III. "Investigations on the Spectrum of Magnesium." By G. D. LIVEING, M.A., F.R.S., Professor of Chemistry, and J. DEWAR, M.A., F.R.S., Jacksonian Professor, University of Cambridge. Received April 28, 1881.

[PLATE 1.]

Since our last communication on this subject ("Proc. Roy. Soc.," vol. 30, p. 93) several authors—Ciamician, Cornu and Fievez—have published observations on the spectrum of magnesium, to some of which allusion is made in the sequel, but these observations by no means exhaust the subject. Our own observations, carried on for a considerable time, have extended to new regions and a variety of circumstances, and the summary of them which we now present to the Society will, we hope, help to bring out the connexion between some of the variations in the spectrum of this element and the conditions under which it is observed, and throw additional light on the question of the emissive power for radiations of short wave-length of substances at the relatively low temperature of flame to which we alluded in our paper on the spectrum of water ("Proc. Roy. Soc.," vol. 30, p. 580).

We begin with an account of these observations.

Spectrum of the Flame of Burning Magnesium.

When magnesium wire or ribbon is burnt in air, we see the three lines of the *b* group, the blue line about wave-length 4570, first noticed by us in the spark spectrum ("Proc. Roy. Soc.," vol. 27, p. 350); and photographs show, besides, the well-known triplet in the ultra-violet between the solar lines K and L sharply defined, and the line for which Cornu has found the wave-length 2850 very much expanded and strongly reversed. These lines are all common to the flame, arc, and spark spectra; and the last of them (2850) seems to be by far the strongest line both in the flame and arc, and is one of the strongest in the spark. But, in addition to these lines, the photographs of the flame show a very strong, somewhat diffuse, triplet, generally resembling the other magnesium triplets in the relative position of its components, close to the solar line M; and a group of bands below it extending beyond the triplet near L. These bands have, for the most part, each one sharply defined edge, but fade away on the other side; but the diffuse edges are not all turned towards the same side of the spectrum. The positions of the sharp edges of these bands, and of the strong triplet near M, are shown in the figure, No. 1. It is remarkable that the triplets near P and S are absent from the flame spectrum, and that the strong triplet near M is not represented at all either in the arc or spark. The hydrogen-magnesium series of lines, beginning at a wave-length about 5210, are also seen sometimes, as already

described by us ("Proc. Roy. Soc.," vol. 30, p. 96), in the spectrum of the flame; but we have never observed that the appearance of these lines, or of the strong line with which they begin, is connected with the non-appearance of b_4. Indeed, we can almost always see all three lines of the b group in the flame, though as b_4 is the least strong of the three, it is likely to be most easily overpowered by the continuous spectrum of the flame. The new observations recorded below leave, we think, no room for doubt that the series of lines beginning at wave-length 5210 are due to a combination of hydrogen with magnesium, and are not dependent solely on the temperature.

The wave-lengths of the strong triplet near M are about 3720, 3724, 3730, and of the defined edges of the bands about 3750, 3756, 3765, 3772, 3777, 3782, 3790, 3799, 3806, 3810, 3815, 3824, 3841, 3845, 3848, 3855, 3858, 3860, 3865.

Burning magnesium in oxygen instead of atmospheric air does not bring out any additional lines; on the contrary, the continuous spectrum from the magnesia overpowers the line spectrum, and makes it more difficult of observation.

Magnesia heated in the oxyhydrogen jet does not appear to give the lines seen in the flame.

We have left out of the figure and from the enumeration of lines the well-known bands of the oxide.

Spectrum of the Arc.

By examining the arc of a battery of 40 Grove's cells, or that of a Siemens' machine, taken in a crucible of lime, under the dispersion of the spectrum of the fourth order given by a Rutherford grating of 17,296 lines to the inch, we are able to separate the iron and magnesium lines which form the very close pair b_4 of the solar spectrum. Either of the two lines can be rendered the more prominent of the pair at will, by introducing iron or magnesium into the crucible. The less refrangible line of the pair is thus seen to be due to iron, the more refrangible to magnesium. Comparison of the solar line and the spark between magnesium points confirms this conclusion, that the magnesium line is the more refrangible of the two.

In the ultra-violet part of the spectrum photographs show several new lines. First, a pair of lines above U at wave-lengths about 2942, 2938·5.* These lines are a little below a pair of lines given by the spark for which Cornu has found the wave-lengths 2934·9, 2926·7. The latter pair are not seen at all in photographs of the arc, nor the former in those of the spark. The strong line, wave-length about

* [Many of our photographs show besides these two lines a third line wave-length about 2937·5, but we have not been able to determine certainly that it is due to magnesium. If so this group probably belongs to the series of triplets.—June 2.]

2850, is always seen, very frequently reversed. Of the quadruple group in the spark to which Cornu has assigned the wave-lengths 2801·3, 2797·1, 2794·5, and 2789·9, the first and third are strongly developed in the arc, the other two not at all. Next follows a set of five nearly equidistant lines, well-defined and strong, but much less strong than the two previously mentioned, wave-lengths about 2782·2, 2780·7, 2779·5, 2778·2, 2776·9. The middle line is a little stronger than the others. The same lines come out in the spark.

Beyond these follow a series of pairs and triplets; probably they are triplets in every case, but the third, most refrangible, line of the triplets is the weakest, and has not in every case been noticed as yet. These succeed one another at decreasing intervals with diminishing strength, and are alternately sharp and diffuse, the diffuse triplets being the strongest. The positions are shown in fig. 2. The series resembles in general character the sodium and the potassium series described by us in a former communication, and we cannot resist the inference that they must be harmonically related, though they do not follow a simple harmonic law. The most refrangible line in the figure at wave-length 2605 represents a faint diffuse band which is not resolvable into lines; it belongs, no doubt, to the diffuse members of the series, and, to complete the series, there should be another sharp group between it and the line at wave-length 2630. This belonging to the weaker members of the series is too weak to be seen.

The approximate wave-lengths found by us for these lines are as follows:—2767·5, 2764·5, 2736, 2732·5, 2731, 2698, 2695, 2693·5, 2672·5, 2670, 2668·5, 2649, 2646, 2633, 2630, 2605.

It is worthy of remark that the line at wave-length 5710, described by us in a previous communication ("Proc. Roy. Soc.," vol. 30, p. 98), is very nearly the octave of the strong line at 2850. Moreover the measures we have taken of the wave-length of this last line, with a Rutherford grating of 17,296 lines to the inch, indicate a wave-length 2852 nearly, which is still closer to the half of 5710.

In Cornu's map of the solar spectrum a line is ascribed to magnesium with the wave-length 3278. Although a line at this place appears in many of our photographs of the arc, we have not been able to identify it as a line due to magnesium. It does not show any increased strength when magnesium is introduced into the arc. When metallic magnesium is dropped into a crucible of magnesia or lime through which the arc is passing, the electric current seems sometimes to be conducted chiefly or entirely by the vaporised metal, so that the lines of other metals almost or wholly disappear; but the line at wave-length 3278 does not in such cases appear, though the other magnesium lines are very strongly developed. The line at wave-length 2850 is often, under such circumstances, enormously expanded and reversed, those at wave-lengths 2801, 2794, and the

alternate diffuse triplets, including those near L and near S, much expanded and reversed, and the group of five lines (2776—2782) sometimes reversed.

When the arc of a Siemens machine is taken in a magnesia crucible, the strong line of the flame spectrum, wave-length 4570, is well seen sharply defined; it comes out strongly and a little expanded on dropping in a fragment of magnesium. When a gentle stream of hydrogen is led in through a hollow pole, this line is frequently reversed as a sharp black line on a continuous background. From comparing the position of this line with those of the titanium lines in its neighbourhood, produced by putting some titanic oxide into the crucible, we have little doubt that it is identical with the solar line 4570·9 of Ångström.

When the arc is taken in a crucible into which the air has access, it may be assumed that the atmosphere about the arc is a mixture of nitrogen and carbonic oxide. When a stream of hydrogen is passed, either through a perforated pole or by a separate opening, into the crucible, the general effect is to shorten the length to which the arc can be drawn out, increase the relative intensity of the continuous spectrum, and diminish the intensity of the metallic lines. Thus, with a very gentle stream of hydrogen in a magnesia crucible, most of the metallic lines, except the strongest and those of magnesium, disappear. Those lines which remain are sometimes reversed; those at wave-length 2850 and the triplet near L being always so. With a stronger stream the lines of magnesium also disappear, the b triplet being the last in that neighbourhood to go, and b_1 and b_2 remaining after b_4 has disappeared.

Chlorine seems to have an opposite effect to hydrogen, generally intensifying the metallic lines, at least those of the less volatile metals, but it does not sensibly affect the spectrum of magnesium. Nitrous oxide produces no marked effect; coal-gas acts much as hydrogen.

Spectrum of the Spark.

In the spark of an induction coil taken between magnesium points in air we get all the lines seen in the arc except two lines at wave-lengths 4350 and 4166, two lines above U, and the series of triplets more refrangible than the quintuple group about wave-length 2780. The blue line wave-length about 4570 is seen in the spark without a jar when the magnesium electrodes are close together, and the rheotome made to work slowly, but requires for its detection a spectroscope in which the loss of light is small.

On the other hand, some additional lines are seen. Of these, the strong line at wave-length 4481 and the weak line at 4586 are well known. Another faint line in the blue at wave-length 4808* has been

* This line we first noticed in a former communication (" Proc. Roy. Soc.,"

observed by us in the spark, and two diffuse pairs between H and the triplet near L. Two ultra-violet lines at wave-lengths 2934·9, 2926·7 (Cornu) are near, but not identical with, two lines of the arc above mentioned; and two more lines at wave-lengths 2797·1, 2789·9 (Cornu) make a quadruple group with the very strong pair which are conspicuous in the arc in this region. The spectrum of the spark ends, so far as we have observed, with the quintuple group (2782—2776) already described in the arc. The lines of this spectrum are given in fig. 3.

When a Leyden jar is used with the coil, some of the lines are reversed. This is notably the case with the triplet near L, the line at wave-length 2850, and those at 2801 and 2794. Cornu ("Compt. Rend.," 1871) noticed the reversal of the less refrangible two lines of the triplet near L under these circumstances. This effect is very much increased by increasing the pressure of the gas in which the spark is taken. For the purpose of observing the influence of increased pressures, we have used a Cailletet pump and glass tubes similar to those employed in the liquefaction of gases by means of such a pump, but with an expansion of the upper part in which were magnesium electrodes attached to platinum wires sealed into the glass. The tube having been filled with gas at the atmospheric pressure, was sealed at its upper end, while the lower end dipped into mercury contained in the iron bottle of the Cailletet pump, and the gas was afterwards compressed by driving more or less mercury into the tube. The gases used were hydrogen, nitrogen, and carbonic oxide; and the image of the spark was thrown on to the slit of the spectroscope by a lens. In hydrogen, when no Leyden jar was used, the brightness of the yellow and of the blue lines of magnesium, except at first that at wave-length 4570, diminished as the pressure increased; while, on the other hand, the *b* group was decidedly stronger at the higher pressure. The pressure was carried up to 20 atmospheres, and then the magnesium lines in the blue and below almost or entirely disappeared, leaving only the *b* group very bright, and the magnesium-hydrogen bands which are described below; even the hydrogen lines F and C were not visible. When a jar was used, the magnesium lines expanded as the pressure was increased; all three lines of the *b* group were expanded and reversed at a pressure of 5 atmospheres; the yellow line, wave-length 5528, was also expanded but not reversed; and the line at 4481 became a broad, very diffuse band, but the line at wave-length 4570 was but very little expanded. The expansion both of the *b* group and of the yellow line seemed to be greater on the less refrangible than on the more refrangible side of each line, so that the black line in those

vol. 27, p. 353), but the wave-length is there given, through an error in taking out the ordinate of the curve of interpolation, as 4797 instead of 4807. Another measure has given the wave-length 4808.

which were reversed was not in the middle. When the jar was used the pressure could not be carried beyond 10 or $12\frac{1}{2}$ atmospheres, as the resistance became then so great that the spark would not pass across the small distance of about 1 millim. between the electrodes. At a pressure of $2\frac{1}{2}$ atmospheres, with a jar, the ultra-violet magnesium triplet near L was very well reversed, and the two pairs of lines on its less refrangible side (shown in fig. 3) were expanded into two diffuse bands.

In nitrogen and in carbonic oxide the general effects of increased pressure on the magnesium lines (not the magnesium-hydrogen bands) seemed to be much the same as in hydrogen. Without a jar the blue and yellow lines were enfeebled, and at the higher pressures disappeared, while the *b* group was very brilliant but not much expanded. With the jar all the lines were expanded, and all three lines of the *b* group strongly reversed. The bands of the oxide (wave-length 4930—5000) were not seen at all in hydrogen or nitrogen; they were seen at first in carbonic oxide, but not after the sparking had been continued for some time.

The disappearance of certain lines at increased pressure is in harmony with the observations of Cazin ("Phil. Mag.," 1877, vol. iv, 154), who noticed that the banded spectrum of nitrogen, and also the lines, grew fainter as the pressure was increased, and finally disappeared. When a Leyden jar is employed there is a very great increase in the amount of matter volatilised by the spark from the electrodes, as is shown by the very rapid blackening of the sides of the tube with the deposited metal, and this increase in the amount of metallic vapour may reasonably be supposed to affect the character of the discharge, and conduce to the widening of the lines and the reversal of some of them. Without a jar the amount of matter carried off the electrode also doubtless increases with the pressure and consequent resistance, and may be the cause of the weakening, as Cazin suggests, of the lines of the gas in which the discharge is passed. It is to be noted, moreover, that the disappearance of the hydrogen lines depends, in some degree, on the nearness of the electrodes. The lines C and F which were, as above stated, sometimes invisible in the spark when the electrodes were near, became visible, under circumstances otherwise similar, when the magnesium points had become worn away by the discharge.

M. Ch. Fievez ("Bull. de l'Académie Royale de Belgique," 1880, p. 91) has investigated the variations in the appearance of the spark spectrum of magnesium under certain different conditions. Using a Rutherford grating of 17,296 lines to the inch, he has noticed certain lines about the *b* group which increase in number with the order of the spectrum observed. He has also noticed dark lines in the solar spectrum corresponding to these lines of magnesium when the two spectra were superposed (fig. 5). We have noticed similar lines in the

spectrum of magnesium given by a Rutherford grating, but attribute them to a different cause. The Rutherford gratings have a periodic inequality in the ruling, due to an imperfection of the screw of the ruling machine, in consequence of which the image of every bright line is accompanied by a series of fainter images at nearly equal distances on either side of it, diminishing rapidly in brightness as they recede from the principal line. These *ghosts* are so much fainter than the principal lines that they are not noticed in the case of any but bright lines, and except in the case of very bright lines only two, one on each side, are seen to accompany each principal line.

FIG. 5.

Solar spectrum by Rutherford grating 4th order after M. Fievez.

Magnesium.

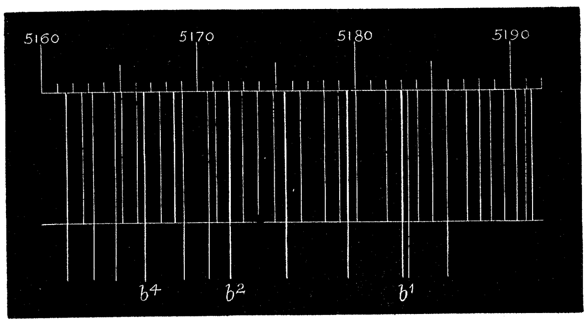


FIG. 7.

Magnesium *b* group with ghosts produced by Rutherford grating.

Spectrum of 4th order.

Spectrum of 3rd order.

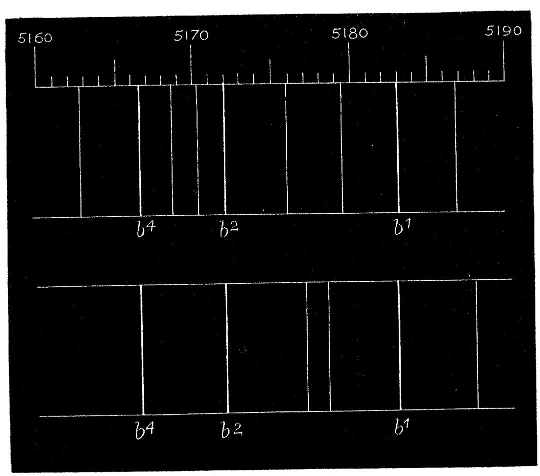


FIG. 6.

The positions of these *ghosts* have been investigated by Mr. Peirce in the "Mathematical Journal" of the Johns Hopkins University, Baltimore, who has found theoretically, and confirmed it by actual

observation, that the distance between successive images of the same line is directly proportional to the dispersion and inversely as the order of the spectrum. Our own observations of the positions of the *ghosts* of the *b* group of magnesium lines in spectra of different orders agree closely with Mr. Peirce's theory, and two different Rutherford gratings both give us the same results. The annexed diagram (figs. 6 and 7) gives the relative positions of the first pair of *ghosts* of each of the lines of the *b* group in the spectra of the third and fourth orders, when the angle between collimator and telescope is 45°. If this is compared with M. Ch. Fievez's map, it will be seen that he has probably been deceived by these *ghosts*, both in the solar spectrum and in that of the spark; but as he does not state the angle between his collimator and telescope, no exact comparison can be made. These ghosts are sometimes very embarrassing when many lines are in the field of view, but they may be detected by comparing the spectra of different orders, as the ghosts have different relative positions in the spectra of different orders. In the spectrum of the third order the first ghost of b_2 on the more refrangible side falls on b_4, and that of b_4 on its less refrangible side falls on b_2.

The Magnesium-hydrogen Spectrum.

In the "Proc. Roy. Soc.," vol. 27, p. 494, and vol. 30, p. 93, we have recorded a series of experiments which led us to attribute to magnesium together with hydrogen a peculiar spectrum. This spectrum we have on no occasion been able to detect in the absence of hydrogen. Observations on the spark discharge in nitrogen, in carbonic oxide, and in hydrogen, at reduced pressures, confirmed the results given in the first-mentioned paper, when the discharge was taken in the gases at atmospheric pressure. It was further shown that this peculiar spectrum could be reversed during the voltaic discharge in a lime crucible, provided magnesium and hydrogen were both present, but not in the absence of hydrogen. Likewise the flame of burning magnesium was found to emit this spectrum when the combustion occurred in an atmosphere containing either free or combined hydrogen. In summing up our results the following opinion was expressed:—

"The experiments above described, with nitrogen and carbonic oxide at reduced pressures, are almost if not quite conclusive against the supposition that the line at 5210 is due merely to the lower temperature of the spark in hydrogen. From De La Rue and Müller's observations it would appear that nitrogen at a pressure of 400 millims. should produce much the same effect on the spark as hydrogen at 760 millims. Now the pressures of the nitrogen and carbonic oxide were reduced far below this without any trace of the line in question being visible. Moreover, the magnesium line at 4481, which is not

seen in the arc, and may be reasonably ascribed to the higher temperature of the spark, may be seen in the spark at the same time as the line at 5210 when hydrogen is present. Nevertheless, temperature does seem to affect the result in some degree, for when a large Leyden jar is used, and the gas is at the atmospheric pressure, the line almost disappears from the spark, to reappear when the pressure is reduced; but by no variation of temperature have we been able to see the line when hydrogen was carefully excluded.

"A line of the same wave-length has been seen by Young in the chromosphere once. Its absence from the Fraunhofer lines leads to the inference that the temperature of the sun is too high (unless at special times and places) for its production. If it be not due to a compound of magnesium with hydrogen, at any rate it occurs with special facility in the presence of hydrogen, and ought to occur in the sun if the temperature were not too high.

"We have been careful to ascribe this line and its attendant series to a mixture of magnesium and hydrogen rather than to a chemical compound, because this expresses the facts, and we have not yet obtained any independent evidence of the existence of any chemical compound of those elements."

Fig. 4 shows more completely than we have given it before the general character of this spectrum, which consists of two sets of flutings and a pair of fainter bands, the flutings closely resembling in character the hydrocarbon flutings, each fluting consisting of a multitude of fine lines closely set on the less refrangible side and becoming wider apart and weaker towards the more refrangible side, but extending under favourable circumstances much further than is shown in the figure. The set in the green is the stronger, and it was to this that our former observations were confined. It has two flutings, one beginning at about wave-length 5210 and the other close to b_1 on its more refrangible side. The other set consists of three principal flutings, of which the first begins at about wave-length 5618, the next at about wave-length 5566, and the third begins with three strong lines at about the wave-lengths 5513, 5512, 5511. Both sets are very well seen when a magnesium wire is burnt in the edge of a hydrogen flame, and in the arc in a crucible of magnesia when a gentle current of hydrogen is led into it. The less refrangible edges of the bands are at wave-lengths about 4849 and 4803.

As Mr. Lockyer, in a paper entitled "A New Method of Spectrum Observation" ("Proc. Roy. Soc.," vol. 30, p. 22) has brought forward this spectrum as illustrative and confirmatory of his views regarding the possibility of elemental dissociation at different heat-levels, we have been induced to review our former work. The view taken by Mr. Lockyer may be expressed in his own words.

"The flame spectrum of magnesium perhaps presents us best with

the beautiful effects produced by the passage from the lower to the higher heat-level, and shows the important bearing on solar physics of the results obtained by this new method of work.

"In the flame the two least refrangible of the components of *b* are seen associated with a line less refrangible so as to form a triplet. A series of flutings and a line in the blue are also seen.

"On passing the spark all these but the two components of *b* are abolished. We get the wide triplet replaced by a narrow one of the same form, the two lines of *b* being common to both. . . . .

"May we consider the existence of these molecular states as forming a true basis for Dalton's law of multiple proportions? If so, then the metals in different chemical combinations will exist in different molecular groupings, and we shall be able, by spectrum observations, to determine the particular heat-level to which the molecular complexity of the solid metal, induced by chemical affinity, corresponds.

"*Examples.*—None of the lines of magnesium special to the flame spectrum are visible in the spectrum of the chloride either when a flame or a spark is employed."

In order to ascertain if this spectrum could be produced at a high temperature in the presence of hydrogen, which element we have already shown to be essential to its production at the atmospheric and at reduced pressures, the series of experiments already mentioned in describing the spark spectrum were made with hydrogen at pressures increasing up to twenty atmospheres.

On the supposition that this spectrum originates from the formation of some chemical compound, probably formed within certain limits of temperature when vapour of magnesium is in presence of hydrogen, the stability of the body ought to depend largely on the pressure of the gaseous medium. Like Graham's hydrogenium, this body might be formed at a temperature at which it would under ordinary circumstances be decomposed, provided the pressure of the hydrogen were correspondingly increased. In fact, it has been shown by Troost that the hydrides of palladium, sodium, and potassium all follow strictly the laws of chemical dissociation enunciated by Deville; and increased pressure by rendering the compound more stable, provided the secondary effect of such pressure in causing a higher temperature in the electric discharge were not overpowering, ought to conduce to a more continuous and brilliant spectrum of the compound. Conversely, if such a more continuous and brilliant spectrum be found to result, in spite of the higher temperature, from increased pressure, it can only be explained by the stability of the substance being increased with the pressure.

Now what are the facts? When the spark of an induction coil, without a Leyden jar, is passed between magnesium electrodes in hydrogen at atmospheric pressure, the flutings in the green are, as before described, always seen, but they are much stronger at the poles

and do not always extend quite across the field. As the pressure is increased, however, they increase in brilliance and soon extend persistently from pole to pole, and go on increasing in intensity, until, at fifteen and twenty atmospheres, they are fully equal in brilliance to the *b* group, notwithstanding the increased brightness these have acquired by the higher temperature, due to the increased pressure. The second set of flutings, those in the yellowish-green, come out as the pressure is increased, and, in fact, at twenty atmospheres only the *b* group and the flutings are noticeable; if the yellow magnesium line be visible at all it is quite lost in the brilliance of the yellow flutings. The tail of fine lines of these flutings extend at the high pressure quite up to the green, and those of the green flutings quite up to the blue. On again letting down the pressure the like phenomena occur in the reverse order, but the brilliance of the flutings does not diminish so rapidly as it had increased. If, now, when the pressure has again reached that of the atmosphere, a large Leyden jar be interposed in the circuit, on passing the spark the flutings are still seen quite bright, and they continue to be seen with gradually diminishing intensity until the sparks have been continued for a considerable time. It appears that the compound, which had been formed in large quantity by the spark without jar at the higher pressures, is only gradually decomposed, and not re-formed, by the high temperature of the spark with jar. This experiment, which was several times repeated, is conclusive against the supposition that the flutings are merely due to a lower temperature. When the pressure was increased at the same time that the jar was employed, the flutings did not immediately disappear, but the expansion of the magnesium lines and the increase of the continuous spectrum seemed to overpower them.

When nitrogen was substituted for hydrogen, the strongest lines of the green flutings were seen when the spark without jar was first passed at atmospheric pressure, probably from hydrogen occluded, as it usually is, in the magnesium electrodes. As the pressure was increased they speedily disappeared entirely and were not again seen either at high or low pressures.

With carbonic oxide the same thing occurred as with nitrogen; but in this gas the flutings due to the oxide of magnesium (wave-length 4930 to 5000) were, for a time, very well seen.

Ciamician ("Sitzungsber. Akad. Wissensch.," Wien, 1880, p. 437) has described a spectrum of magnesium of the first order (in Plücker's nomenclature) obtained by taking sparks from an induction coil, without a jar, between magnesium electrodes in an atmosphere of hydrogen. He gives a figure to a scale of this spectrum, but it is not to a scale of wave-lengths, so that exact comparison of his observations with ours is difficult. The least refrangible set of

flutings in his figure corresponds very well with that we have described in the yellowish-green. The next set, in the green, in his figure does not, however, correspond exactly with ours; it begins nearer to *b* than we have observed and consists of four flutings, whereas we observe but two in this set. It looks as if, in his figure, the magnesium-hydrogen spectrum were superposed upon the hydrocarbon spectrum in this region. Further, he gives a third more refrangible set of flutings which we have only observed as two blue bands, not fluted. This third set of flutings, as drawn in his figure, appears to be somewhat more refrangible than the set due to the oxide, and occupies partly the place of the blue hydrocarbon series, but a passage in the text, in which he says that the magnesium spectrum of the second order might, without measurement, easily be taken to be identical with that of carbon, almost negatives the supposition that this set of flutings is the blue hydrocarbon set and mistaken for a magnesium spectrum of the first order. To whatever it may be due, we have not seen anything closely resembling it under the circumstances described by him, though our observations on the spark spectrum of magnesium in hydrogen have now been repeated with all the variations of circumstance which we could devise.

Mr. Lockyer states (*loc. cit.*) that none of the lines of magnesium, special to the flame spectrum, are visible in the spectrum of the chloride, either when a flame or a spark is employed. But we find that when the spark is taken between platinum points from a solution of the chloride of magnesium, in a tube such as those used by Delachanal and Mermet, the line at wave-length 5210 can frequently be seen in it when the tube is filled with air, and that if the tube be filled with hydrogen the green flutings of magnesium-hydrogen are persistent and strong.

Repeated observations have confirmed our previous statements as to the facility with which the magnesium-hydrogen spectrum can be produced in the arc by the help of a current of the gas. In a magnesia crucible, by regulating the current of hydrogen, the flutings can be easily obtained either bright or reversed.

Comparison of the Spectra.

When we compare the spectra of magnesium in the flame, arc, and spark, we observe that the most persistent line is that at wave-length 2850, which is also the strongest in the flame and arc, and one of the strongest in the spark. The intensity of the radiation of magnesium at this wave-length is witnessed by the fact that this line is always reversed in the flame as well as in the arc when metallic magnesium is introduced into it, and in the spark between magnesium electrodes when a Leyden jar is used. It is equally remarkable for its power of

expansion. In the flame it is a broad band, and equally so in the arc when magnesium is freshly introduced, but fines down to a narrow line as the metal evaporates.

Almost equal in persistence are the series of triplets. Only the least refrangible pair of these triplets is seen in the flame, another pair is seen in the spark, but the complete series is only seen in the arc. We regard the triplets as a series of harmonics, and to account for the whole series being seen only in the arc we must look to some other cause than the temperature. This will probably be found in the greater mass of the incandescent matter contained in the crucible in which the arc was observed.

The blue line of the flame at wave-length 4570 is well seen in the arc, and is easily reversed, but is always a sharp line, increased in brightness but not sensibly expanded by putting magnesium into the crucible. In the spark, at atmospheric pressure, it is only seen close to the pole or crossing the field in occasional flashes; but seems to come out more decidedly at rather higher pressures, at least in hydrogen.

The series of bands near L, well developed in the flame, but not seen at all in the arc or spark, look very much like the spectrum of a compound, but we have not been able to trace them to any particular combination. Sparks in air, nitrogen, and hydrogen have alike failed to produce them. The very strong, rather diffuse triplet at M, with which they end, so closely resembles in general character the other magnesium triplets, that it may well be connected with that constitution of the magnesian particle which gives rise to the triple sets of vibrations in other cases, but, if so, its presence in the flame alone is not easily explained.

The occurrence of this triplet in the ultra-violet, and of the remarkable series of bands associated with it, as well as the extraordinary intensity of the still more refrangible line at wave-length 2850, which is strongly reversed in the spectrum of the flame, corroborates what the discovery of the ultra-violet spectrum of water had revealed, that substances at the temperatures of flames while giving in the less refrangible part of the spectrum more or less continuous radiation, may still give, in the regions of shorter wave-length, highly discontinuous spectra, such as have formerly been deemed characteristic of the highest temperatures. This subject we will not discuss further at present, but simply remark what we have stated formerly, that "it opens up questions as to the enormous power for radiation of short wave-length of gaseous bodies at the comparatively low temperature of flame with regard to which we are accumulating facts."

In the arc and spark, but not in the flame, we have next a very striking group of two very strong lines at wave-lengths about 2801 and 2794, and a quintuple group of strong but sharp lines above

them. The former are usually reversed in the spark with jar, and all are reversed in the arc when much magnesium is present. There are also several single lines in the visible part of the spectrum common to the arc and spark. All of these may be lines developed by the high temperature of the arc and spark. An indigo and a violet line in the arc have not been traced in the spark, but their non-appearance may be due to the same cause as that above suggested for the non-appearance of the higher triplets, the smallness of the incandescent mass in the spark.

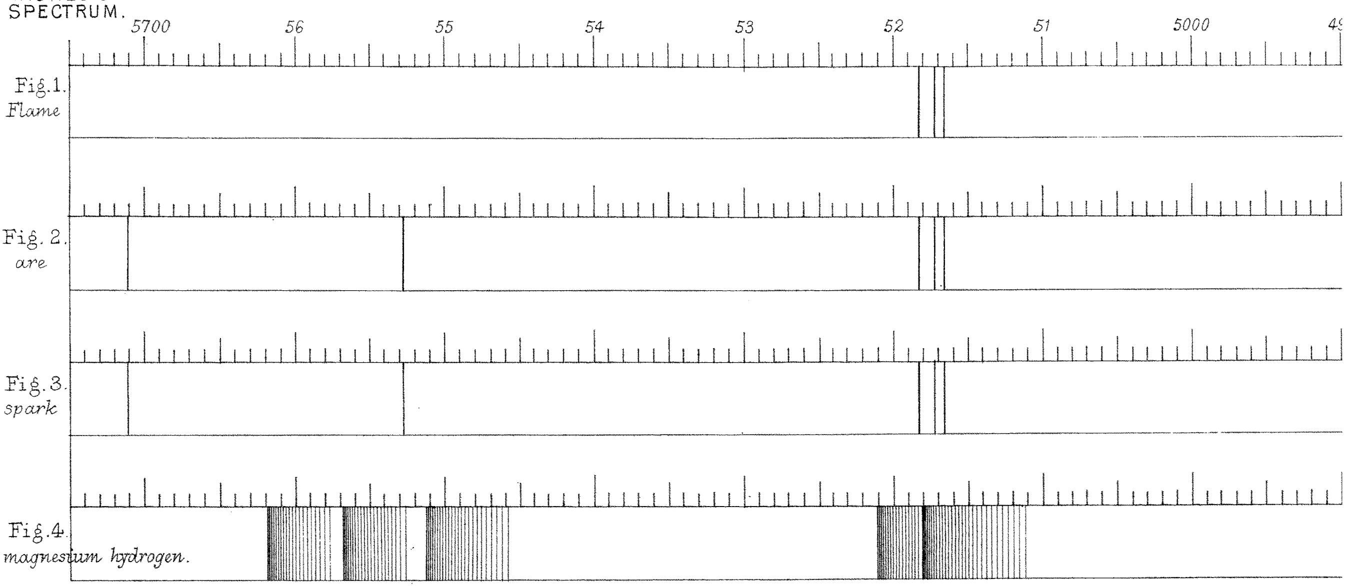
A pair of lines in the arc near U appear to be represented in the spark by an equally strong, or stronger, pair near but not identical in position. The possibility of such a shift, affecting these two lines only in the whole spectrum and affecting them unequally, must in the present state of our knowledge be very much a matter of speculation. Perhaps sufficient attention has not hitherto been directed to the probability of vibrations being set up directly by the electric discharge independently of the secondary action of elevation of temperature. Some of the observations above described, and many others well known, indicate a selective action by which an electric discharge lights up certain kinds of matter in its path to the exclusion of others; and it is possible that in the case of vibrations which are not those most easily assumed by the particles of magnesium, the character of the impulse may slightly affect the period of vibration. The fact that, so far as observations go, the shift in the case of this pair of magnesium lines is definite and constant, militates against the supposition suggested. On the other hand, the ghost-like pairs of lines observed in the spark below the triplet near L, suggest the idea that some of the particles have their tones flattened by some such cause.

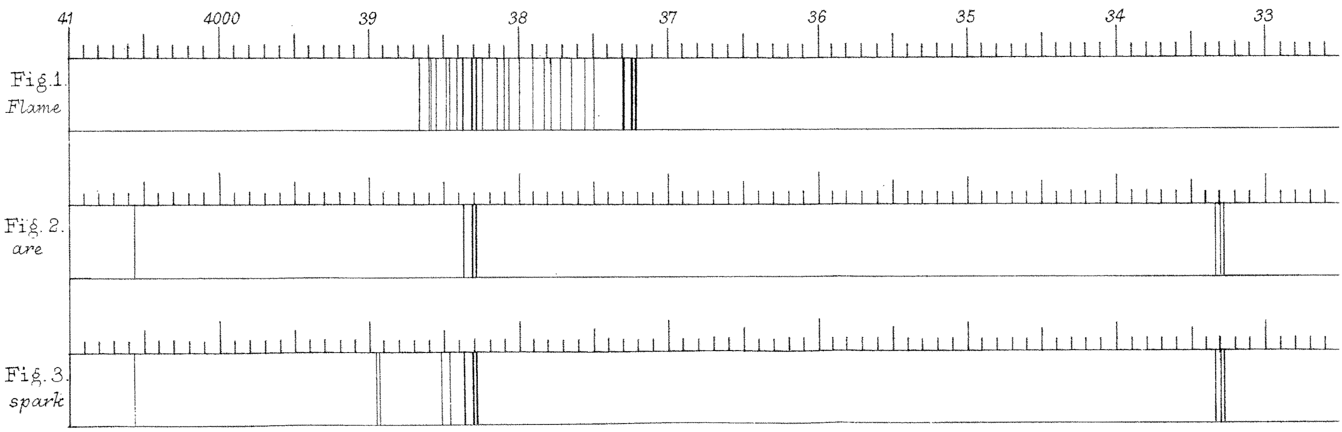
The strong pair at wave-length 2801, 2794, are accompanied in the spark, but not in the arc, by a much feebler, slightly more refrangible pair, but these have not the diffuse ghost-like character of those just alluded to.

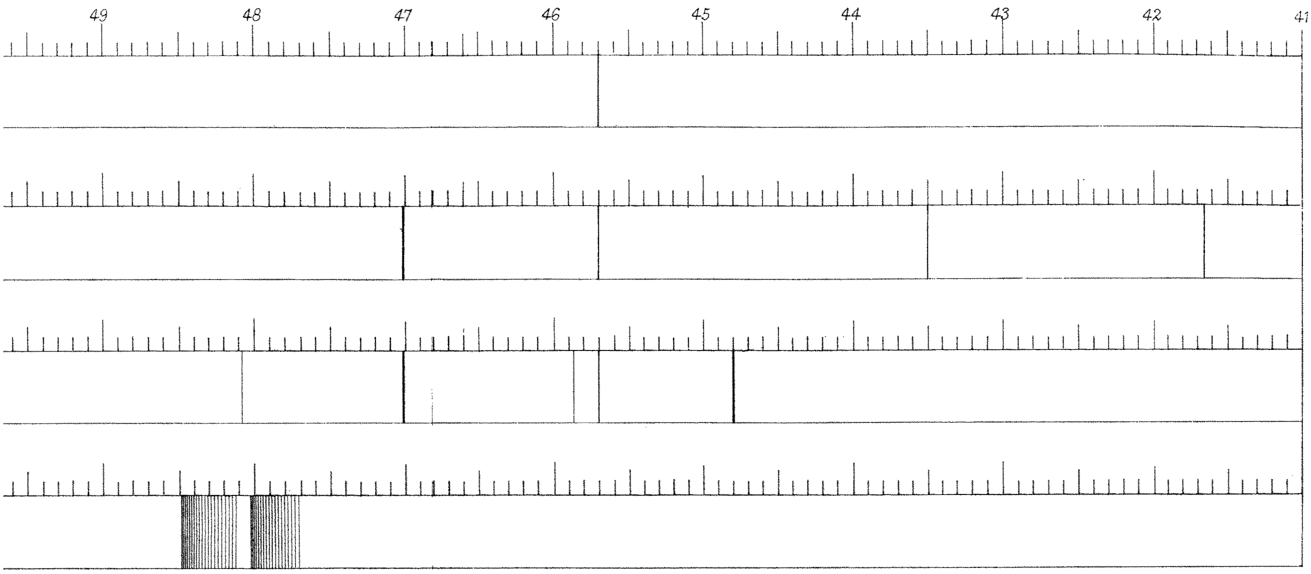
These lines are phenomena of the high potential discharge in which particles are torn off the electrodes with great violence, and may well be thrown into a state of vibration which they will not assume by mere elevation of temperature.

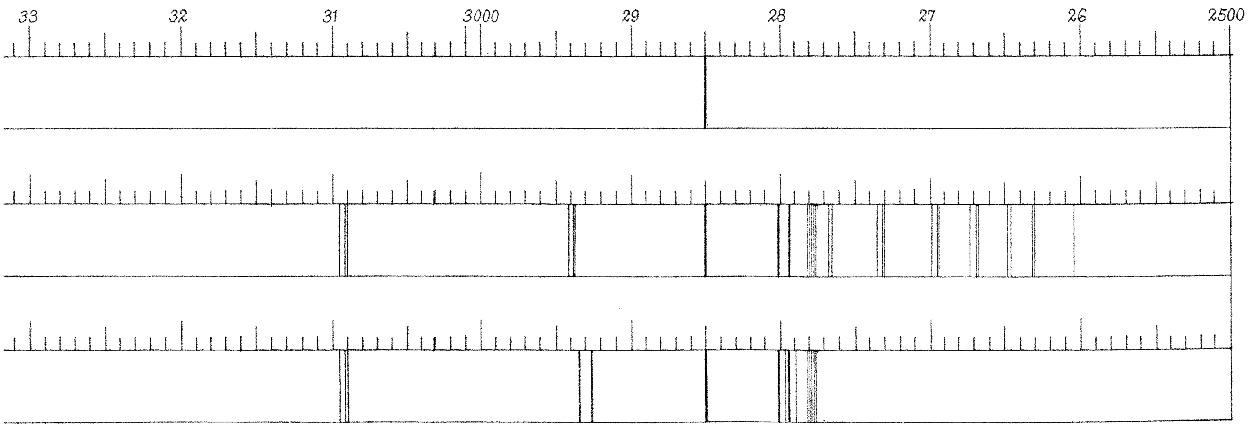
There are two lines in the spark besides the well-known line at wave-length 4481 which have not been observed in the arc, but they are feeble and would be insignificant if it were not the fact that they, as well as the line at wave-length 4481, all short lines seen generally only about the poles, appear to be present in the solar spectrum. In the sun we seem to have all the lines common to the flame, arc, and spark (unless the line given in Ångström's map at 4570·9 be not identical as we believe it to be with the magnesium line), and possibly, judging by Rutherford's photograph, the strong triplet of the flame at M; but one line common

MAGNESIUM SPECTRUM.









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to the arc and spark at wave-length 4703 does not appear in Ångström's map. It is hard to account for its absence, as it is present in Kirchhoff's map and in Rutherford's photograph. We have noticed, however, that when the spark is taken in hydrogen, the line at wave-length 4570 appears stronger than that at wave-length 4703, while the reverse is the case when the atmosphere is nitrogen. It is possible then that the atmosphere may, besides the resistance it offers to the discharge, in some degree affect the vibrations of the metallic particles.

When we have made all the simplifications that we can by eliminating, as we hope we have done satisfactorily, the hydrogen-magnesium flutings, and by supposing the whole series of triplets to be harmonically related, and possibly some of the single lines also to be similarly related, we have still the fact that the chemical atoms of magnesium are either themselves capable of taking up a great variety of vibrations, or are capable by mutual action on each other, or on particles of matter of other kind, of giving rise to a great variety of vibrations of the luminiferous ether; and to trace satisfactorily the precise connexion between the occurrence of the various vibrations and the circumstances under which they occur, will require yet an extended series of observations.

IV. "Note on the Reduction of the Observations of the Spectra of 100 Sun-spots observed at Kensington." By J. NORMAN LOCKYER, F.R.S. Received May 12, 1881.

[PLATE 2.]

In anticipation of a more detailed communication, I beg to lay before the Royal Society some of the results of the reduction of the six most widened lines between F and *b* seen in the spectra of 100 sun-spots, observed at Kensington between November 12th, 1879, and September 29th, 1880, limiting my remarks solely to the spectrum of iron.

In the accompanying map, the Fraunhofer lines agreeing in position with the iron lines given by Ångström and Thalén are entered in the horizon headed "Sun," in the next are plotted the lines assigned to iron by Ångström, who used the electric arc in his experiments. In the next horizon are entered the iron lines given by Thalén, who employed the induction coil in his experiments. In these three horizons the lengths of the lines represent their intensities.

The individual observations of the sun-spots having been plotted out on another map, the number of times each line was seen was ascertained, and is entered in the next horizon under "Frequencies in Sun-Spots."

FIG. 5.

Solar spectrum by Rutherford grating 4th order after M. Fievez.

Magnesium.

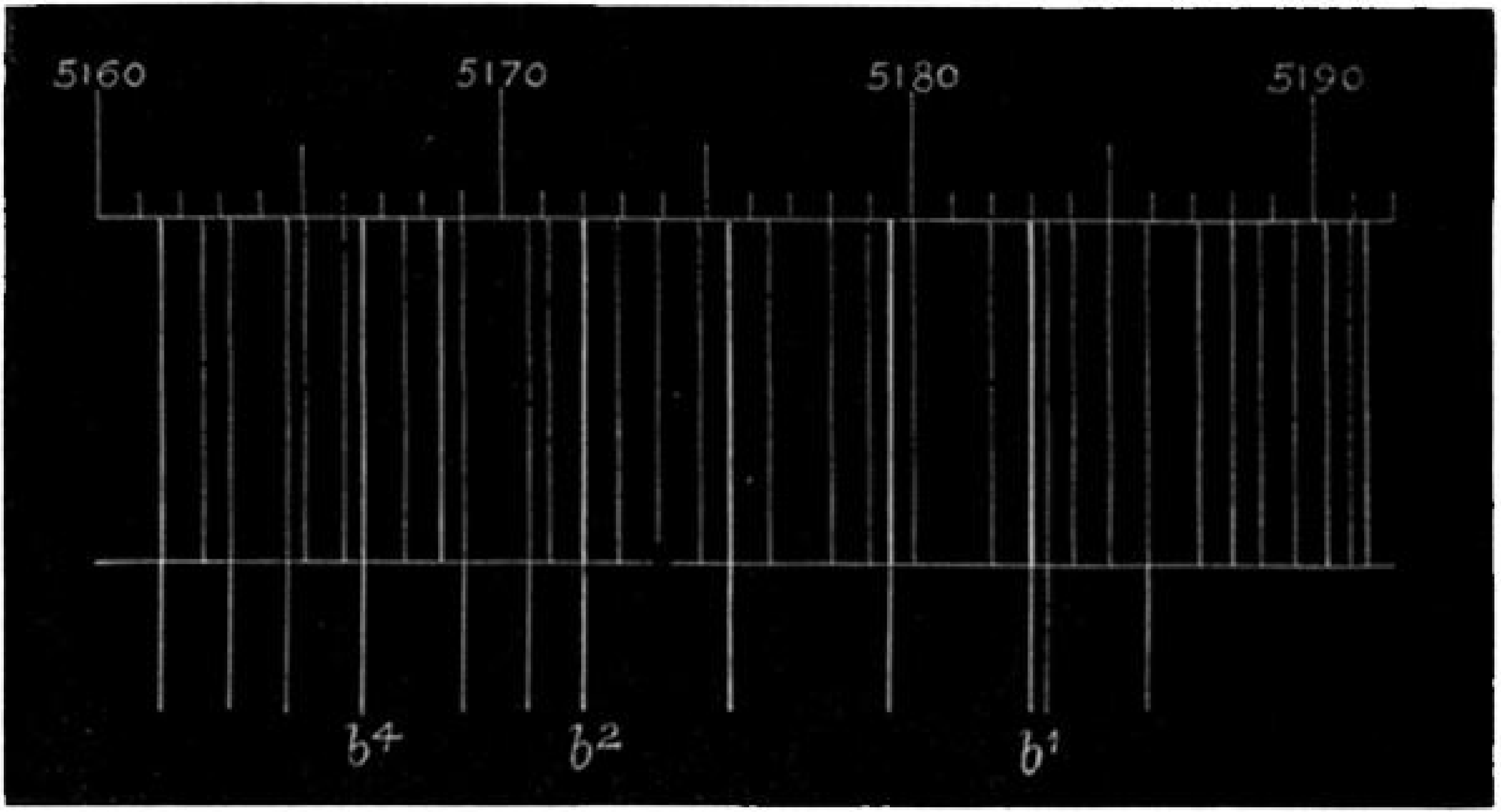
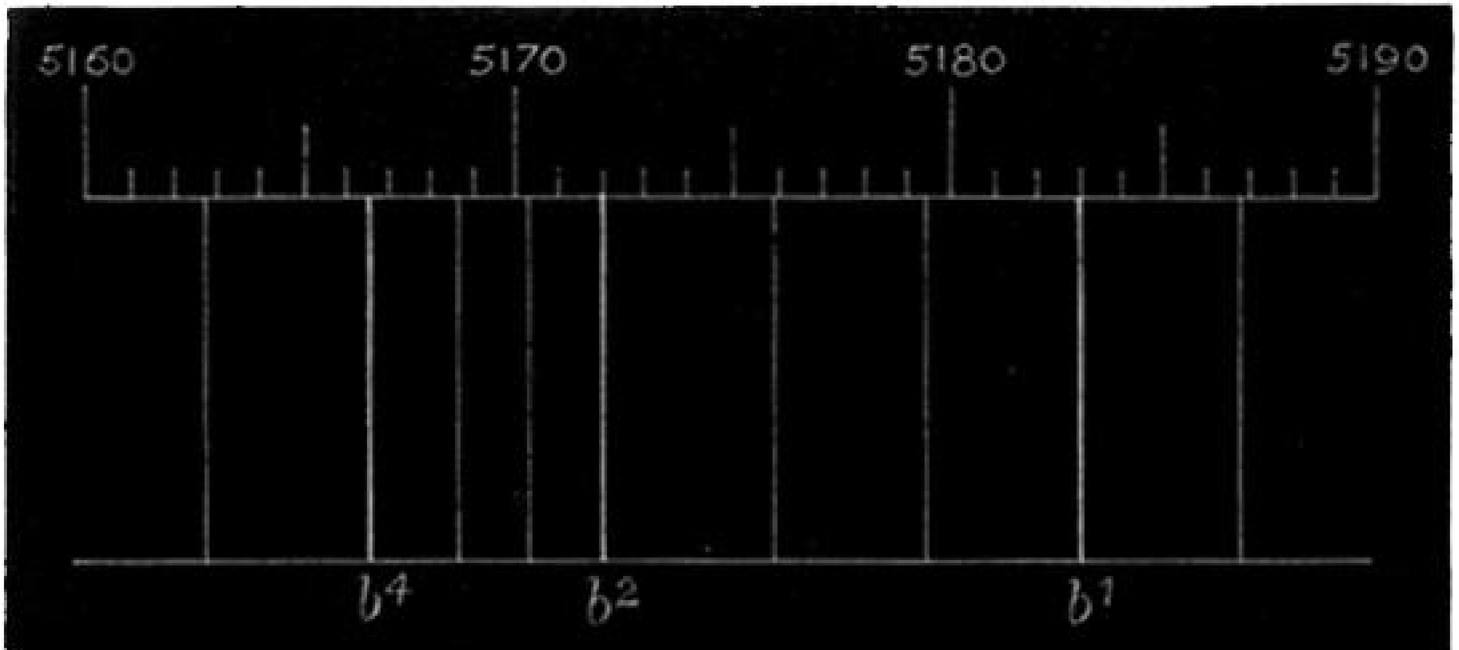
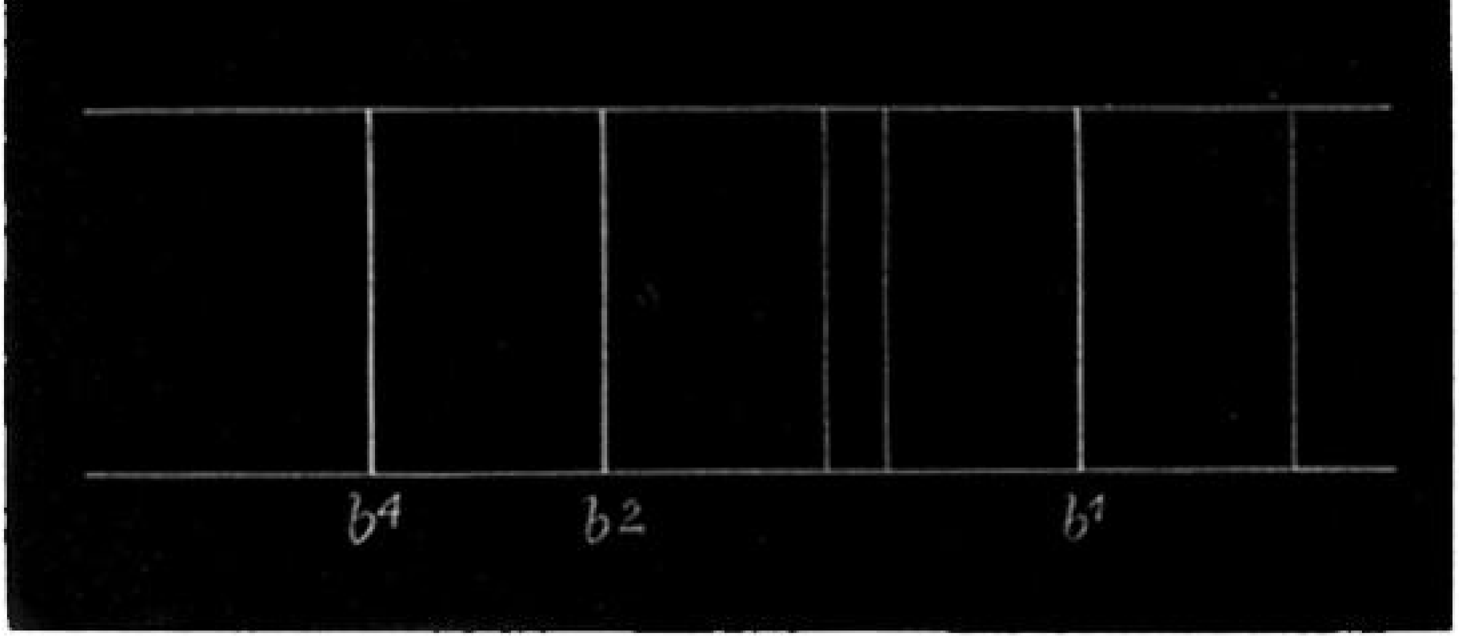


FIG. 7.

Magnesium *b* group with ghosts produced by Rutherford grating.

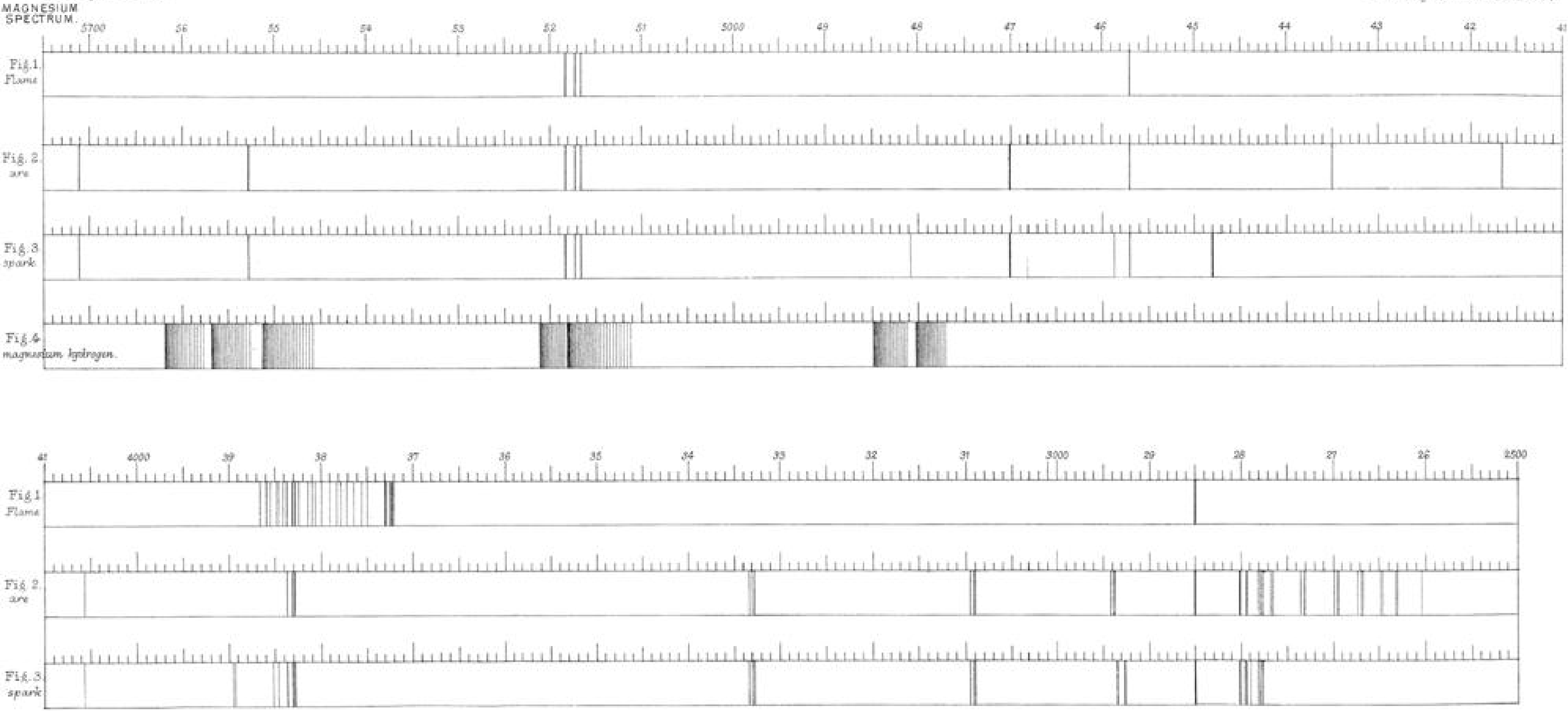


Spectrum of 4th order.



Spectrum of 3rd order.

FIG. 6.


MAGNESIUM SPECTRUM.
5700 56 55 54 53 52 51 5000 49 48 47 46 45 44 43 42 41
Fig.1. Flame
Fig. 2. arc
Fig. 3. spark
Fig. 4. magnesium hydrogen.
41 4000 39 38 37 36 35 34 33 32 31 3000 29 28 27 26 2500
Fig. 1. Flame
Fig. 2. arc
Fig. 3. spark