by a cloudy appearance, which is due to the metallic vapours generated by the first discharge.

Our later experiments, to be described further on (p. 211), point to the conclusion that the oscillations following the first discharge pass through this cloud of metallic vapour. Some sharp linear luminous filaments may be seen in the original on one side of the main discharge. These set out from small projections on the electrodes and precede the main discharge, as may be ascertained by carefully watching the image on the focussing plate of the camera. The preliminary discharges may be avoided by giving careful attention to the polish of the electrodes.

Fig. 12, November 10, 1897.—A photograph of the spectrum of the preceding discharge, taken with 15 sparks. The image of the central column was thrown on the slit. The spectrum is that of zinc and air, with one or two lines of copper, and apparently the calcium lines H and K. A trace on the calcium line at 4227 also shows on the original.

Fig. 13, Plate 9, November 10, 1897.—The same as fig. 12, except that the cloudy portion of the discharge was focussed on the slit, which had to be widened a little in this case. Thirty sparks had to be taken to secure an impression which could be compared in intensity with the previous one. The absence of air lines, verified also by

eye observations, proves that the cloudy luminosity is due to metallic vapours. The presence of metallic lines in fig. 2 does not prove the presence of metallic molecules in the main discharge, as it is impossible to obtain an image of the latter free from that of the luminous cloud lying in front and behind it.

Fig. 14, Plate 9, November 12, 1897.—Spark between iron poles, showing the luminous filaments preceding the discharge.

Figs. 15 and 16, Plate 9, November 13, 1897.—Sparks taken under similar circumstances as fig. 14. In fig. 16 a current of air is blown through the spark gap. The effect of this current of air is remarkable, as the time of luminosity of the air column was found in subsequent experiments to be less than 10^{-6} second, and the actual displacement of the air during that time must have been quite inappreciable. The most probable explanation is that the spark passes through those portions of the air which have been made conducting by preliminary invisible discharges. The air put into the sensitive state by these first partial discharges has time to move over a sensible distance before the main spark passes.

It is remarkable how the metallic vapours in this photograph seem to be drawn into the glass tube.

Fig. 17, Plate 9.—Photograph of a succession of sparks taken with a small jar and large induction coil. This photograph illustrates the fact that, in the ordinary arrangement adopted to produce metallic spectra, the air discharge is predominant, while the metallic cloud is chiefly confined to the neighbourhood of the electrodes.

5. *Measurement of Molecular Velocities.*

We may now pass to the description of the results obtained when the spectrum of a single spark is taken on a moving film. A preliminary trial with various metallic electrodes had shown us that the sharpest results were obtained with zinc, and we chose, therefore, that metal for investigation under various conditions. Fig. 18 (Plate 10) gives the spectrum as we obtained it on the stationary film. The lines of zinc which appear on it are*:—

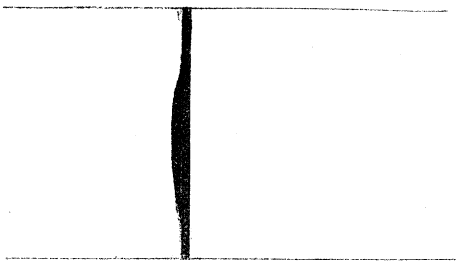
4924·8 4912·1	α.	Zinc doublet not visible in the arc spectrum.
4810·7	β.	
4722·3	γ.	Zinc triplet, strong both in arc and spark.
4680·4	δ.	
4058·0	ϵ.	Not mentioned as seen in the spark by previous observers, but given by KAYSER and RUNGE as a strong line in the arc.

* All wave-lengths are given on ROWLAND'S scale in air, and are taken from the most reliable available determinations. To identify the lines on the photographs we have attached Greek letters to the principal metallic lines shown in the figures, and these letters are also attached to the wave-lengths as given in the text.

The figure is enlarged in the ratio of about 4·2.

Fig. 19, Plate 10.—Disc spinning with linear velocity at centre of spectrum, $v = 99$ met./sec. The air lines are seen to run straight across the spectrum, but the metallic lines are curved and broadened. It follows that the metallic vapours remain luminous longer than the air lines, and that the metallic particles are projected with a

Fig. 11.



measurable speed from the electrodes. The broadening of the nitrogen doublet at 5004, marked N_1 in the photographs, only amounts to about ·04 millim., which limits the luminosity as far as that line is concerned to $\frac{\cdot 04}{97000} = 4 \times 10^{-7}$. The air line at 3995, and marked N_2, is drawn out rather more, but is thinner near the poles than in the centre of the spark; its appearance, which in some of the photographs taken is even more marked than here, is illustrated in fig. 11. We must conclude that the air remains luminous in the centre of the spark rather longer than near the poles. This fact, which is very apparent for the luminosity of the metallic vapours, will be referred to again further on (p. 210).

The displacements on this photograph being the first that were actually measured, the best methods of drawing the reference lines (see p. 198) had not been adopted, and these lines were therefore at unequal intervals. In the tabular arrangement of our results we give in the first columns the coordinates of the curved lines which have actually been measured; x denoting the horizontal displacement at a distance y from the edge of the spectrum. If y_1, y_2; x_1, x_2 are coordinates of two points which are near together, and v is the linear velocity in metres per second, the molecular speed is $V = Kv \frac{y_2 - y_1}{x_2 - x_1}$ (p. 197), at a distance $h = K \frac{y_1 + y_2}{2}$ from the pole, where K is the factor correcting the optical reduction, which is 1·16 in all our photographs. The displacements being difficult to measure, a small error, in x_1 and x_2 near the pole, may produce very large differences in the result. For the comparison of different metals with each other we therefore calculate also the quantity $V' = Kv \frac{y}{x}$ which is the average speed between the pole and a point at a distance $h' = Ky$ from the pole;

the quantity x being larger a small error does not affect the result so largely as one in the difference $x_2 - x_1$.

TABLE I.—Zinc, $\lambda = 4810{\cdot}7$ (β).

Date, Feb. 15, 1898. No. XV. $v = 102$. Distance between poles: 1 centim.

x.	y.	V.	h.	V′.	h'.
millims.	millims.				
		Lower pole.			
·07	·56	896	·33	896	·66
·18	1·12	631	·98	740	1·30
·38	1·66	316	1·61	530	1·93
·59	2·20	300	2·24	438	2·55
		Upper pole.			
·09	·44	548	·26	548	·51
·21	·88	472	·77	506	1·02
·33	1·52	598	1·39	541	1·76
·64	2·16	241	2·13	395	2·50

$\lambda = 4924{\cdot}8$ (α).

x.	y.	V.	h.	V′.	h'.
millims.	millims.				
		Lower pole.			
·01	·56	6632	·33	6632	·66
·23	1·12	297	·98	569	1·30
·42	1·66	347	1·61	471	1·93
·68	2·20	241	2·24	381	2·55
		Upper pole.			
·10	·44	505	·26	504	·51
·24	·88	371	·77	427	1·02
·50	1·52	289	1·39	356	1·76
·75	2·16	306	2·13	340	2·50

The above experiment was only considered to be of a preliminary nature, and the photographs obtained were used chiefly to find the best method of reducing the observations, but it gives a good idea of the general nature of the results. It is seen that the velocity near the pole is a very uncertain quantity, owing to the sources of error which will be discussed (p. 210), but the velocity gradually diminishes, and about

2 millims. from the poles it reduces to about 400 metres / second, which is not very different from the velocity of sound in air at the ordinary temperature. It is well to realise this, for it shows that the sound-wave which is produced by the spark has moved outwards through a distance of a few millimetres only by the time the metallic molecules have reached the centre of the spark.

In order to see whether the capacity of the jars and distance between the poles have an appreciable effect on the result, the displacements of the zinc lines were measured for sparking distances of approximately ·5, 1·0, and 1·5 centims., and in each case the capacity was altered by taking the discharge from 2, 4, and 6 jars. Table II. embodies the result; the velocity (V′) given being, as above explained, the average speed between the pole and a point at a distance of 2 millims. from it.

TABLE II.—Average Velocity (V′) in metres / second of Zinc Molecules.

Sparking distance.	Wave-length.	Number of jars.		
		2	4	6
centims.				
·51	4925 (α)	814	556	416
	4811 (β)	1014	668	529
1·03	4925 (α)	400	499	415
	4811 (β)	501	548	545
1·54	4925 (α)	723	1061	435 ?
	4811 (β)	1210	1526	492 ?

The first striking fact shown by the table is the uniformly slower speeds derived from the doublet at 4925 as compared with that of the least refrangible line of the adjoining triplet, and we have assured ourselves that there is no difference in displacement between the two first components of the triplet. The third component is too weak and too near an air line to admit of satisfactory measurement. It was one of the main objects of our investigation to discover, if possible, such differences in the velocities as might indicate the presence of different kinds of molecules, but we hesitate to ascribe the differences found to such a cause. The line 4925 is the least refrangible component of a double line, which is wider and much stronger at the base than in the centre of the spark. In order to measure the displacement, the cross wire of the reading microscope has to be set on the edge of the displaced line, first near the pole, and then on a corresponding point nearer to the centre of the spark gap. Where the line is strong, the edge of the line would be the least refrangible edge of the *least* refrangible component, but when the line is weak, the strongest part of the line would be that part where the two components begin to overlap, *i.e.*, the

edge of the *most* refrangible component, and there would be a tendency to setting the microscope on the strongest part of the line rather than on the edge of it. It is easily seen that an error would be liable to arise, giving too great a displacement or too small a velocity. We are not at all certain that if this source of error were eliminated the double line would not show higher rather than lower values for the velocity, and hope to decide this question by using greater dispersion.

Comparing different capacities with each other, we find that for the spark gap of 5 millims. the velocities are greater for small than for large capacities; we offer at present no explanation of this unexpected result, which requires confirmation and further investigation. When the sparking distance is increased to 1·5 centim., the course of the sparks becomes so erratic that not much importance can be attached to the figures. A query has been attached to those that are specially doubtful. On the whole, there seems a tendency towards greater velocities in this case.

Our normal spark gap of 1 centim. does not show any decided difference due to capacity, and with our normal capacity of six jars the spark gap does not seem to affect the result. Hence we are justified in thinking that under the conditions named a reliable comparison may be made between the velocities obtained for different metals.

We have collected in Table III. the velocities V and V′ as measured on our photographs. The results are nearly always the mean of two sets of measurements from different photographs. In some cases, such as magnesium, iron, manganese and silver, no satisfactory measurements could be made. The spectrum, as it appears on our films, does not always give the same distribution of intensity among the lines as is shown by the spectra of sparks taken with an induction coil and jars of small capacity, and it differs also, of course, from the arc spectrum. A discussion of the peculiarities of our spectra lies outside the range of this paper, and must be reserved for another occasion, but in the following account some of the chief features of our spectra are shortly pointed out. The metals are arranged in order of atomic weights.

TABLE III.

Metal.	Wave-length.	V′ (metres per second).	V (metres per second).
Aluminium	4512 (α) 4478		
	4446	1890 ?	1300 ?
	3613 β 3602 3585		
Zinc	4925, 4912 (α)	415	406
	4811 (β), 4722 (γ)	545	524
Cadmium	5379, 5339 α	435	472
	5086 β, 4800 γ, 4416 δ, 3613 ε	559	515
Bismuth	5209 α, 4561 β, 3696 γ	1420	1480
	4302 δ, 4260 ε	533	488
	3793 ζ	394	270
Mercury, from Cadmium Amalgam	5461 α, 4359 β	988	550
	3663 γ	590	406
„ from Zinc Amalgam . .	4359 β 3663 γ	481 383	

Magnesium.—In photographs taken on a stationary film we note the complete absence of the triple line in the green, which forms a prominent feature of the magnesium spectrum under ordinary conditions. The whole energy of the spectrum seems to be concentrated into the line at 4481 (α), which is exceptionally strong, and into the triplet beginning with 3838·4 (β), which appears as a doublet in our films, the two last lines probably not being resolved. A strong line seen both in arc and

ordinary sparks at 4703 is also absent. When the spectrum is photographed on the rotating film, the lines resolve into remarkable clouds (fig. 20, Plate 10), which do not admit of measurement. The appearance of the lines shows, however, that the velocities of the magnesium particles is great, and approximately the same as that of aluminium.

Aluminium.—The prominent lines are the two triplets beginning with 4512 (α) and 3613 (β) respectively, and the doublet which lies between H and K. The former do not appear in the arc spectrum, which shows the violet doublet strongly. The velocities we have obtained are the largest we have measured, but the displacements (fig. 21, Plate 10) are very small, and the lines are measurable only near the poles, so that the numbers are doubtful. The violet triplet seems displaced through a greater distance than the blue, but the measurements are so uncertain that we have taken the average displacement without distinguishing between them. The violet doublet almost disappears in the rotating film, leaving only a faint cloudy formation similar to that shown in the magnesium spectrum, but possessing peculiarities which require further investigation.

Manganese.—Many lines of manganese appear on our stationary photographs, but on the rotating film they completely disappear under the usual conditions of our experiments. When the slit is widened and the speed reduced, the displacements could be observed, but were not measured.

Iron.—The iron lines were not well marked, and completely disappeared in the rotating films.

Copper did not show any well-marked lines, the displacements of which could be measured.

Zinc.—This metal has already been discussed in detail, and it only remains to mention that the line at 4058 (ϵ) disappears on the rotating film.

Silver showed no prominent lines when our battery was discharged through it, but the calcium lines are always seen (see p. 212).

Cadmium.—A number of cadmium lines appear on our photographs, which agree in position with the lines so frequently measured; but there is some difference in the relative intensities as noted by different observers. The double line 5379 and 5339 (α) shows a greater displacement than that of the other lines, and the distance between the components is so great that the explanation given for the corresponding zinc lines does not seem to hold here. Fig. 22 shows the behaviour of the cadmium lines.

Mercury.—Sparks were taken from a surface of liquid mercury, and though the displacements can be readily seen (fig. 23), and the edges of the lines are fairly sharp at some distance from the electrode, they are so diffuse in close proximity to it that no satisfactory measurements could be made at points corresponding to those taken in the case of other metals. Better results were obtained when the electrodes were either amalgamised zinc or cadmium; but the measurements in these cases, though they are given in the table, are difficult to make and cannot be trusted. When cadmium amalgam is used (fig. 24), the photographs show clearly that the mercury

line 3663 (Hg, γ) is parallel to the cadmium line 3613 (Cd, ϵ), and the measurements are fairly consistent, but when the pole was zinc amalgam, the displacements of the mercury lines seemed decidedly greater than that of the zinc lines. This would indicate a higher velocity for zinc than for cadmium molecules, while our previous results had given almost identical values for the displacements of the zinc and cadmium lines. There is here some contradiction which requires clearing up by further experiments.

Bismuth (fig. 25, Plate 11) gave us most interesting results, as it possesses some lines, such as γ, which are curved so little that the velocities of the molecules giving these lines is found to be larger than that observed in any other case except aluminium. On the other hand, the line at 3793 (ζ) indicates the smallest velocity measured. There are some special difficulties standing in the way of the measurement of the bismuth lines, which made us hesitate some time before definitely asserting the different curvature of the lines, but we think that our best photographs, one of which is reproduced in fig. 25, leave no doubt on the question. One of the difficulties lies in the fact that bismuth and mercury are the only metals in which the lines are repeated, owing to the oscillatory discharges. When six jars are in circuit, the appearance is that of fig. 26, and the lines become mixed and difficult to measure. Another difficulty lies in the great difference in the sharpness of the lines even on the stationary film, the lines which show a small curvature being much sharper. There was a possibility of an illusion due to this cause, similar to that explained in the case of the double zinc lines, but we cannot believe that the difference in curvature between the lines marked (γ) and (ζ) in fig. 5 can be due to this cause.

[April 26.] We possess very few investigations on the spectrum of bismuth. Lecoq de Boisbaudran, who is acknowledged to have purified his substances with extreme care, gives the line 5209 (α) as one of the characteristic lines of bismuth, and he also gives 4302 (δ) and 4260 (ϵ) as belonging to bismuth. The relative intensities of the lines as given by him cannot be expected to coincide with our own, as he used very different spark conditions. Our spectrum agrees, on the other hand, perfectly with that given by Hartley and Adeney,* who traced no coincidence between the lines we made use of in this research with those of other metals.

As the great difference in the molecular velocities suggested the possibility that bismuth was a mixture of elements, we obtained, through the kindness of Messrs. Johnson and Matthey, samples of bismuth prepared from three different sources. The visible portion of the spectrum was examined with great care, but no difference in the relative intensities of the lines could be detected.

6. *Discussion of Results.*

When we compare together the results obtained for different metals, the first question that arises refers to the connexion between the velocities and atomic weight,

* 'Phil. Trans.,' vol. 175, p. 130, 1884.

or rather vapour densities. Dr. FEDDERSEN was led by his researches to conclude that the spark through air volatilised the metal, which afterwards, according to him, took no further part in the discharge. If that is the case the process of molecular diffusion should, at equal temperatures, be inversely proportional to atomic weight. There is no doubt that the first luminosity of the discharge is entirely due to the spark breaking through the air. The air lines are so little widened in our photographs that it is only close to the pole that any metal vapour can be present while the air is luminous. During the interval between the initial current and the first return, the metal vapour will diffuse chiefly, if not entirely, by reason of the molecular velocities. The initial discharge starts a sound-wave which must leave for a short time the air between the electrodes in a state of rarefaction, and it is perhaps right to consider that the mass of metallic vapour suddenly formed is driven by its own pressure into the partial vacuum formed by the heated air. It would seem more correct, therefore, to compare the process with that of a gas under pressure flowing into a vacuum than to that of pure thermal diffusion. There is not much difference between these views, and we may take it that in our experiments we have approximately measured the velocity of sound in the metallic vapour. This gives a relation between its temperature and density. Neglecting a possible difference in the ratio of specific heats, the relation

$$V = 80\sqrt{T/\rho}$$

should hold approximately, T being the absolute temperature, V the velocity of sound, and ρ the vapour density referred to hydrogen. Thus, for cadmium, the average molecular velocity found was 560, and substituting $\rho = 56$, we obtain $T = 2700$, which seems a possible but rather low value. We must conclude that the molecule of cadmium in the spark cannot have a mass which is much smaller than that determined directly near the boiling point of the metal.

If we compare different metals with each other we are struck with the almost identical numbers obtained for zinc and cadmium. It is possible, of course, that zinc vapour may be diatomic, but it seems more probable that as the spectrum of zinc and cadmium show homologous lines, the molecular constitution of the two vapours is the same. Aluminium, with a small atomic weight, has a high velocity, and so has magnesium, but the ratio of the velocity of aluminium to cadmium is roughly as 3 : 1, while the ratio of the square roots of the atomic weights is only as 2 : 1.

The uncertainty of our numbers is so great that we only wish at present to draw the general conclusion that the two metals having the lowest atomic weights, which have been examined by us, are also those showing the highest velocities. For the same reason we forbear discussing the question as to the different behaviour of different lines, especially with regard to other peculiarities possibly existing in the behaviour of lines which show abnormal velocities. The data are at present too scanty and uncertain to allow us to attach any value to the coincidence of such peculiarities.

An interesting question arises as to whether, in the case of an alloy, the different components affect each other or not. The evidence, so far, goes to show that they do; the zinc lines, for instance, are less curved when the zinc is amalgamated, and similarly when electrodes of bismuth are moistened with calcium chloride the displacement of the bismuth lines is reduced.

7. *Experiments without Prismatic Decomposition.*

Dr. Feddersen took photographs of the entire spark by means of the revolving mirror, and the appearances he obtained were very irregular, though his experiments allowed him to draw some general important conclusions. We considered it to be of interest to take some photographs after removal of the prism, retaining the slit; fig. 29 (Plate 12) shows the appearance with zinc poles under the normal condition of our experiment, *i.e.*, with the six jars and a pole distance of 1 centim. The straight luminous initial discharge which passes the air gap is followed by a number of curved lines, which represent the oscillatory discharges. Fig. 30, in which the oscillations are spread out by the interposition of self-induction, gives a better representation of the phenomenon. We notice, in the first instance, the alternation at each pole between strong and feeble discharges: the strong discharge at one pole being opposite a weak discharge at the other. This peculiarity was pointed out already by Dr. Feddersen. Our experiments do not allow us to decide at which pole the discharge is most luminous, and it would be important to find this out, as it would allow us to decide whether the discharge through the metal vapour resembles more that of a vacuum tube or that of the voltaic arc. Fig. 30 shows the initial discharge to be followed by a second straight luminous band before the curved lines begin. The curvature is irregular, and the two poles do not behave exactly alike.

The distance between successive discharges is the same for all metals we have tried, which shows that the resistance of the metal vapour cannot be a dominating portion of the whole resistance, for doubtless different metal vapours will differ in resistance, especially as they must be present in very varying quantities, owing to differences in volatility. As we can count about ten discharges, we may take it that the damping is small and therefore the time of an oscillation $2\pi\sqrt{LC}$, if L is the self-induction. From this we calculate that our self-induction was about 3000; for steady currents a rough estimate of our circuit gave a self-induction of 1000, and we know that for rapid oscillations it must be greater. If we adopt the higher number, we may further conclude that the total resistance of our circuit must have been small compared to 20 ohms, while, taking the lower estimate for the coefficient of self-induction, the resistance was small compared to 12 ohms, a further proof, if one were needed, of the fact that once the insulating property of air is broken down, its conductivity may be large. We do not wish to enter further into some interesting

questions connected with this matter, as we are only concerned with the bearing of our experiments on the main subject of our research.

The curved lines of the oscillatory discharges may serve as a basis for the calculation of the molecular velocities, and if this is done, higher values are obtained than those we have derived from our experiments with the complete apparatus. Aluminium and magnesium gave again, however, the highest velocities near the pole, but that of the zinc molecules exceeded considerably the velocities found for cadmium.

There is here, however, a considerable difficulty in the interpretation of the result, as without the prism it is impossible to separate the different lines, and, what is perhaps more important, we do not get the effect of the first discharge at all, as that is hidden behind the dense luminous column of the straight air discharge.

If a photograph be taken of the spark on the rotating film, the image is always drawn out most near the middle of the spark, and we obtain images such as fig. 31. It is not quite easy to see why the metallic particles should remain luminous in the centre of the spark longer than near the pole, unless there is some inflow of cold air from the poles inwards. Such an inflow might be produced through the effects of rarefaction produced by the initial heating of the air by the spark.

8. *Sources of Error.*

Different photographs, obtained exactly in the same way, sometimes differ considerably in the value they give for the molecular velocity, and there is little doubt that the chief cause of error lies in the fact that the discharge is not a straight line parallel to the slit, but takes place in irregular curves, and, as appears already on Dr. Feddersen's photographs, the successive oscillations of the same discharge take sometimes very different courses. When we first began to work we used smaller capacities, and our results were more irregular, because the course of the discharge was more erratic. The large capacity acts in the direction of making the path of the discharge straighter, unless the sparking gap becomes too great. If the molecular stream is a straight line, our calculations are based on the further assumption that the image of the point of divergence falls exactly on the slit. If that point is at a distance h, measured perpendicularly to the slit, the molecules would have to traverse a distance $\sqrt{y^2 + h^2}$, if the projection of the distance along the slit is y. Calling V the velocity of the molecular stream, v that of the photographic film, it follows from $x = \mathrm{V}t$ and $vt = \sqrt{y^2 + h^2}$ that

$$\mathrm{V}^2x^2 - v^2y^2 = h^2v^2.$$

x and y are proportional to the coordinates of the spectroscopic lines as measured on the film, and the curve represented by the equation is a hyperbola.

The error introduced is such that a constant velocity would appear as one infinitely large close to the pole and gradually diminishing. If h is small, the hyperbola would soon coincide with its asymptote, and in that case the error in the molecular velocities

as deduced from points which are not in close proximity to the poles, would not be large. Some of our photographs give evidence of being affected by this error.

Other inaccuracies which cannot readily be evaluated are introduced by the curvature of the spark. If we imagine the molecular streams to follow the course of the spark, the appearance on our photographs might be considerably modified. In particular, if the curvature lies in a plane passing through the slit, the molecules near the pole will move towards the slit or away from it, and the components of the velocity resolved along its direction will have a smaller value than near the centre of the spark, where its direction is nearly always parallel to the slit. The error introduced is in a direction opposite to that found in the previous case, the molecular velocities near the poles now appearing too small.

One further point remains to be noted. Photographs like those illustrated by fig. 29 and fig. 30 cannot be easily explained, unless we take it that the metallic molecules actually carry the electric current. If that is the case, and if the process of discharge is similar to that advocated by one of us in 1882* and now generally accepted, the molecular stream will carry with it the ionic charge, at any rate in the positive part of the discharge. Now, considering successive oscillations, electric forces must continue to act on the metallic molecules, first accelerating, then retarding, and then again alternately accelerating and retarding. Under the conditions of our experiments, and with the velocities measured by us, the molecules would only have got to a distance of about 1 millim. from the pole before the second acceleration takes place. If that is a correct view, we should expect a sinuous curve for the molecular path, and there seems indeed a tendency towards such a form in some photographs, as for instance that given in fig. 22. The only way to overcome this complication will be to increase the period, so that we may be able to measure the velocity of the stream separately for each oscillation. The effect of magnetic forces on the velocity of the stream may also supply useful information.

9. *Effect of Self-Induction in the Spark Circuit.*

In the course of our investigation we were led to insert a coil of wire into the spark circuit in order to separate the oscillatory discharges. We discovered in this way a curious effect on the appearance of the spectrum, the air lines completely disappearing when the coil was inserted, provided the self-induction was sufficient. The most plausible explanation seems to be that the air lines are produced entirely by the first initial discharge, when the spark gap contains no metallic vapour. The subsequent oscillations pass, on the contrary, through the metal vapour, which in the meantime has had time to diffuse away from the electrodes. By inserting the coil, the initial discharge takes place more slowly and apparently does not heat up the air sufficiently to yield the line spectrum. The whole duration of the spark is considerably lengthened, and the

* 'Bakerian Lectures,' 1884 and 1890; 'Roy. Soc. Proc.,' vol. 37, p. 317, 1884, and vol. 47, p. 526, 1890.

discharge may pass through the metal vapour, which after a few millionths of a second fills the whole spark gap. The spectrum is modified by the change in the mode of sparking, and Mr. HEMSALECH is at present investigating this change, but our joint photographs are sufficient to show that the spectrum is *not* reduced to that of the arc discharge, the double zinc line at 4925, even with large self-inductions, remaining strong, though it thins out a little. We consider the method of investigating spectra a most useful one, and it allows us to distinguish at once what is an air line and what is not. The obnoxious noise of the spark is also much diminished.

[April 26, 1899.] Professor KAYSER has kindly drawn our attention to a paper by Mr. AUER v. WELSBACH ('Wiener Sitzungsberichte,' 88, II., 1883), in which an interesting device is described by which strong spark spectra may be obtained without the usual induction coil. It is essentially an arrangement by which the spark at the break of the primary current is used in place of a gap in the secondary circuit. The air lines also disappear under these conditions. In how far the spark is of a similar nature to that used by us is difficult to say without direct comparison of the spectra obtained.

When the above method is applied to different metals, it is found that the calcium lines H and K of the solar spectrum appear in most, possibly in all, cases. There is perhaps nothing surprising in this, owing to the presence of calcium in the dust of the air, and the probability of its occurring as an impurity in many metals. But what is surprising is the great intensity of these calcium lines, as compared with those of the metal proper when the poles used are silver. We deposited some of the metal electrolytically, and Mr. J. CROWTHER fused the deposit into poles on a block of willow charcoal, which contains only a very small amount of ash, but we must admit the possibility of some traces of calcium having been taken up by the silver in the process.

The silver so prepared gave not only the H and K lines, but also the line at 4226, with undiminished vigour. We do not offer any explanation as to the possible sources of calcium, either in the metal or in the dust of the air, but the fact is rendered remarkable by the appearance of the lines in question when the spectrum is taken on the rotating wheel. Fig. 27 is a photograph taken on the stationary film without self-induction, and the H and K lines are seen strongest near the centre of the spark. With self-induction, the strongest lines of the spectrum are those of calcium. In fig. 28 the disc was spinning, and there was no self-induction. The lines H and K present a comet-like appearance, K being much the strongest. The head of the curve corresponding to the K line is displaced towards the violet, and if our interpretation of these curves is correct, the photograph seems to prove that the H and K vibrations start not at the pole, but in the centre of the spark, and luminosity begins not when the main initial discharge strikes through the air, but, roughly speaking, about the 200,000th part of a second afterwards, when the luminosity of air as shown in our photographs has completely

ceased. Further experiments are in progress, and the matter is only mentioned here because any one repeating our experiments on the influence of self-induction will be struck by the intensity of the H and K lines when the spark is taken from silver poles. The extraordinary persistency with which the slightest trace of calcium is known to give the lines in question renders any investigation on the actual source of the calcium present very difficult. The effect of polishing, which was necessary to obtain good sparks, undoubtedly results in calcium contamination, as we were able to ascertain by experiment, but silver poles carefully prepared and not brought into contact with any foreign material, but polished by friction against each other, still gave the H and K lines very prominently.

10. *Conclusion.*

We point out in conclusion the principal results arrived at in the preceding investigation.

We do not consider that the numbers arrived at for the molecular velocities can lay claim to great accuracy, owing to the irregularities in the results, some of which have not quite been traced yet. But we think that we are able to say generally that metals of light atomic weight, like aluminium and magnesium, are projected from the poles with greater velocities than the heavier ones we have tried, such as zinc, cadmium and mercury. Different curvatures of different lines are marked in the case of bismuth, and are not easily explained, except by assuming the presence of different kinds of molecules having different masses, the lighter ones diffusing more quickly. We have thus established a method which is likely to prove of extreme value in separating the effects of different molecules.

Our experiments also allow us to draw another important conclusion. When two lines of a metal are of unequal intensity, it is not always due to the fact that at any period of the discharge the vibrations which appear the strongest are really the most intense. Our eye or the photographic film only perceives the total energy sent out, and the time of luminosity is in many cases very different for different lines. A vibration which is weak but persists may appear stronger than one of greater intensity which only appears for a very short time.

We have been led in addition to a new method of taking spark spectra with an induction coil, by the discovery that self-induction in the spark circuit leads to the disappearance of the air lines, which are often very troublesome in the investigation of spark spectra.

Finally, the appearance of the calcium lines in the photograph of the silver spectrum has shown the existence of a new type of spectroscopic lines, namely, one that starts in the centre of the spark and is propagated towards the poles.

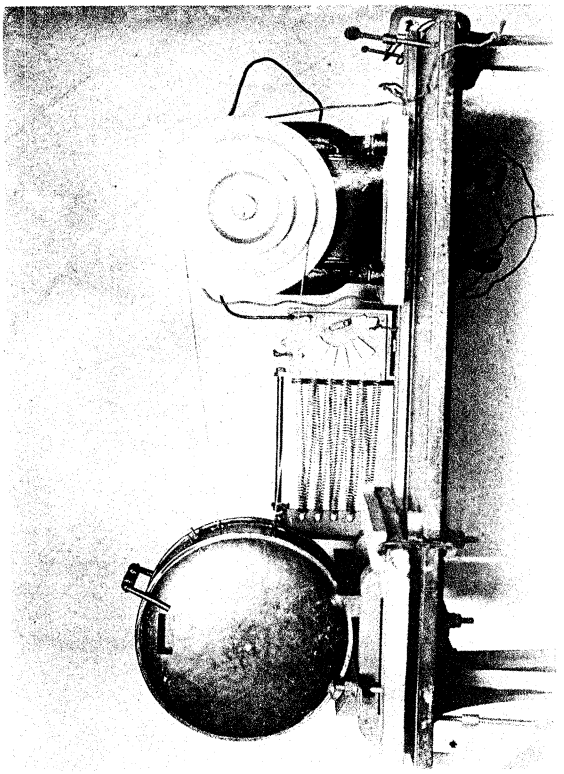


Fig. 5

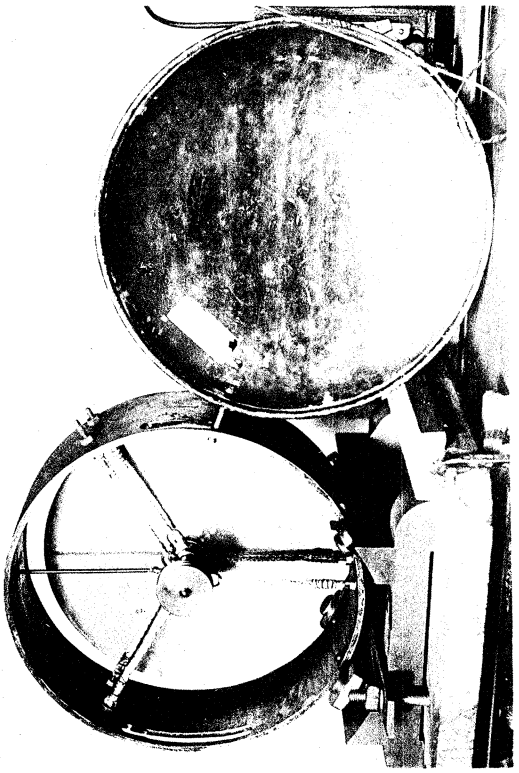


Fig. 3

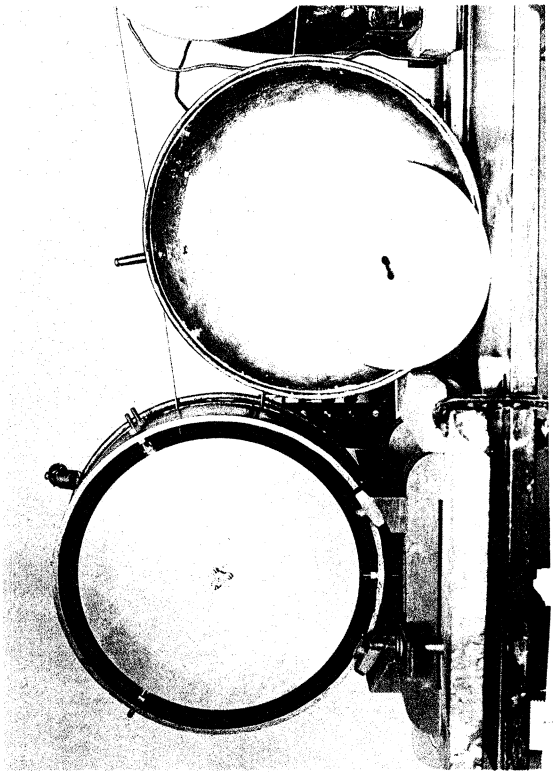
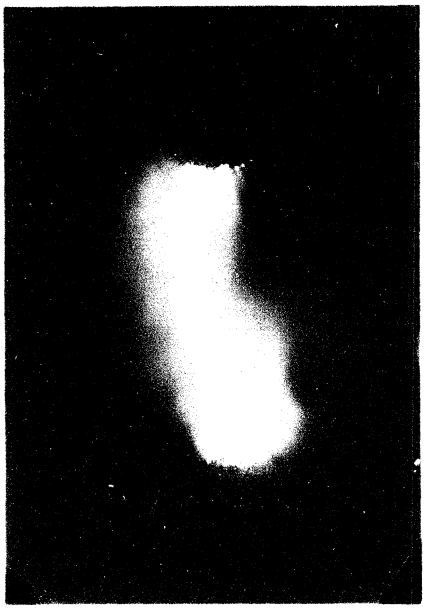


Fig. 4

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES



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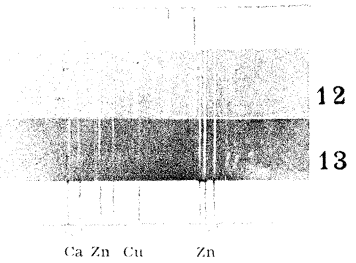

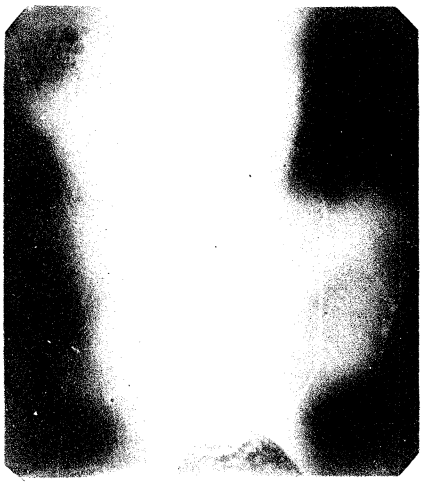

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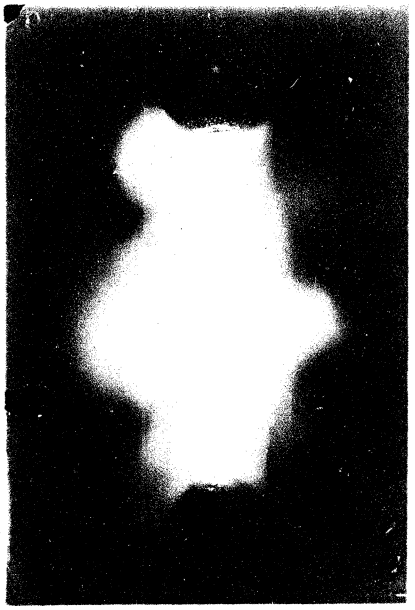

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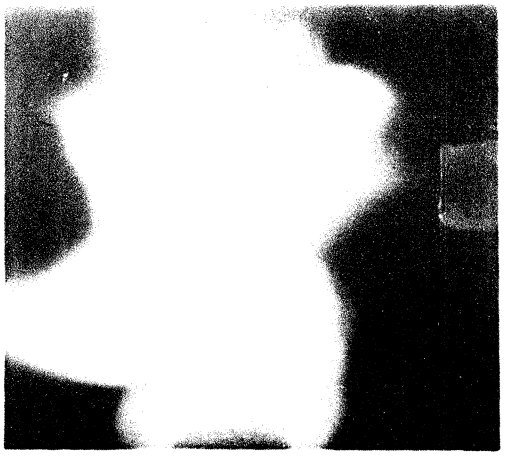

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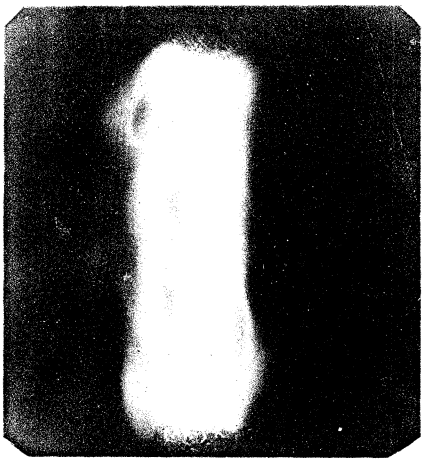

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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

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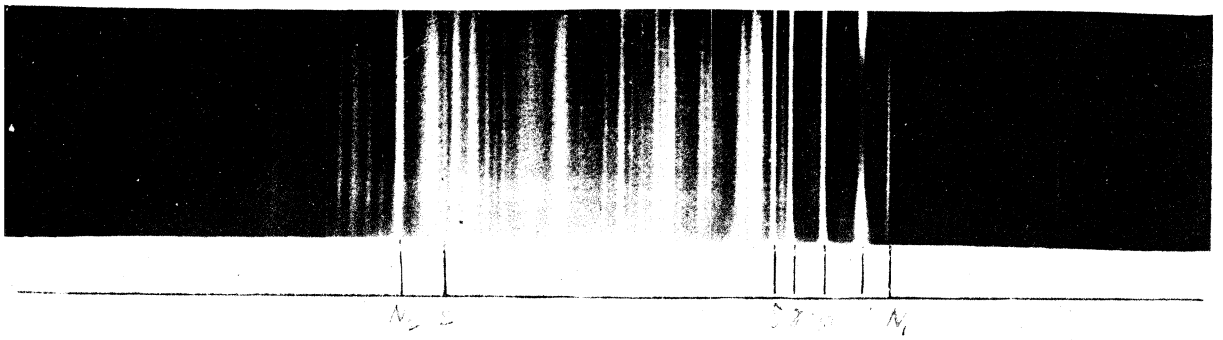

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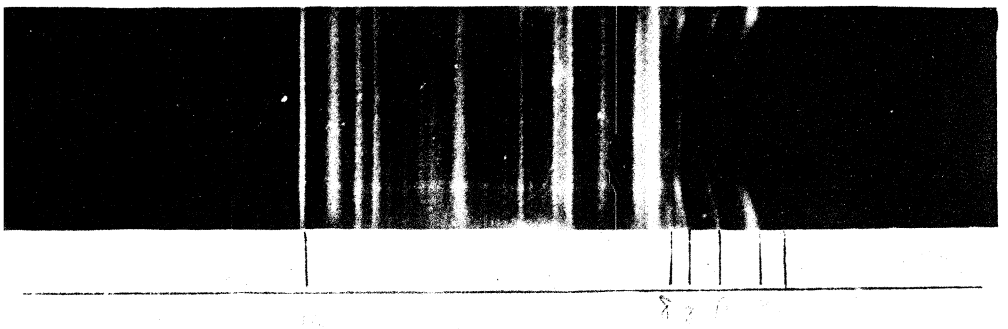

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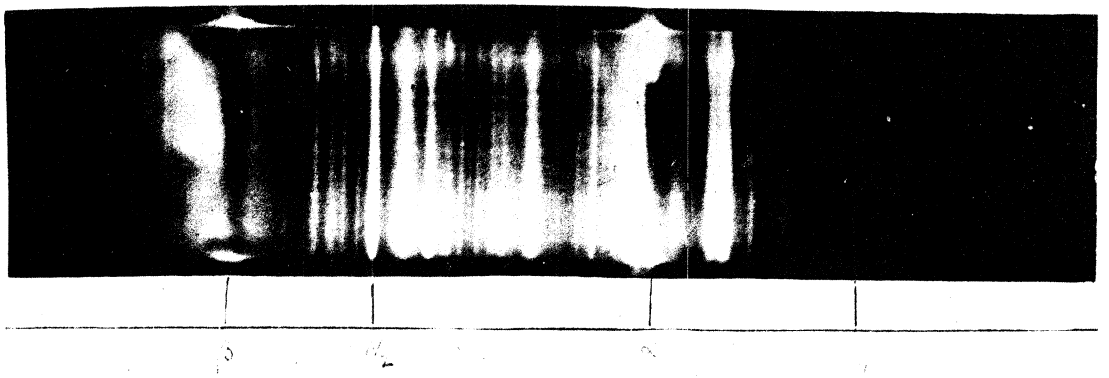

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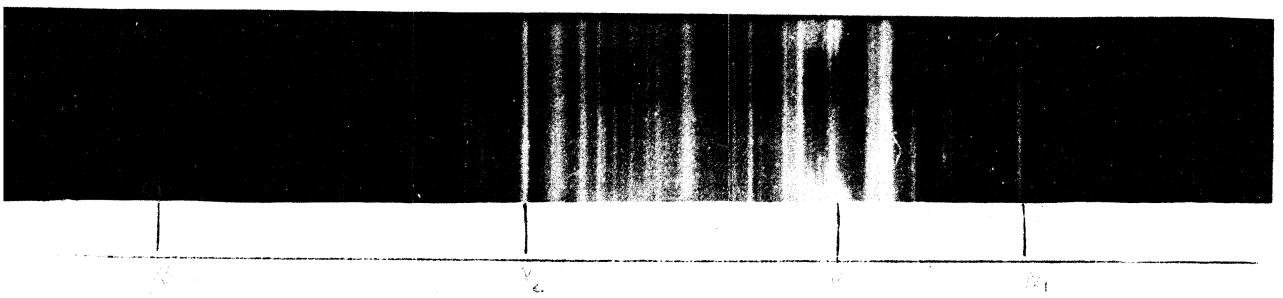

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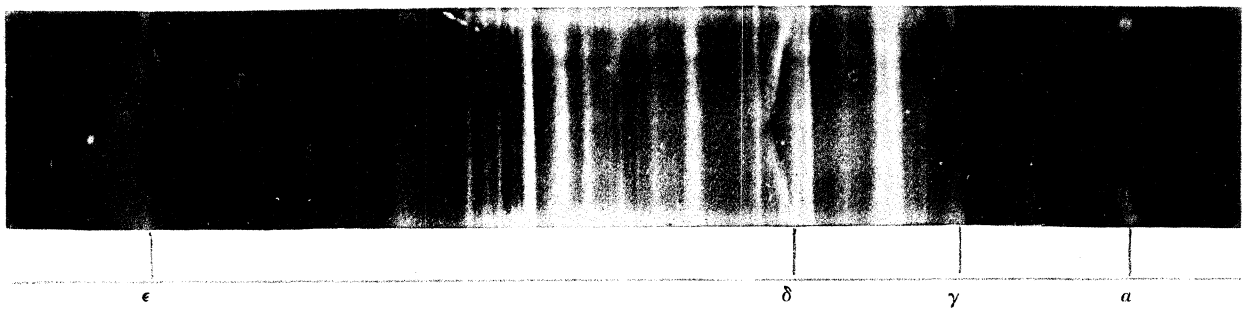
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES



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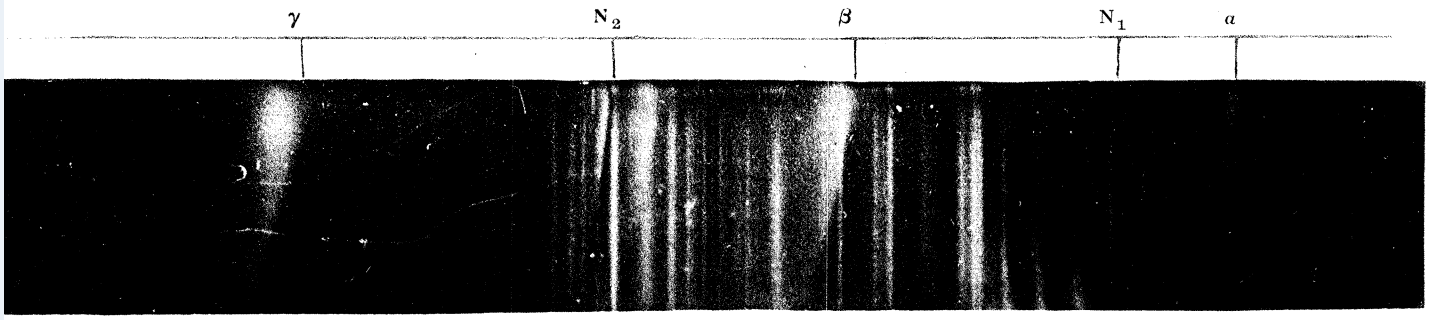

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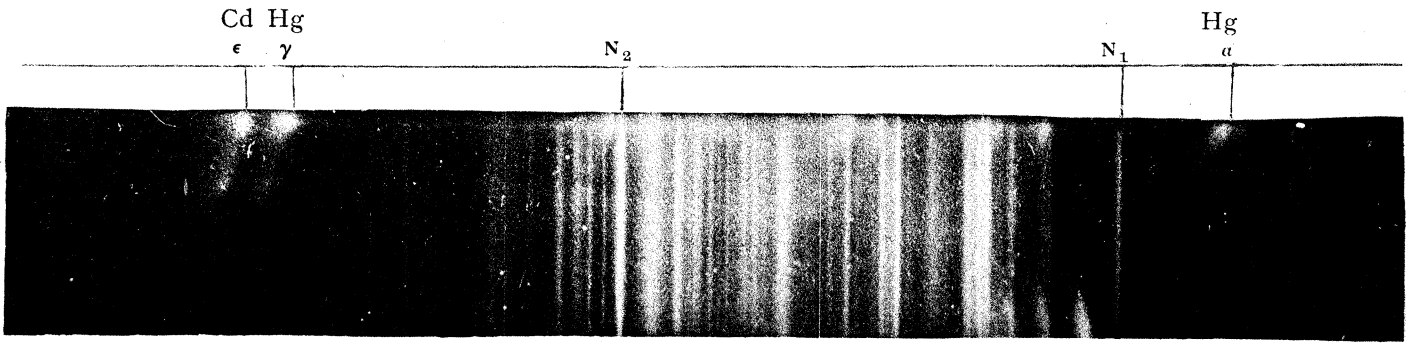
Upper Pole Mercury, Lower Pole Zinc.



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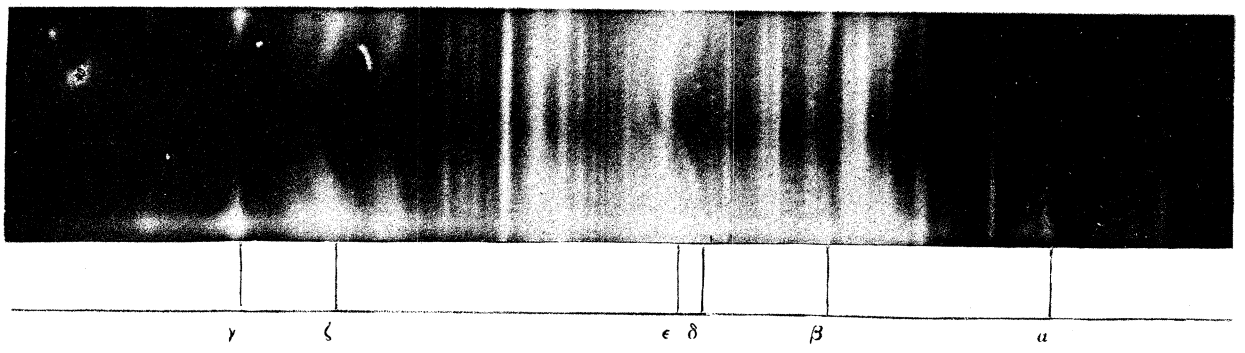

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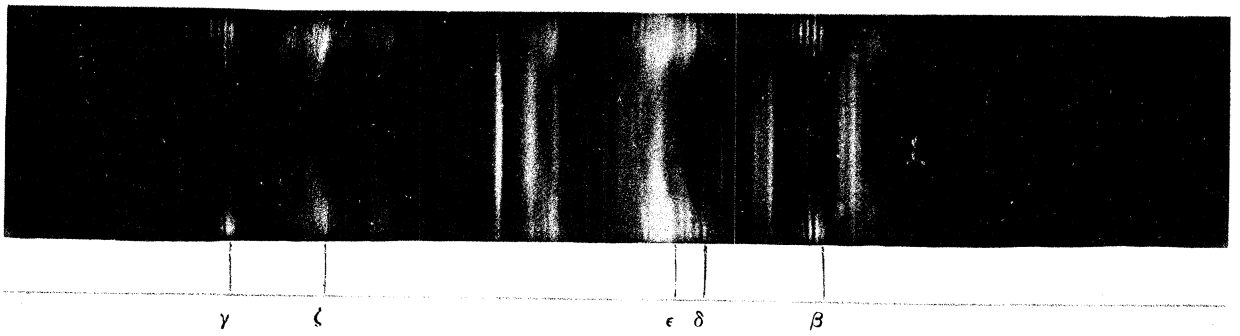

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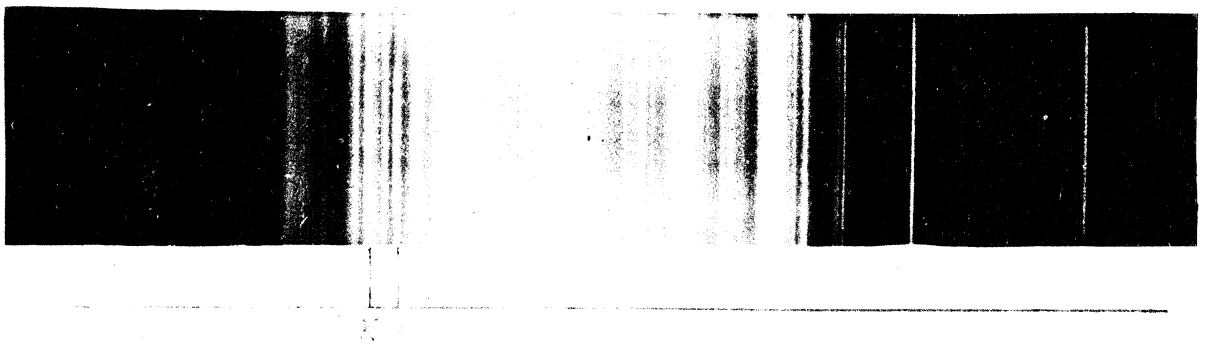

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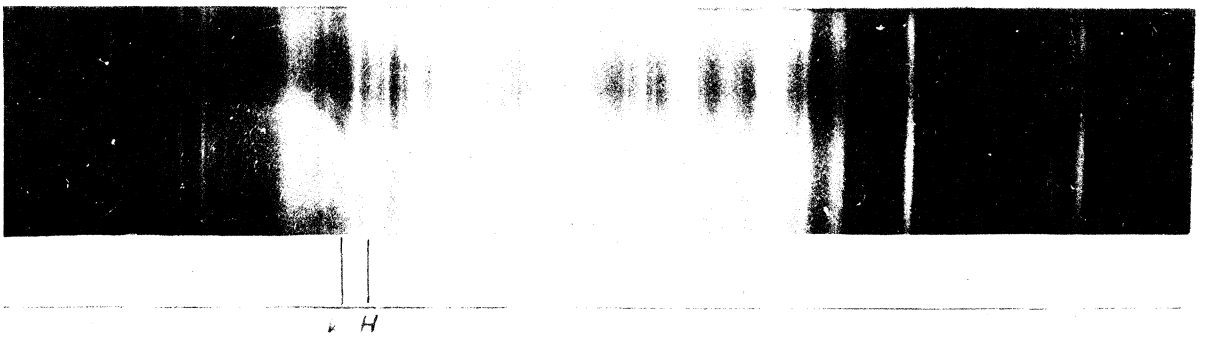

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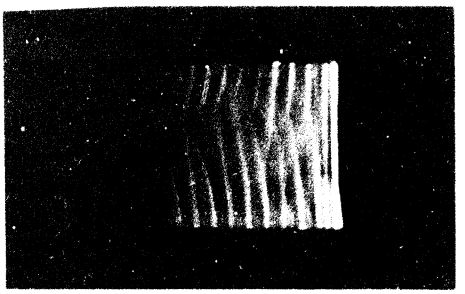

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PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

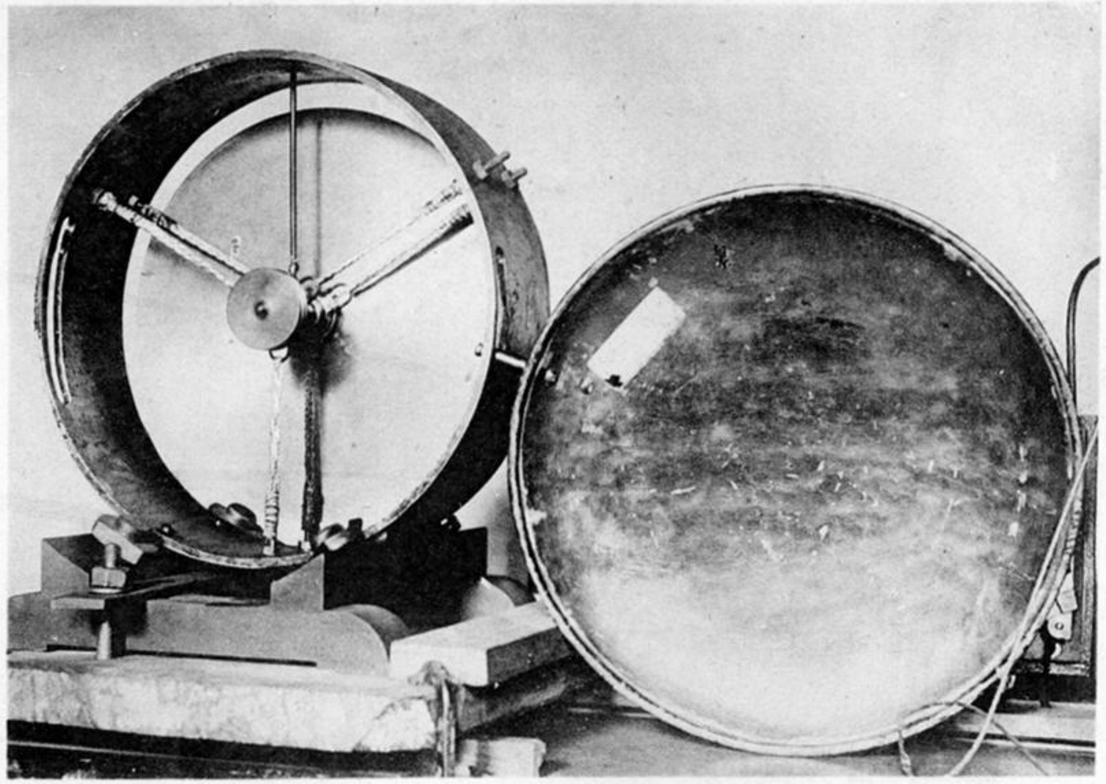


Fig. 3

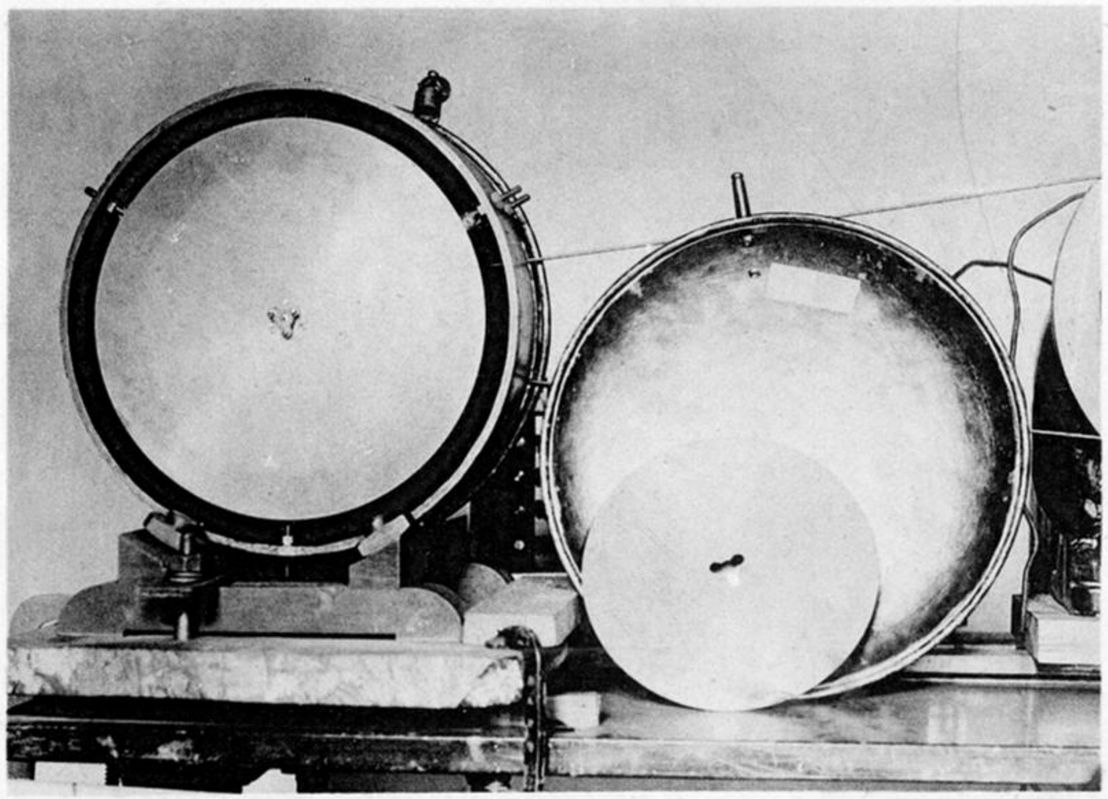


Fig. 4

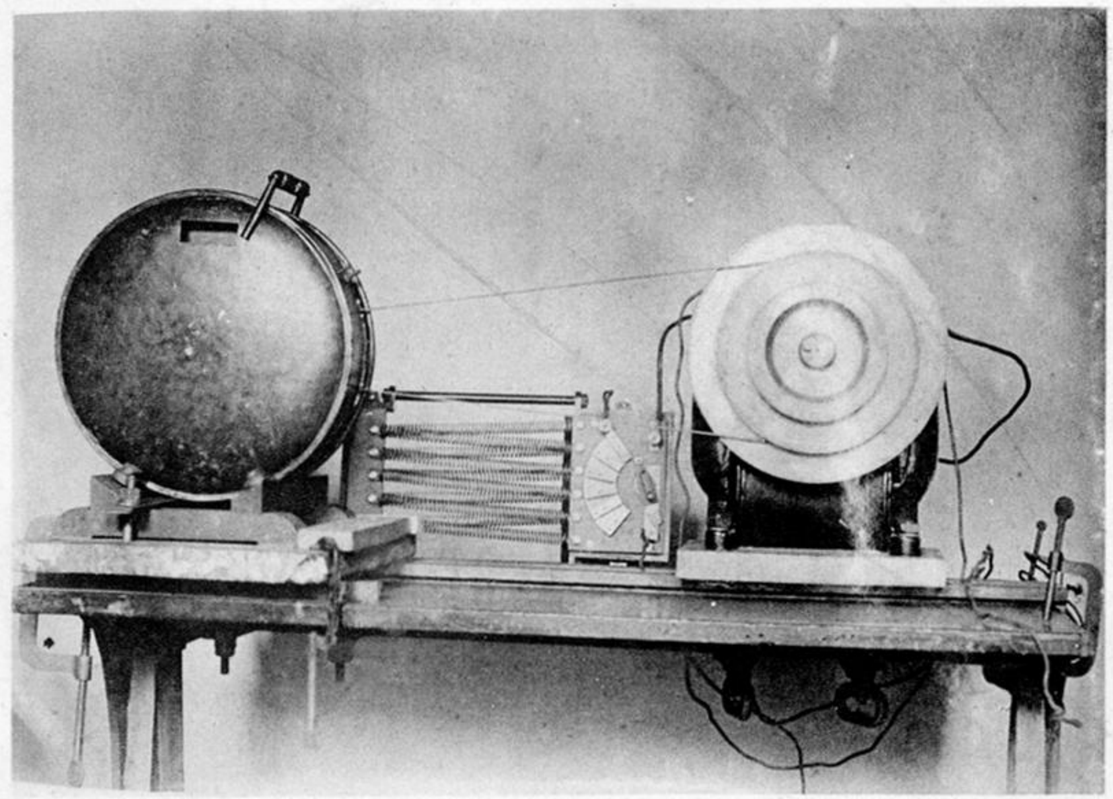
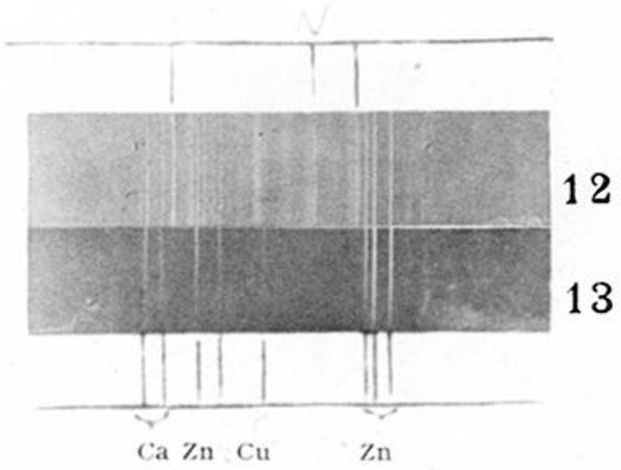
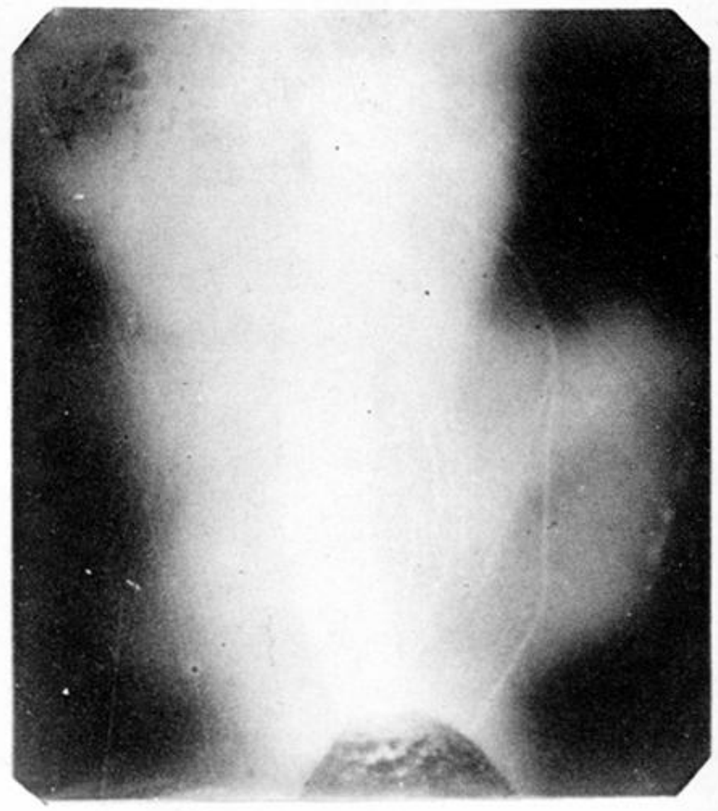


Fig. 5

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

11





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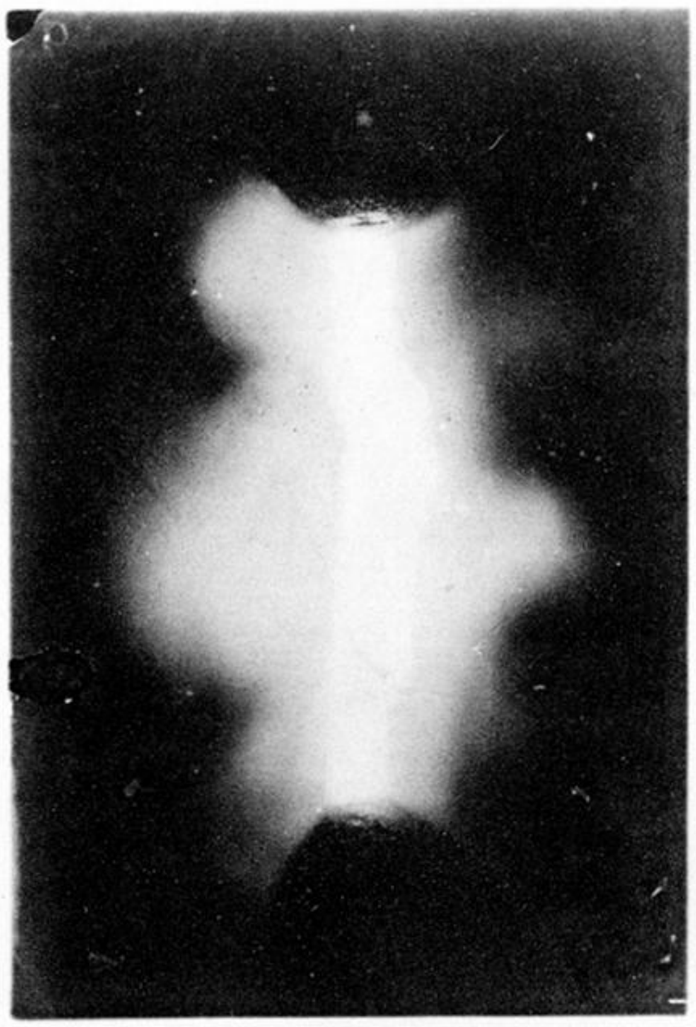

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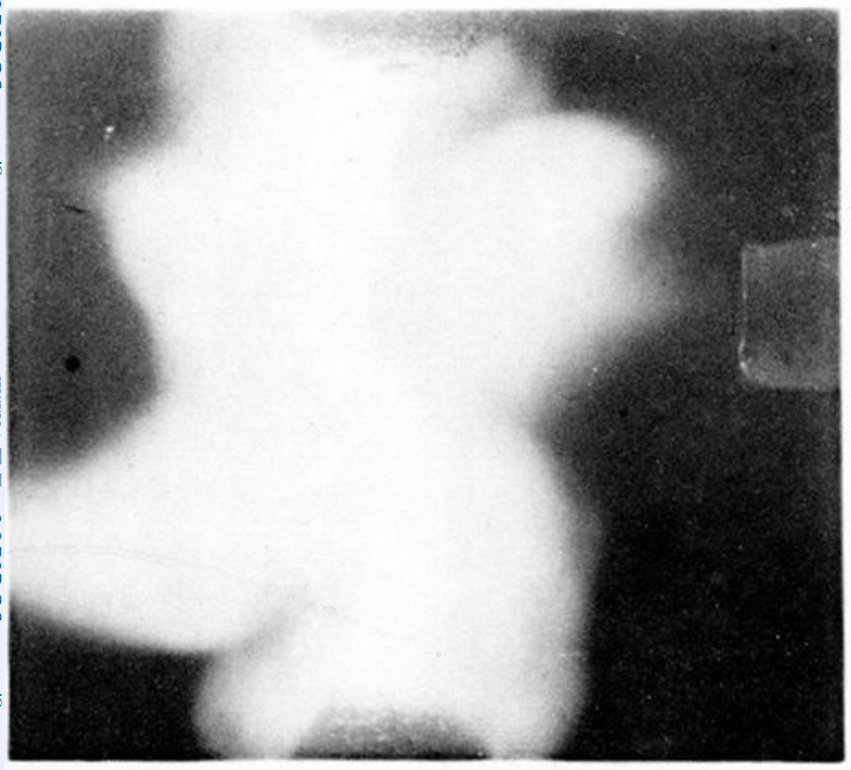

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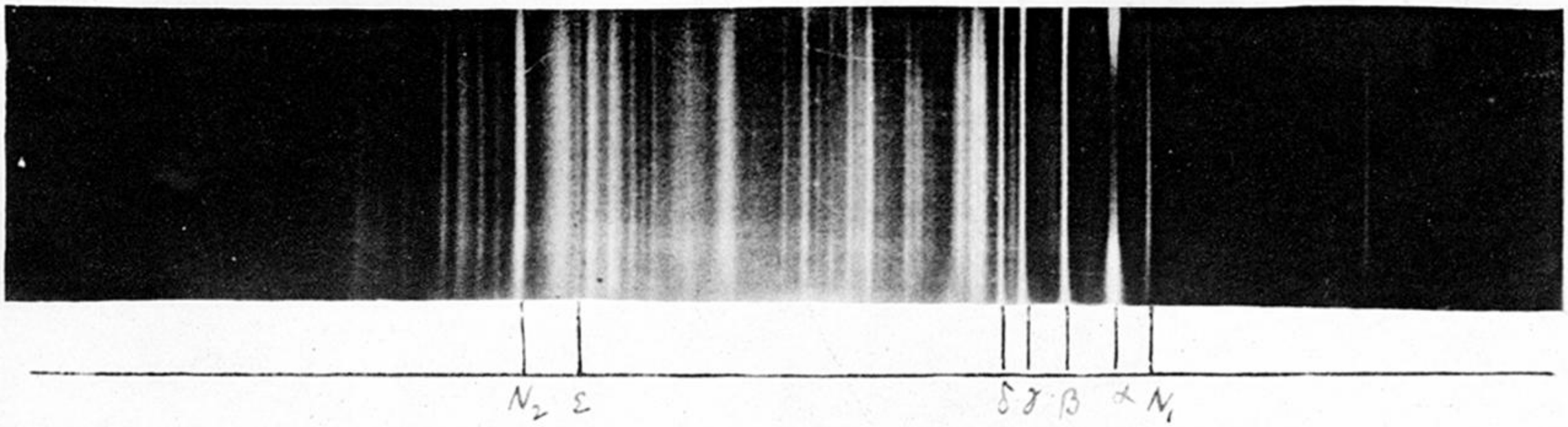

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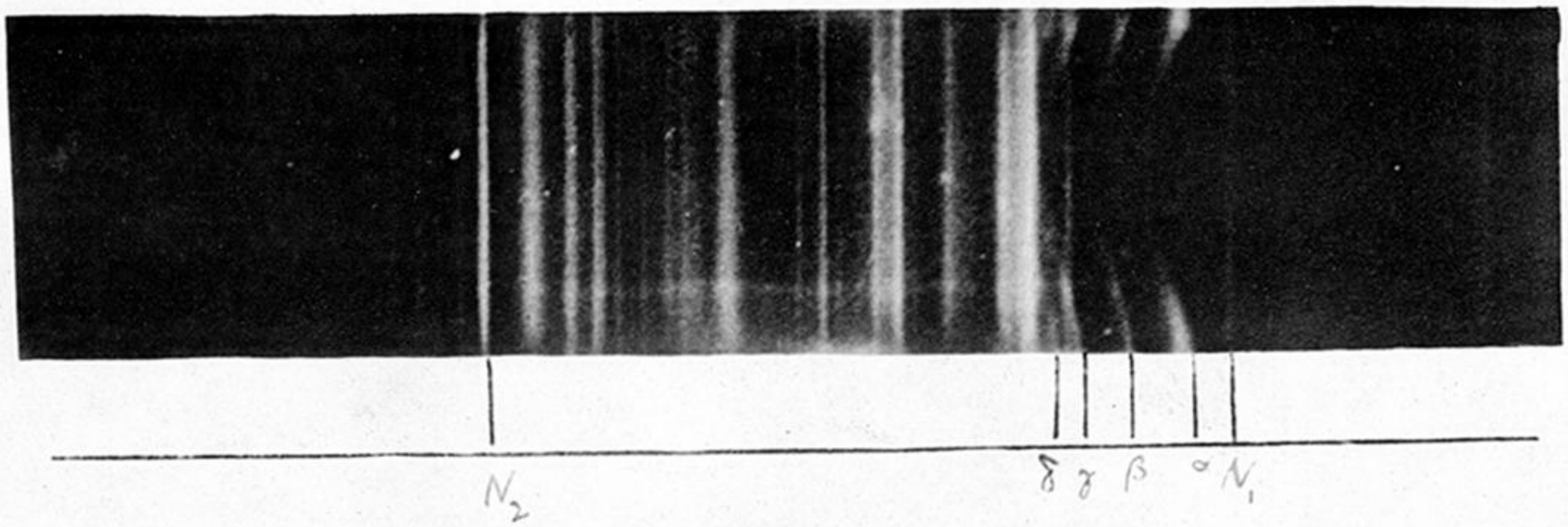

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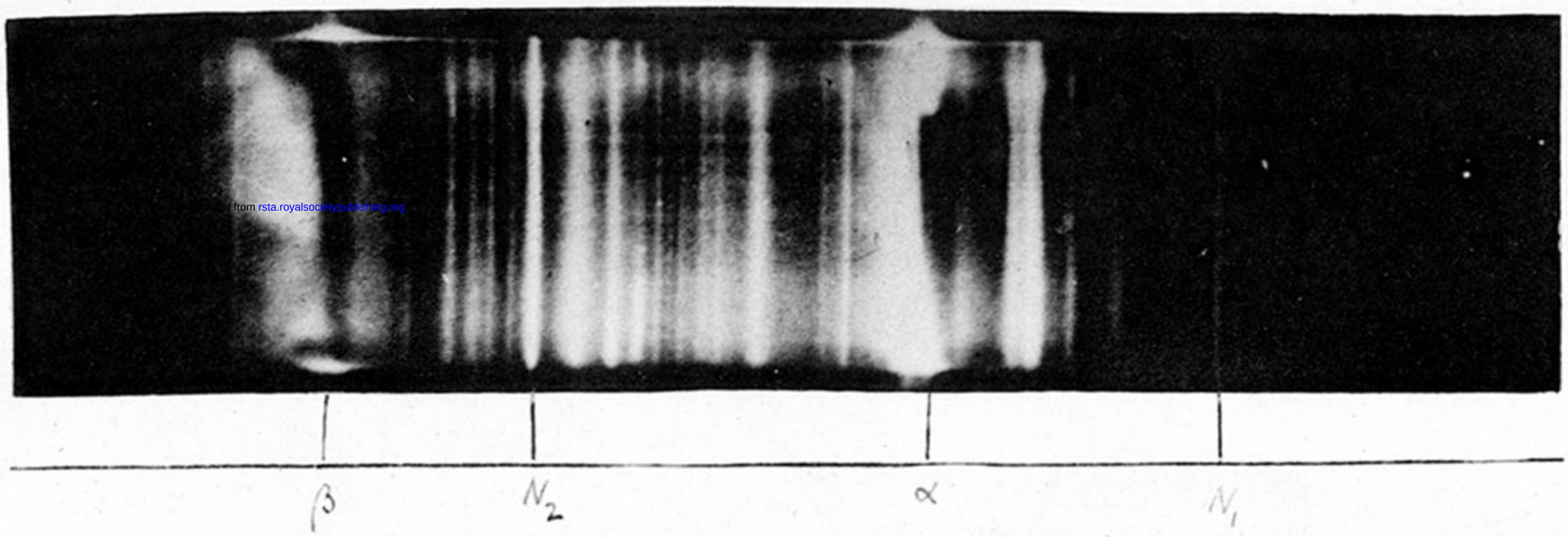

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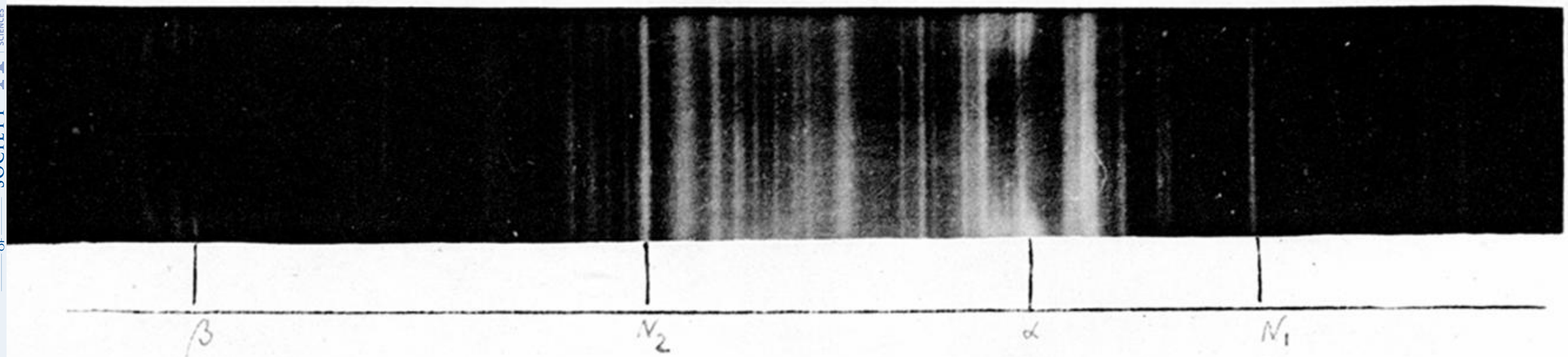

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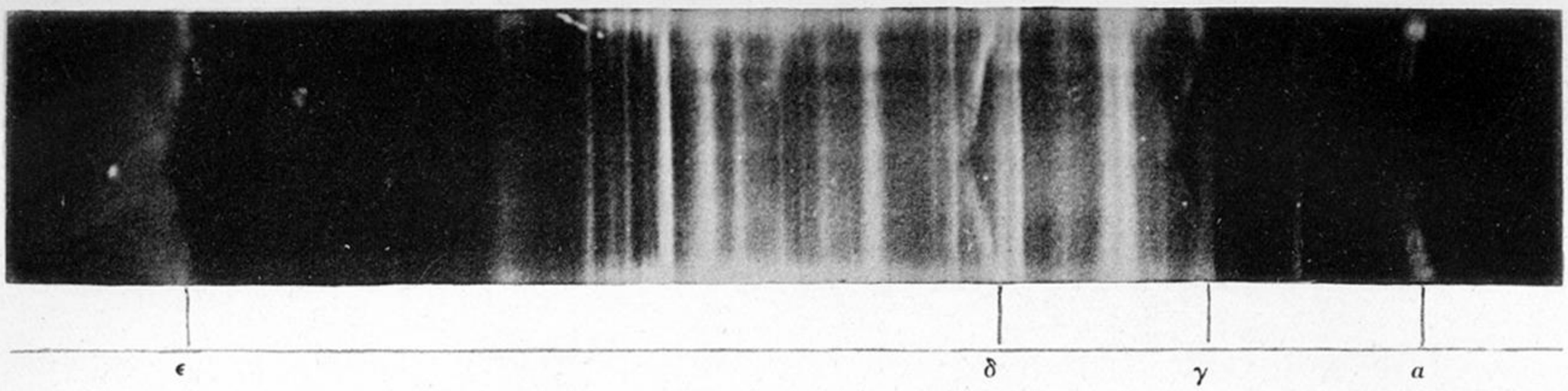

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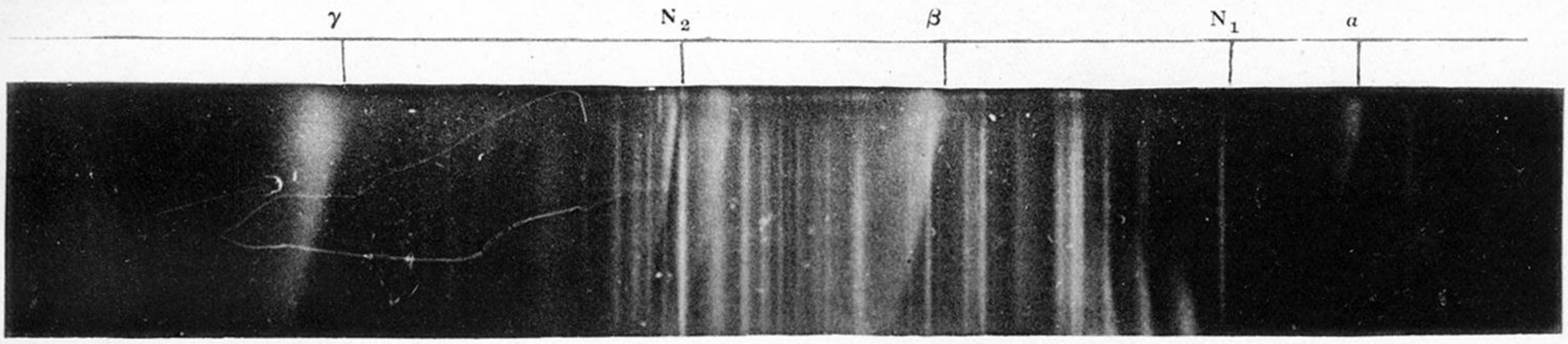

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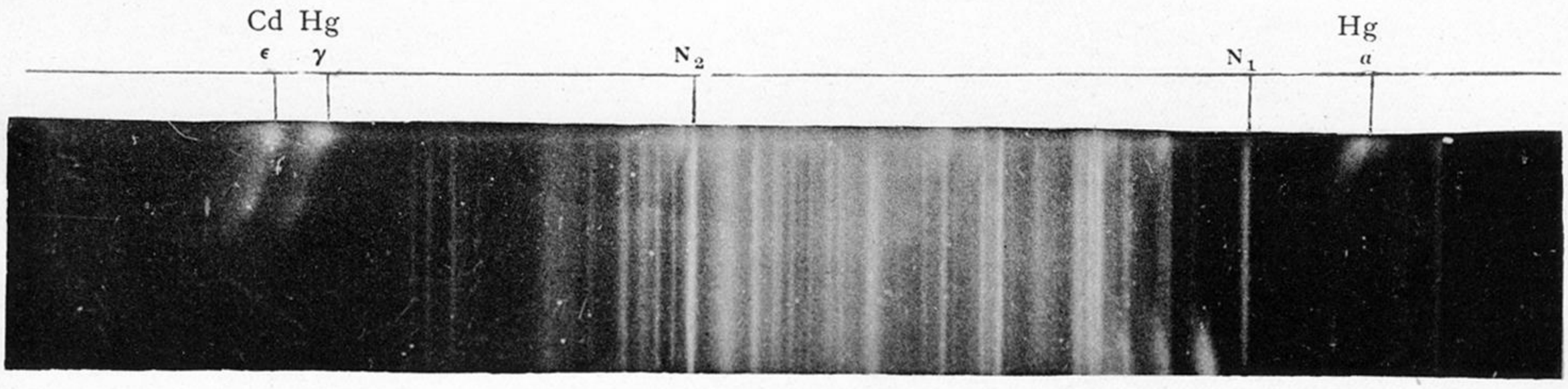
Upper Pole Mercury, Lower Pole Zinc.



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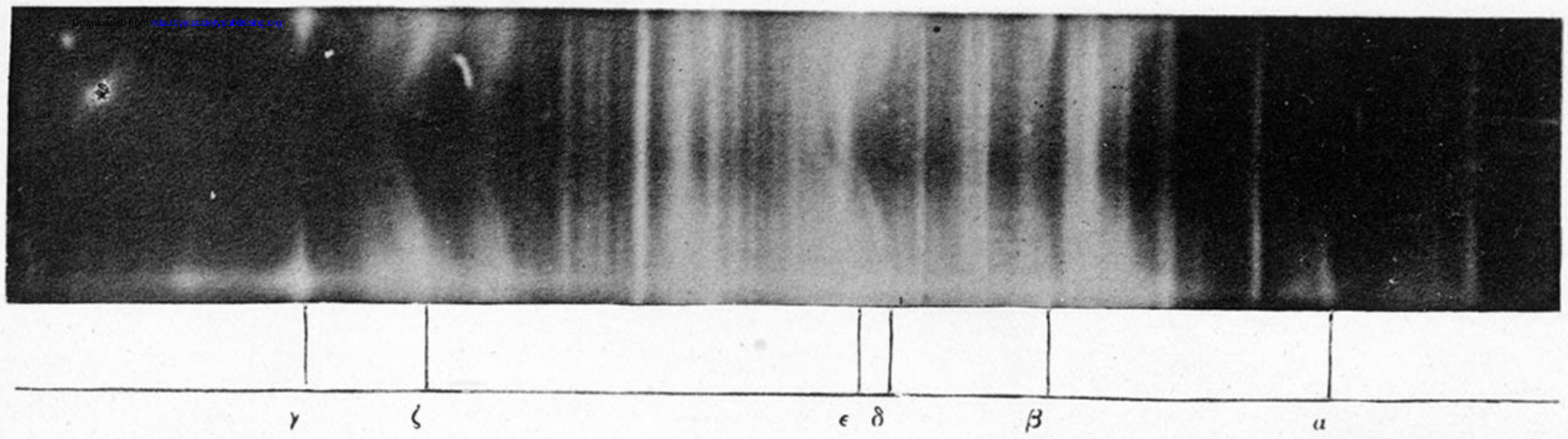

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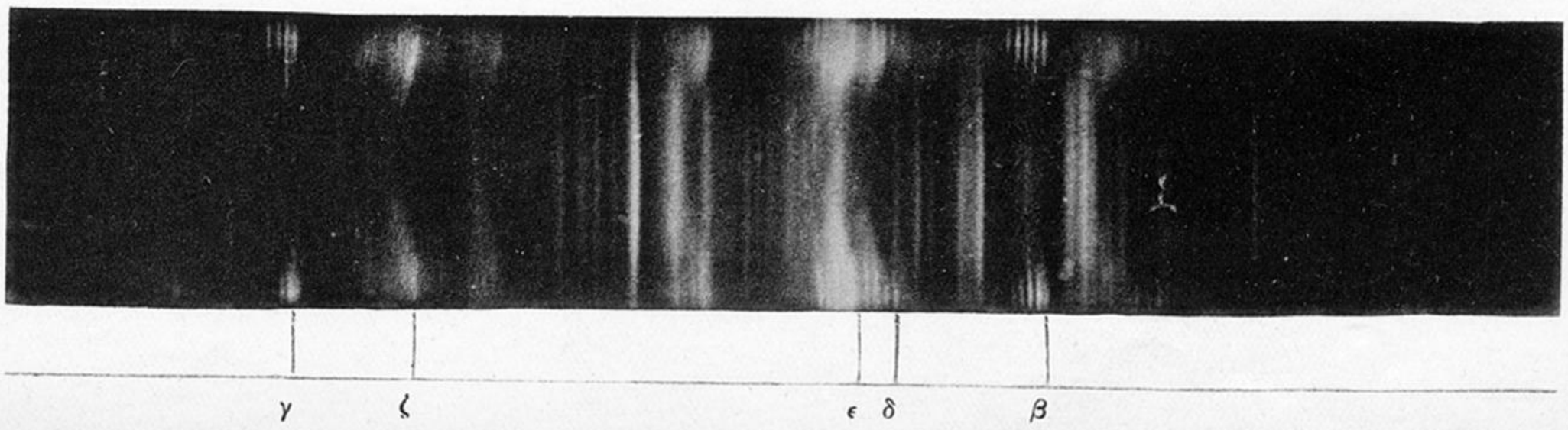

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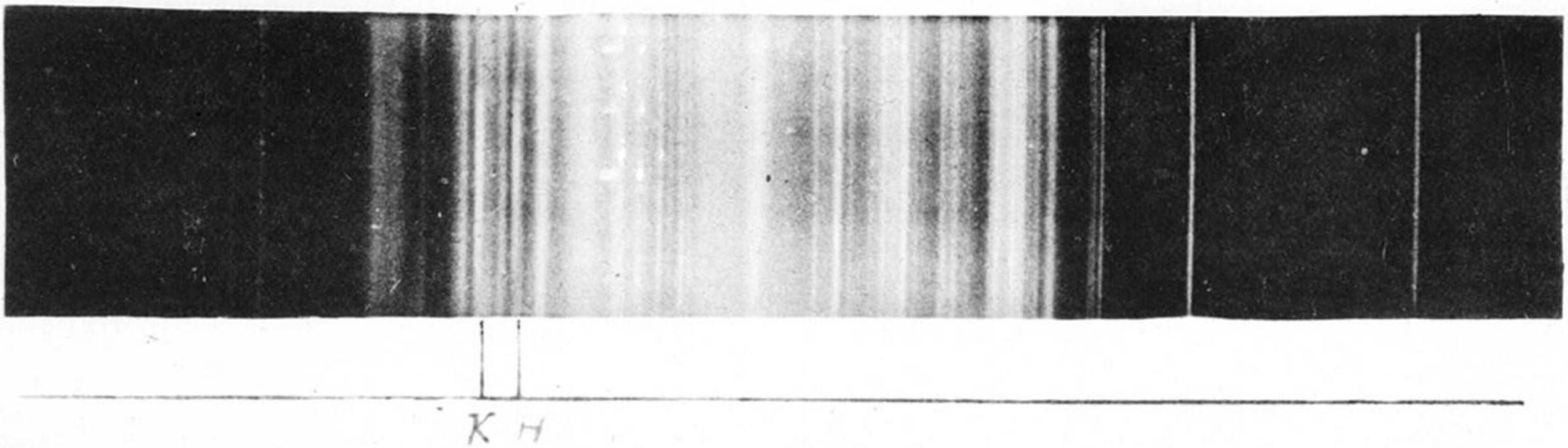
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

SILVER.



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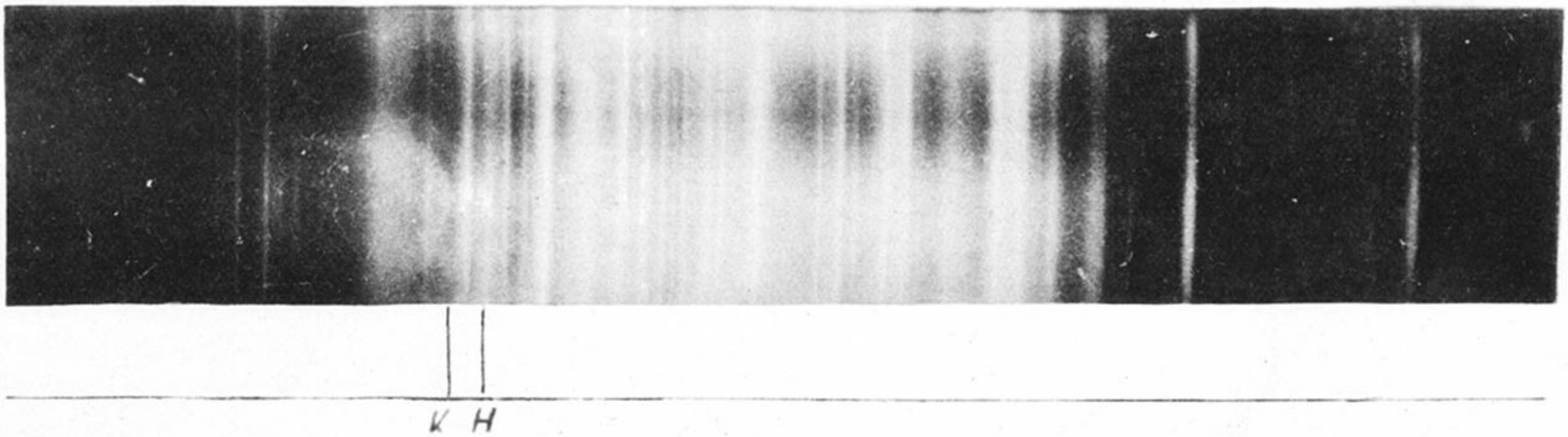

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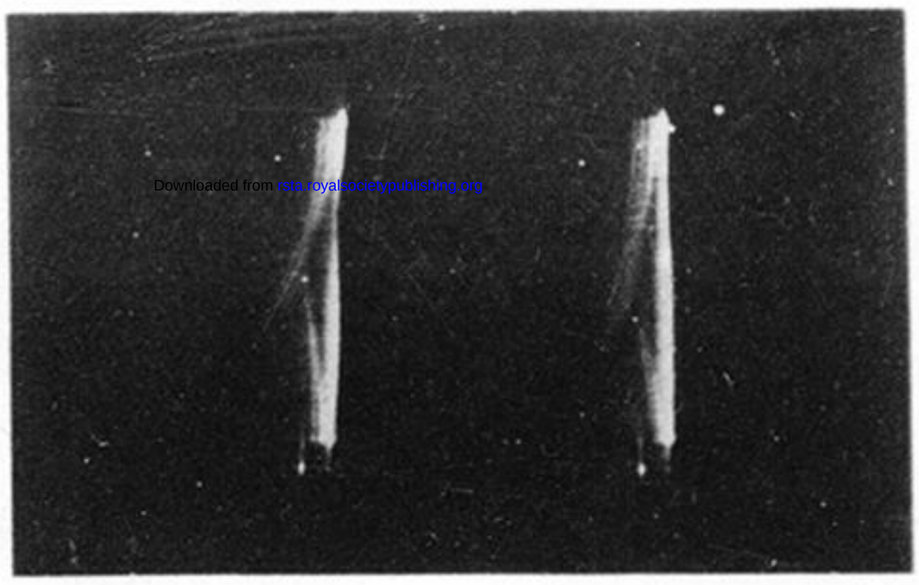

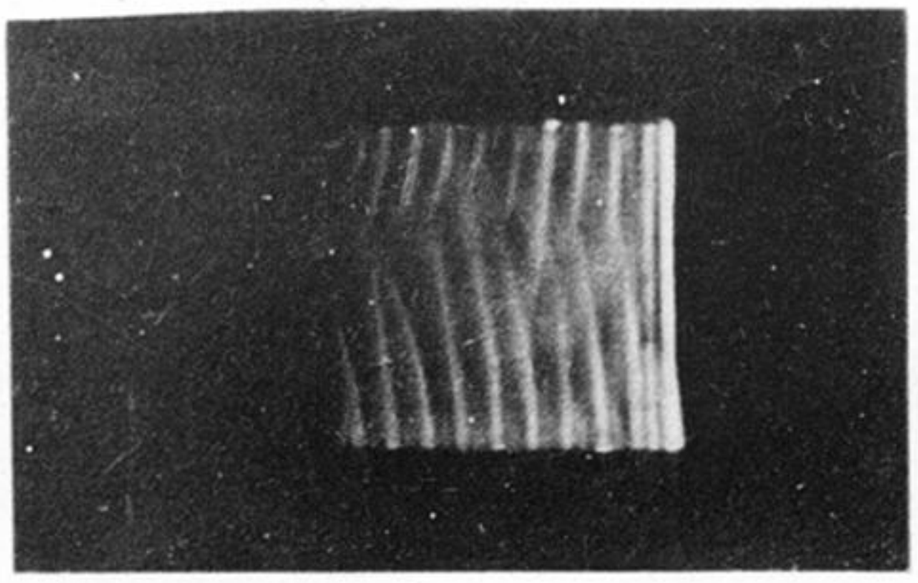

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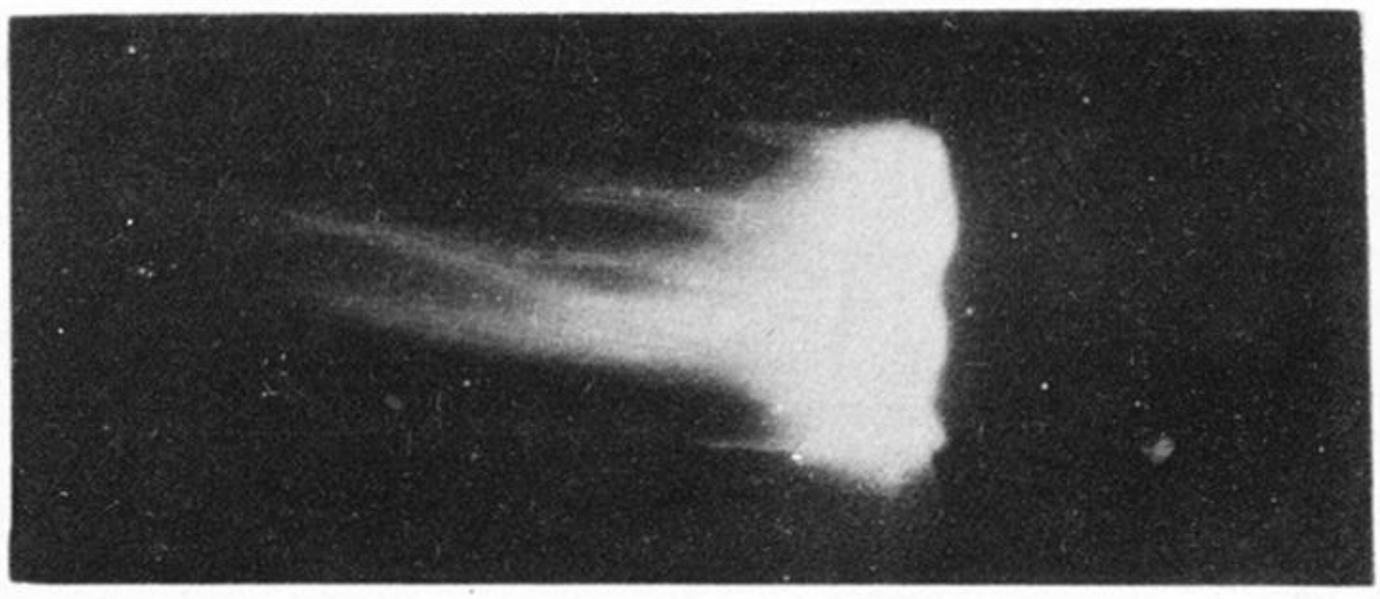

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