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On the Photographic Spectra of Meteorites

William Crookes

Phil. Trans. R. Soc. Lond. A 1918 **217**, 411-430
doi: 10.1098/rsta.1918.0011

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XI. *On the Photographic Spectra of Meteorites.*

By Sir William Crookes, *O.M., F.R.S., LL.D., D.Sc., &c.*

Received October 19,—Read November 2, 1916.

[Plates 19, 20.]

For several years I have been engaged on the spectrum analysis of Meteorites. Many meteoric specimens have come into my possession—through the kindness of friends—especially am I indebted to the Trustees of the Natural History Museum and to Dr. Prior, who presented me with specimens of such of the meteorites of which the quantity in their possession would not be appreciably diminished by the loss of the two or three grms. required for my experiments.

The Research is divided naturally into the examination of meteoric stones and meteoric irons. I propose at present to deal with meteoric stones or aerolites. These wonders of the sky consist generally of one or more silicates (mainly olivine and bronzite), interspersed with particles of nickeliferous iron, troilite, &c. Recent developments have led to many original devices and modification of details in the working spectrograph, thus furnishing information which may be of interest to those engaged on this branch of spectroscopic analysis.

As the whole value of the Research depends upon the excellence of my Spectrograph I propose to describe certain novel features of the Instrument. In previous papers I have already made brief reference to it, and therefore there is no need to describe it completely. It is peculiar in this respect; it has been devised and constructed in my laboratory for the work it was required to do, by a process of evolution, each part having been modified and improved as the work went on—thus in its present form it is the outcome of a great deal of experimental construction under working conditions. As an instance, I may say that the slit has been reconstructed at least six times—each change that the working conditions has rendered necessary making it more efficient until now it approaches perfection.

The Spectrograph.

The instrument was originally devised for the photography of the ultra-violet region, but was ultimately extended so as to include the visible spectrum down to the limit of sensibility of the commercial panchromatic plate which is in the neighbourhood of

 [Published, December 21, 1917.

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λ 7000 Å.U.; the two main aims in the whole construction were, first, that the definition of the lines should be pushed to the highest stage of perfection; secondly, that the mechanical construction should be such that the adjustments once made any number of spectra could be obtained without uncertainty in the excellence in definition. When I commenced to build the instrument, I was greatly assisted by the advice and suggestions of the late VICTOR SCHUMANN. Although the instrument is very different in design to any constructed by him, still the experience he had gained in his researches upon the spectroscopy of the ultra-violet region, which he freely placed at my disposal, was of the greatest possible value.

Having decided upon the general plan, the instrument was built up, first temporarily in wood, afterwards permanently in iron and gun-metal—and set to work. This was in February, 1899, and since then it has been in continual use; some thousands of photographs having been made. During this period each detail of the instrument has been subject to a process of evolution and reconstruction, each step leading to some advantage demanded by actual work.

The parts of the instrument are all assembled upon a large truly surfaced cast-iron table measuring 31 × 51 inches; the dispersion is given by five excellent double prisms made of right and left handed quartz, each double prism consisting of two halves made respectively of left and right handed quartz, prisms such as were first used by CORNU to avoid double refraction.

The objective and collimating lenses are simple planoconvex, 40 mm. in diameter and 700 mm. focus. The spectrum is thrown upon a celluloid film so curved that all the lines are at their true focus.

The dispersion by the five prisms is considerable, and with the collimating and object lenses used would involve a spectrum of some 24 inches in length. As there are both mechanical and optical reasons against the use of such a large sized plate it was decided to "build up" the complete spectrum in eight successive plates, involving a length of 3 inches for each step. The reason for this decision is simple; to obtain perfect definition of any line it must be in or very near to the "optical centre" of the instrument, *i.e.*, the imaginary line passing through the slit, the centre of the two lenses, the centres of the prisms, and the centre of the curvature of the plate: and it was found by many experimental photographs that the best definition over each three-inch film was obtained when the least refrangible line shown was in the position of minimum deviation. The many devices that from time to time have appeared in spectroscopic construction for rotating the prisms by link motion were rejected as uncertain and complicated—experiment having shown that the excellence of definition was maintained within a range of several inches on either side of the optical centre and position of minimum deviation. The exact "data" involving the focus, position of the spark, angle of the plate, and position of prisms and lenses to give the finest definition of the photographed lines were found experimentally, and when found their positions were engraved upon the instrument and recorded so that for future work

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the instrument could be quickly set to give a photograph in perfect detail for any desired portion of the spectrum.

The Slit.

The slit—of necessity one of the most important parts of the instrument—has been subject to more alteration and modification than any other portion. On account of the close proximity of my chemical laboratory I decided at the outset to avoid the use of steel for this purpose; on this point I differed from Prof. SCHUMANN, who was a strong advocate of hardened steel jaws, and all his splendid photographs were made with spectrographs having steel slits. I obtained good results by using rolled metallic cobalt—very hard and non-corrosive—ultimately I hit upon the plan of employing quartz instead of metal.*

I find this substitute answers so perfectly that I cannot imagine anything better.

At first I had great difficulty in getting the edge true. The sides and angle must be ground true and polished. It is difficult to fashion a knife-edge of quartz at an angle of 45°, because small splinters occasionally break off. Ultimately I got over this difficulty by putting a very narrow bevel on the front of the plate, so making the angle of each jaw 90°, thus (fig. 1):—

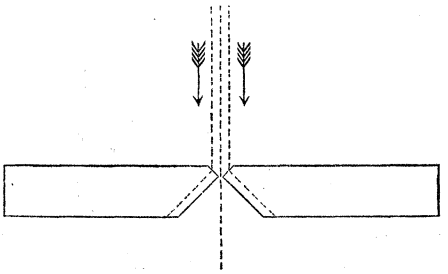

Fig. 1.

Owing to refraction no light can get through the part of the quartz which is cut at an angle. The edge made in this way is absolutely black and opaque even in sunlight, and should bear a high microscopic power without showing irregularity. To prevent light from coming through the flat part of the quartz plate, the surface, all but the extreme edge, is coated with gold by cathode deposition. It is very beautiful to see the absolute opacity and trueness of edge of one of these slits when examined under a high power.

Jaws made in this way have now been in continuous use for many years and give perfect satisfaction; they are absolutely unaffected by the atmosphere, can easily be cleaned, and with common care do not wear out.

The width of slit I use is small; for general work I use 0·008 mm. only, but for years this very fine width was a source of annoyance and anxiety, the reason being

* 'Chemical News,' No. 1846, vol. lxxi., p. 175, April 11, 1895.

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that it was necessary for purposes of adjustment, alignment of the spark, &c., to open the slit wide and then close it again. I found that even with the very best screws and construction there was always some uncertainty as to the absolute width of the slit used in any photograph—thus producing annoying variations in spectra, made at different times which should have been identical. During the first ten years of work many slits were constructed, each showing a slight improvement; even then the uncertainty was not completely removed and the mechanical construction had become deeply complicated. Ultimately the difficulties were removed by the device that I call the *Fixed* slit system. This device gives perfect satisfaction and has the advantage of extreme simplicity.

The Fixed Slit System.

Three such slits were prepared by taking brass blocks all of the same thickness, and upon each was permanently fixed a pair of quartz jaws set with openings of 0·008, 0·025, and 0·06 mm. respectively—these three widths being sufficient to embrace all the demands likely to occur.

The portion of the instrument upon which the slit is fixed is finished in the way shown in fig. 2; it carries two pointed pins, one of which appears marked C, a steel

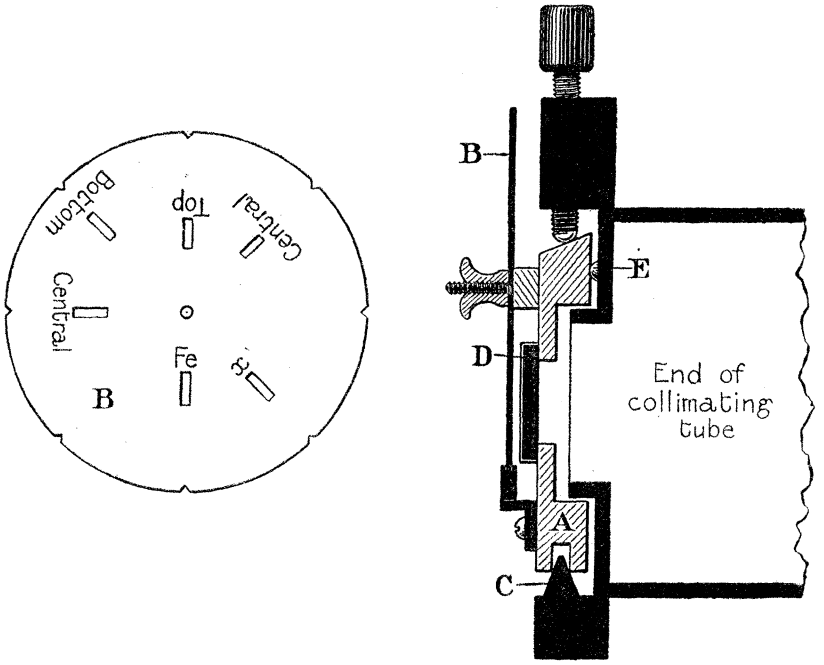

Fig. 2.

stop E, and a screw; the whole is closed to light except for a small rectangular central opening 1 mm. wide and 10 mm. long. A is one of the brass blocks carrying the quartz jaws D; this block can be instantly attached or removed by a slight turn

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of the screw, and by the "hole, slot, and plane" device its position is invariable, as can be seen.

In front of the slit and attached to its plate is a circular brass disc B; this disc completely covers the quartz jaws D; it is pierced with several openings, any one of which can, by a touch of the finger, be brought in front of the slit and held there by a spring which engages in a notch—(as shown below).

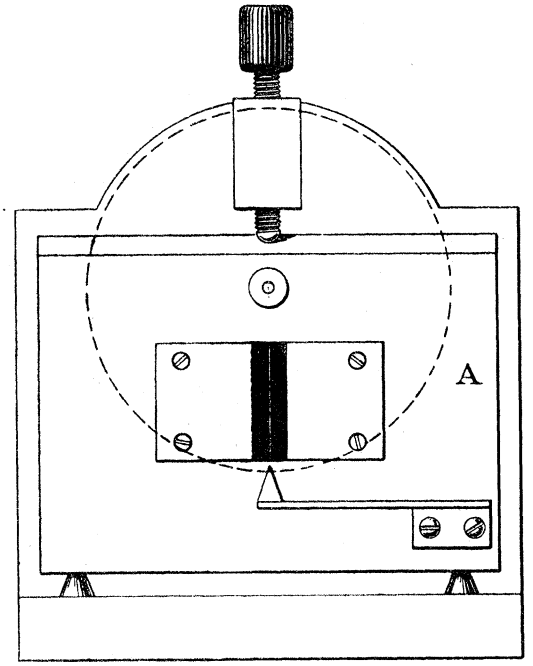

Fig. 3.

By these means light from various sources can be passed into the spectrograph through different portions of the slit and ultimately reaches the photographic film. For instance, in the particular work that forms the subject of this paper, the disc B is so fixed that the aperture marked Fe faces the slit, and the iron arc is projected upon it; then when a sufficient exposure has been given the disc is rotated so as to bring the aperture marked x opposite the slit, and the light from a silver-aerolite arc is passed in, the resulting photograph shows two spectra slightly overlapping, one of iron and the other of the silver-aerolite. No disturbance of the spectrograph or of the photographic film occurs during the operation.

A front view of the slit plate A is shown in plan in fig. 3; the dotted circle is the part covered by the disc.

The jaws do not wear or corrode. It is only necessary to clean and free them from dust by drawing between a sharply cut wedge of peg-wood.*

Before enumerating the metallic constituents of the aerolites I wish to place on

* Peg-wood splints are used by watchmakers to clean out pivot-holes in watches.

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record the outcome of a research which, although not giving the expected result, furnishes information that may be valuable.

In connection with the several theories as to the origin of Meteorites it was thought that a thorough examination of the occluded gases might possibly reveal the presence of some of the inert gases, or of those hypothetical elements thought to be present in some of the hotter stars. At the present time the manipulation and spectroscopic investigations of gases have reached a high state of development, and a far more thorough investigation of the subject is possible than was the case years ago when much work was done by Prof. A. W. Wright, of Yale College.*

It is now possible and comparatively easy to separate from the gaseous mixture liberated by heating the meteorite, the hydrogen, oxygen, carbon compounds, &c., whose presence is not indigenous, and to reveal any of the non-valent elements that may be present. One of the most popular methods is to employ the process of absorption by charcoal at low temperatures—the same method that has been employed with so much success upon the gases contained in spring waters, &c. There are, however, certain experimental and manipulative difficulties that I wished to avoid.

Some years ago Frederick Soddy, Esq., F.R.S., published an account of a device in which the absorption by metallic calcium at its volatilisation temperature was made to answer the same purpose.†

Soddy's vacuum furnace, although a very ingenious piece of apparatus, is too elaborate for my purpose—so while adopting the principle I have modified the details.

The calcium cut into small fragments is placed in a small vessel of iron open at one end like a miniature test-tube and introduced into a similar but larger tube of fused quartz; it is then only necessary to attach the quartz tube to the pump and gas apparatus, and by applying a Meker burner so as to heat it to full redness the volatilisation of the calcium and subsequent absorption of the chemically valent gases are entirely under control.

By this means the gases—obtained by heating to redness each of the aerolites—were examined spectroscopically at different pressures. Fig. 4 gives an outline of the apparatus actually used. A special and simple form of Sprengel pump was made as shown, so that if needful it could be replaced by a new one for each meteorite. A is the vacuum tube; B the quartz tube with the iron vessel containing lumps of clean metallic calcium; C, a tube of hard glass, with the powdered aerolite; D, phosphoric acid to absorb moisture; E, an inverted tube filled with mercury in which any gas not used could be collected.

The procedure was to exhaust thoroughly, and well spark the vacuum tube so as to expel any gas occluded in the electrodes, and continue the exhaustion until the

* 'American Journal of Science and Arts,' 3rd series, 1876, p. 253.

† 'Proceedings of the Royal Society,' vol. 78, series A, 1907.

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tube ceased to conduct the current. The aerolite was then heated so as to expel the occluded gases, the pump set going, and the spectrum of the gas examined at various pressures down to about 20 mm.—when the pumping was stopped.

The calcium tube B was now strongly heated with a "Meker" burner; at first the gauge was depressed owing to gas liberated by the heat, and then absorption suddenly took place, and the gauge ran up to one or two millimetres or less. The spectrum was kept under examination the whole time, and for convenience the spectrum given by helium was thrown on to the eye-piece by means of a right-angled prism, so that any indication of D_3, however faint, could be instantly observed.

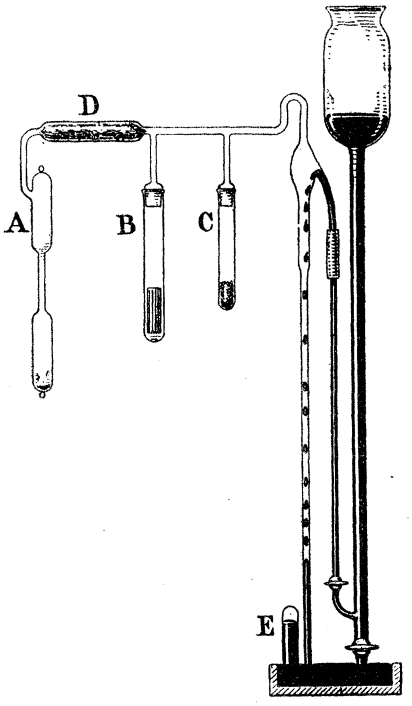

Fig. 4.

Working in this way no indication whatever was found of the lines of any of the inert gases. The absorption in each case could be carried until the tube refused to conduct the current. The final lines observed before the tube ceased to be luminous were those of mercury—generally accompanied by a faint trace of the red line of hydrogen.

In each aerolite examination—after having satisfied myself of the absence of unabsorbable gases—a further quantity of gas was driven out by heat and the pressure adjusted to about 2 mm., the vacuum tube being sealed off at this pressure and kept with full particulars of its source for future reference.

The amount of gas that could be driven out of the aerolites by heat varied considerably. In some cases it was possible to expel several successive volumes of gas and each time to repeat the absorption by calcium; in other cases the amount

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of occluded gases was much less, but in all cases the calcium absorption was done at least twice, so that a very minute percentage of the inert gases would have been rendered visible.

When all the aerolites had been examined a final experiment was made to prove the efficiency of the method. A little samarskite was powdered and treated in the same way. On absorbing the liberated gases by heating the calcium—as soon as the pressure had been reduced to a few millimetres—the complete spectrum of helium was revealed.

The only gases recognised were the compounds of carbon hydrogen, and in one or two cases only H_2S; this latter is somewhat remarkable, as at the time its spectrum appeared to be novel; the other aerolites were most carefully examined for it without success.

It was found impossible to get an induction spark to pass between two fragments of an aerolite, so attempts were made to make use of an arc. A fragment of the stone was ignited in a cup hollowed out of the lower carbon pole—the upper electrode being a carbon rod. As shown in fig. 5, if an arc was struck between the two carbons by momentary contact with a third rod of carbon, the fragment of stone quickly became hot and ultimately fused and formed a molten sphere; the arc could then be maintained between this sphere and the upper carbon. Photographs were obtained of the resulting arc and the spectra of several of the meteoric stones examined. The plan followed was to arrange three stops or apertures that could be adjusted in front of the slit, and by their aid to project upon the photographic film, first the spectrum given by iron; then the spectrum of the aerolite ignited between two poles of carbon; and below that the spectrum given by carbon poles alone. In this way it was easy to observe any lines in the aerolite spectrum that did not appear in either the iron or the carbon, and thus the composition could be determined. This method was not altogether satisfactory owing to impurities in the carbon rods and the consequent uncertainty of some of the observed lines being due to constituents of the aerolite or to impurities in the carbon. I therefore tried other means.

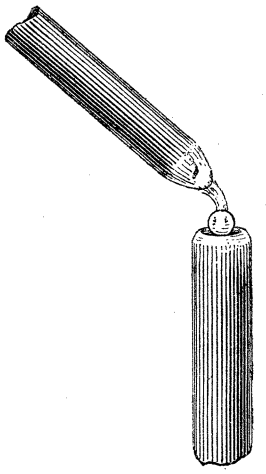

Fig. 5.

The aerolite was finely powdered and mixed with a metallic powder, the composition of which was known. The mixture was strongly compressed in a hydraulic press, and from the solid mass thus obtained a pair of poles were fashioned.

Iron was one of the first metals used for experiment, but was discarded owing to the fact that iron is a plentiful constituent of stony meteorites. Silver was finally chosen because of the comparative ease of getting it pure—also because the lines in any part of its arc spectrum are few in comparison with the lines of iron which are

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exceedingly numerous all along the spectrum. Moreover, the softness of silver makes it easy to get strongly coherent poles from its mixture with the aerolite. The silver powder I used was specially prepared by a method given to me by Dr. A. Scott, F.R.S. The purest commercial silver was dissolved in nitric acid, the solution evaporated to dryness in a silica crucible, and the solid residue fused till any copper nitrate which might be present was decomposed. The mass was extracted with water, and the filtered solution of silver nitrate precipitated by means of a boiling solution of ammonium formate and acetate into which the silver solution was slowly run. After the liquid had become brilliantly clear and the silver well agglomerated, the metal was thoroughly washed and dried. The aerolite in fine powder was mixed with an equal weight of the silver, and the mixture slightly damped and compressed into a block in a hydraulic press at a pressure of 250 atmospheres. The resulting cake—after drying—was raised to dull redness, and was then cut across to form two poles between which to form the electric arc. The poles were mounted in special clips in a mechanical arrangement to enable the arc to be accurately focussed on the slit and kept there during the exposure.

The Arc Spectrum of an Aerolite.

In order to identify the different elements present I have worked by a method unlike that adopted by most observers. Instead of measuring the wave-lengths of the lines and establishing their identity by reference to published tables of wave-lengths, I have made it a rule to obtain, first, a qualitative idea of the constituents present, then to photograph the spectrum of the aerolite and silver mixture in juxtaposition with that of each suspected element by a device already described. In this way I have been able with certainty to identify every line in the spectrum of each aerolite examined. This removes the uncertainty due to irregularities in the determination of wave-lengths by different observers. I can take no responsibility for the accuracy of the figures by which I identify these lines; they are copied from the most recent and trustworthy sources—had it been possible to reproduce the actual photographed spectra that I am now exhibiting there would have been no need to have printed any figures at all. The spectrum of the aerolite is easily distinguished from the mixed silver and aerolite spectrum by reference to a photograph of the silver taken separately.

The advantage of my method becomes apparent if—for illustration—I take one element—nickel—common to all meteorites. In the range of my instrument there are no less than three hundred and forty strong lines which I have identified, and on the aerolite spectrum I have marked all the nickel lines that can be seen, together with the wave-length given in the most recent determination—but the *point* is that any line marked is actually present as found by reference to the spectrum of pure nickel, and does not rest upon a coincidence of figures.

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Examination of the Arc Spectra of Thirty Aerolites.

List of aerolites thus far examined :—

L'Aigle (from Orne, France).

The photographed spectrum of this aerolite extends from λ 2973 to λ 5896, and includes in addition to the lines of iron 2 aluminium, 1 calcium, 23 chromium, 3 magnesium, 3 manganese, 27 nickel, 2 potassium, 6 sodium.

Alfianello (from Brescia, Italy).

The photographed spectrum extends from λ 3018 to λ 6643, and includes in addition to the lines of iron 1 aluminium, 2 calcium, 23 chromium, 2 magnesium, 3 manganese, 40 nickel, 6 sodium.

Aubres (from Nyons, Drôme, France).

There was great difficulty in maintaining the arc. The photographed spectrum extends from λ 2507 to λ 5896, and contains in addition to the lines of iron 10 chromium, 6 magnesium, 3 manganese, 6 nickel, 4 silicon, 2 sodium.

Baroti (from Bilaspur, Simla, Punjab, India).

The photographed spectrum extends from λ 2851 to λ 5896, and shows in addition to the lines of iron 2 aluminium, 2 calcium, 25 chromium, 2 magnesium, 3 manganese, 2 potassium, 4 sodium, 38 nickel.

Barratta (from Deniliquin, New South Wales).

The photographed spectrum of this aerolite extends from λ 2853 to λ 5206, and shows in addition to the lines of iron 2 aluminium, 2 calcium, 26 chromium, 3 magnesium, 3 manganese, 29 nickel, 2 sodium.

Bustee (from India).

This aerolite behaves in a very similar way to El Nakhla el Baharia, and it was only possible to obtain one photograph. Very few lines were found, and these were chiefly those due to chromium and magnesium; the lines of nickel cannot be seen. In addition to the lines of iron the following were identified between λ 2852 and λ 4289, 2 calcium, 10 chromium, 6 magnesium, 3 manganese, 2 sodium.

Chandakapur (from Berar, India).

This is a very rare aerolite, and as I had only 2·184 grm. of the material very great care had to be taken in obtaining the spectrum.

The photographed spectrum extends from λ 2507 to λ 6643, and contains in addition to the lines of iron 1 aluminium, 3 calcium, 36 chromium, 7 magnesium, 3 manganese, 43 nickel, 6 silicon, 6 sodium.

Chantonnay (from Vendée, France).

The photographed spectrum of this aerolite commences at λ 2551 and extends to λ 5896, and contains in addition to the lines of iron 2 aluminium,

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1 calcium, 18 chromium, 2 magnesium, 3 manganese, 27 nickel, 2 potassium, 6 sodium.

Chateau-Renard (from Triguères, Loiret, France).

The photographed spectrum of this aerolite extends from λ 3230 to λ 5896, and includes in addition to the lines of iron 2 calcium, 28 chromium, 2 magnesium, 3 manganese, 44 nickel, 2 potassium, 6 sodium.

Crumlin (from County Antrim, Ireland).

The quantity of material in this case was small, the lines in the photographed spectrum extend from λ 2967 to λ 5896, and includes in addition to the lines of iron 2 aluminium, 31 chromium, 2 magnesium, 3 manganese, 38 nickel, 6 sodium.

Dandapur (from Goruckpur, North-West Provinces, India).

The photographed spectrum of this aerolite commences at λ 3002 and extends to λ 5896, and includes in addition to the lines of iron 1 calcium, 24 chromium, 2 magnesium, 3 manganese, 47 nickel, 2 potassium, 4 sodium.

Daniel's Kuil (from Griqualand East, South Africa).

The photographed spectrum of this aerolite commences at λ 2788 and ends at λ 6634, and includes in addition to the lines of iron 1 aluminium, 30 chromium, 3 magnesium, 3 manganese, 49 nickel, 6 sodium.

Dhurmsala (from Kangra, Punjab, India).

The whole of the material available, 5 grm., was used and the photographed spectrum extended from λ 2795 to λ 6643, and includes in addition to the lines of iron 2 calcium, 28 chromium, 5 magnesium, 3 manganese, 38 nickel, 2 potassium, 6 sodium.

Durala (from Kurnal, Punjab, India).

The photographed spectrum of this aerolite extends from λ 2975 to λ 5896, and includes in addition to the lines of iron 2 calcium, 19 chromium, 4 magnesium, 3 manganese, 37 nickel, 2 potassium, 4 sodium.

Eli Elwah (Hay, Waradgery County, New South Wales).

The photographed spectrum extends from λ 3246 to λ 4957, and includes in addition to the lines of iron 7 chromium, 2 magnesium, 3 manganese, 27 nickel, 2 sodium.

El Nakhla el Baharia (from Alexandria, Egypt).

This very soft stone when mixed with silver powder and compressed into a block proved to be very fusible and the arc could only be maintained for a few seconds, three short exposures only were obtained, and these were not sufficient to bring out the nickel lines.

The photographed spectrum extends from λ 3466 to λ 5896, and includes in

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addition to the lines of iron 9 chromium, 2 magnesium, 3 manganese, 2 potassium, 4 sodium.

Futtehpur (from North-West Provinces, India).

The photographed spectrum extends from λ 2852 to λ 5896, and includes in addition to the lines of iron 2 aluminium, 3 calcium, 31 chromium, 4 magnesium, 3 manganese, 48 nickel, 2 potassium, 4 sodium.

Gilgoin (from Brewarrina, Clyde County, New South Wales).

The lines shown in the photographed spectrum of this aerolite extend from λ 2598 to λ 5896, and includes in addition to the lines of iron 3 calcium, 24 chromium, 6 magnesium, 3 manganese, 37 nickel, 2 potassium, 6 sodium.

Girgenti (from Sicily).

The photographed spectrum extends from λ 2852·2 to λ 5896, and includes in addition to the lines of iron 2 aluminium, 2 calcium, 25 chromium, magnesium, 3 manganese, nickel, 2 potassium, 4 sodium.

Gnarrenburg (from Hanover, Prussia).

The photographed spectrum of this aerolite extends from λ 2714 to λ 5896, and includes in addition to the lines of iron 2 aluminium, 3 calcium, 31 chromium, magnesium, 3 manganese, 50 nickel, 2 potassium, 6 sodium.

Hvittis (from Abo, Finland).

The photographed spectrum of this aerolite commences at λ 2852 and extends to λ 5896; it includes in addition to the lines of iron 1 calcium, 30 chromium, 3 magnesium, 3 manganese, 31 nickel, 4 sodium.

Jelica (from Servia).

The photographed spectrum of this aerolite commences at λ 2852 and extends to λ 5896, and includes in addition to the lines of iron 1 calcium, 29 chromium, 3 magnesium, 3 manganese, 34 nickel, 2 potassium, 4 sodium.

Jhung (from Punjab, India).

The lines shown in the photographed spectra extend from λ 2883 to λ 5896, and includes in addition to the lines of iron 2 aluminium, 2 calcium, 22 chromium, 3 magnesium, 3 manganese, 43 nickel, 2 potassium, 6 sodium.

Kansada (from Ness County, Kansas, U.S.A.).

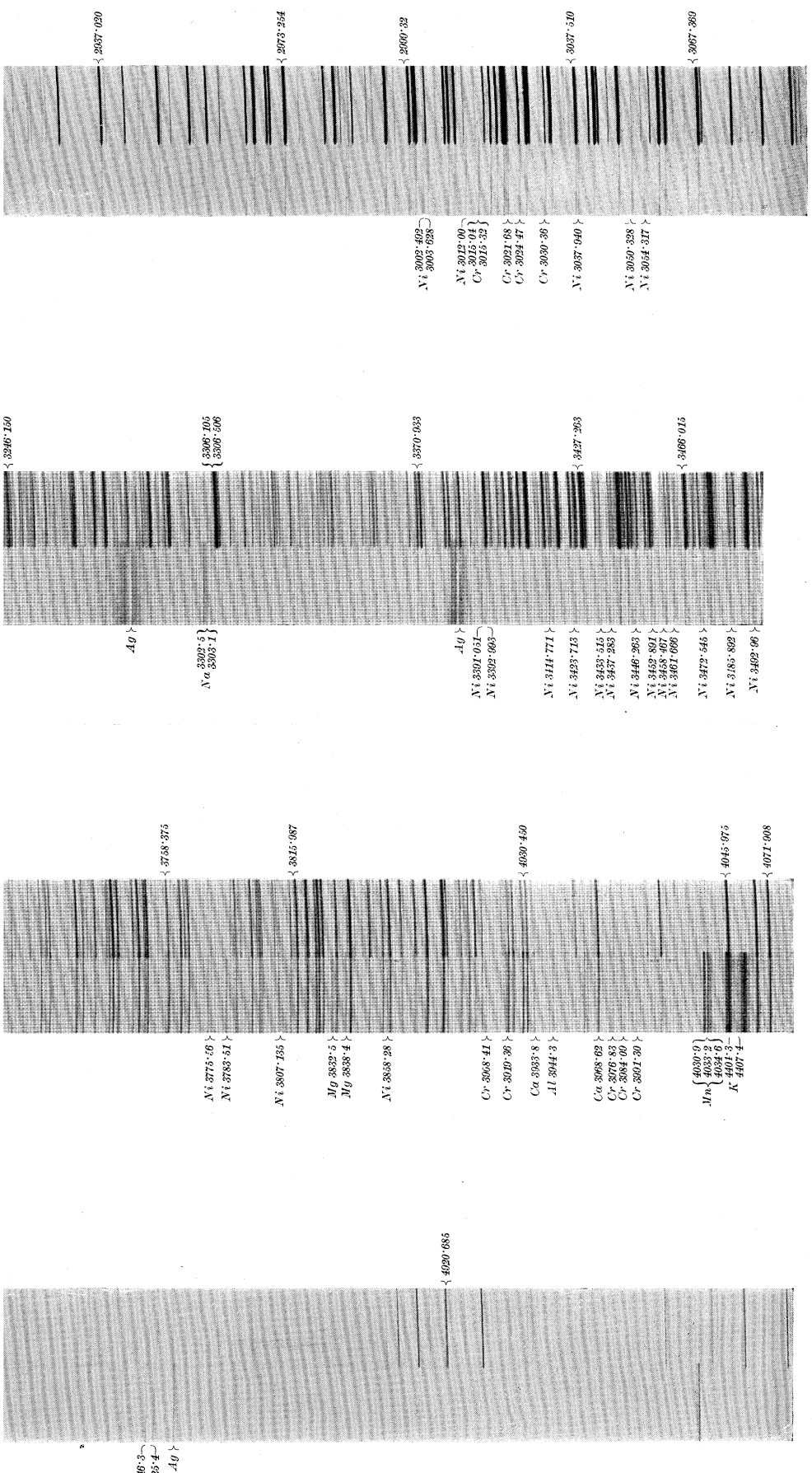
The photographed spectrum of this aerolite commences at λ 2852 and extends to λ 4652, and includes in addition to the lines of iron 1 calcium, 26 chromium, 1 magnesium, 3 manganese, 45 nickel, 4 sodium.

Khairpur (from India). (See Plate 19.)

The photographed spectrum of this aerolite commences at λ 2852 and ends at λ 5896, and includes in addition to the lines of iron 2 aluminium, 3 calcium, 29 chromium, 4 magnesium, 3 manganese, 41 nickel 2 potassium, 6 sodium.

THE ARC SPECTRUM OF THE AEROLITE KHAIRPUR (

PUR (+Ag) COMPARED WITH IRON.



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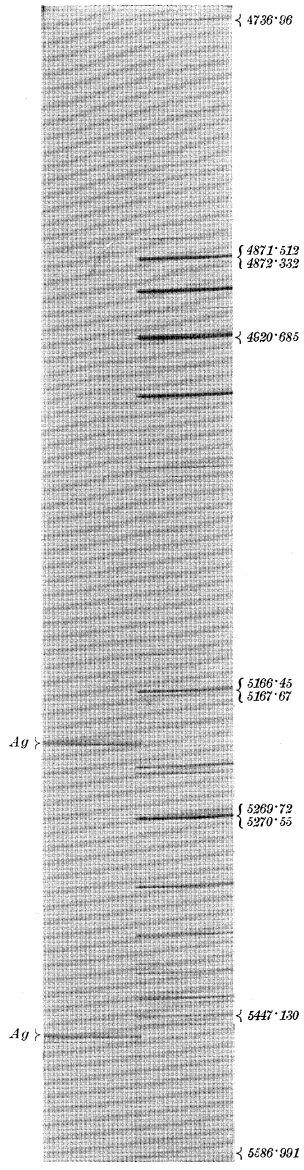
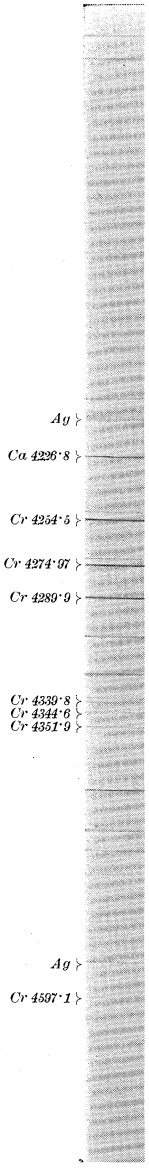
ROLITE



ROLITE



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

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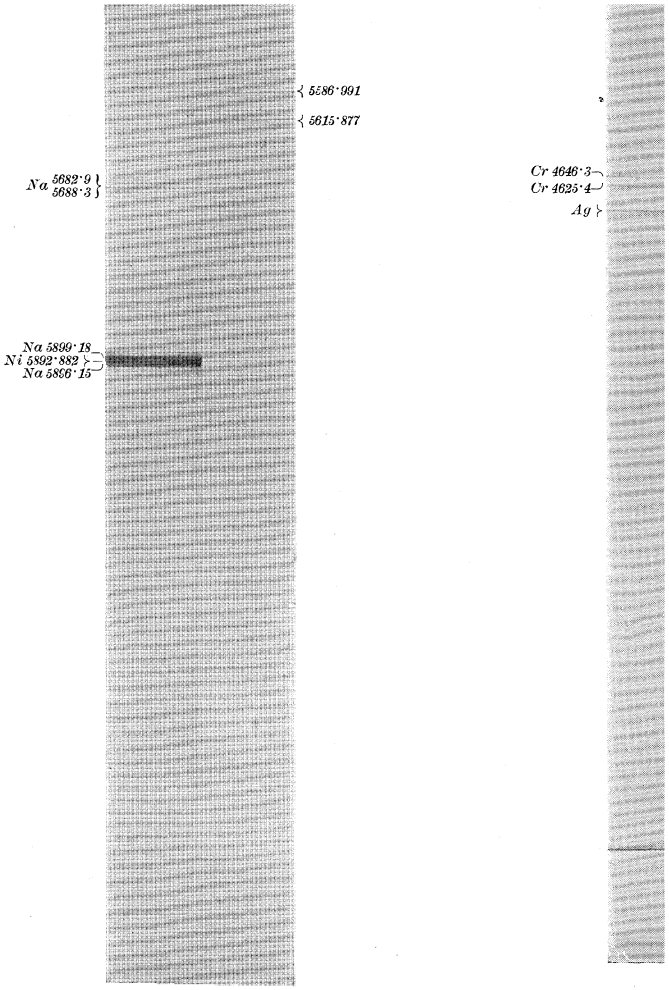
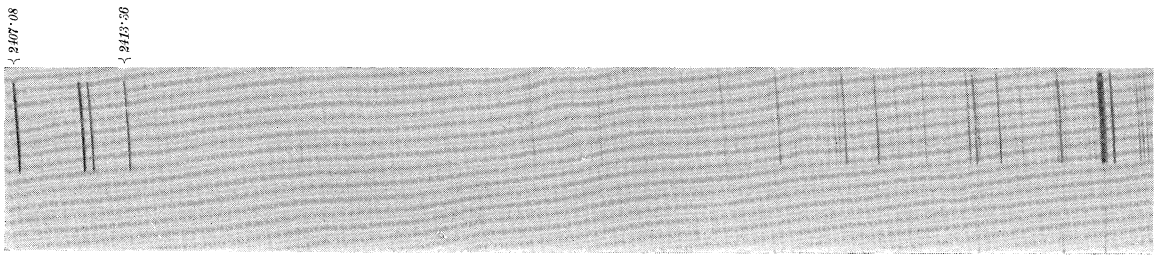
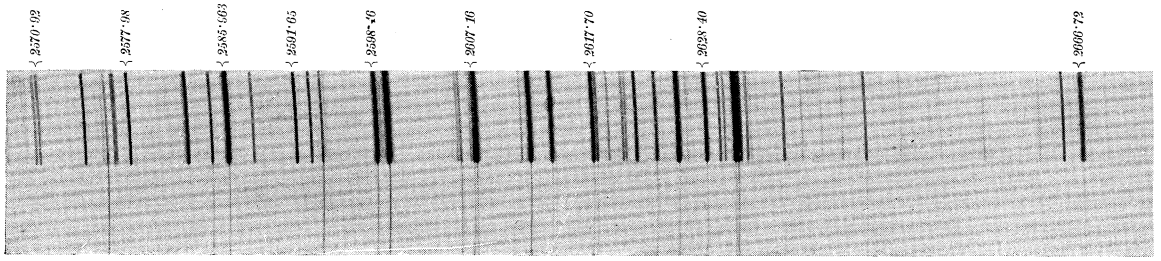


THE ARC SPECTRUM OF THE AEROLITE MT. DYRRING

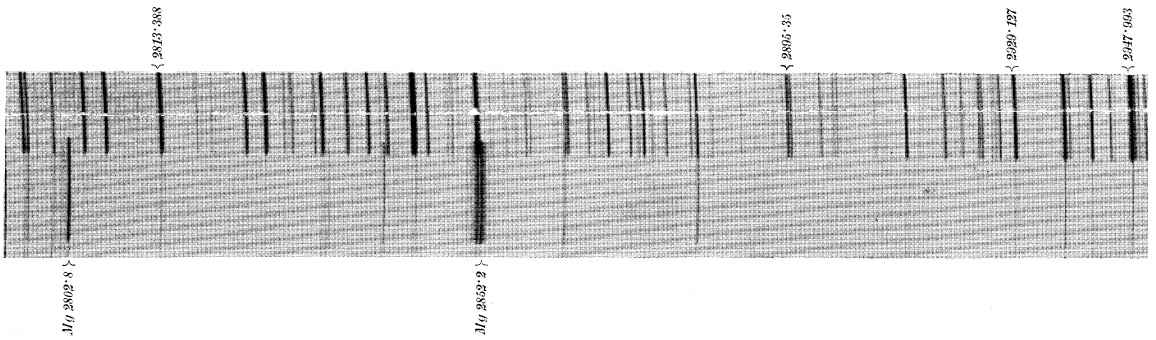
OLITE



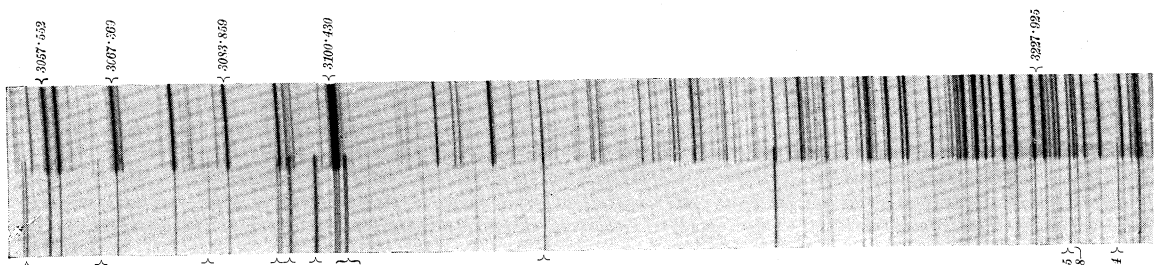
OLITE



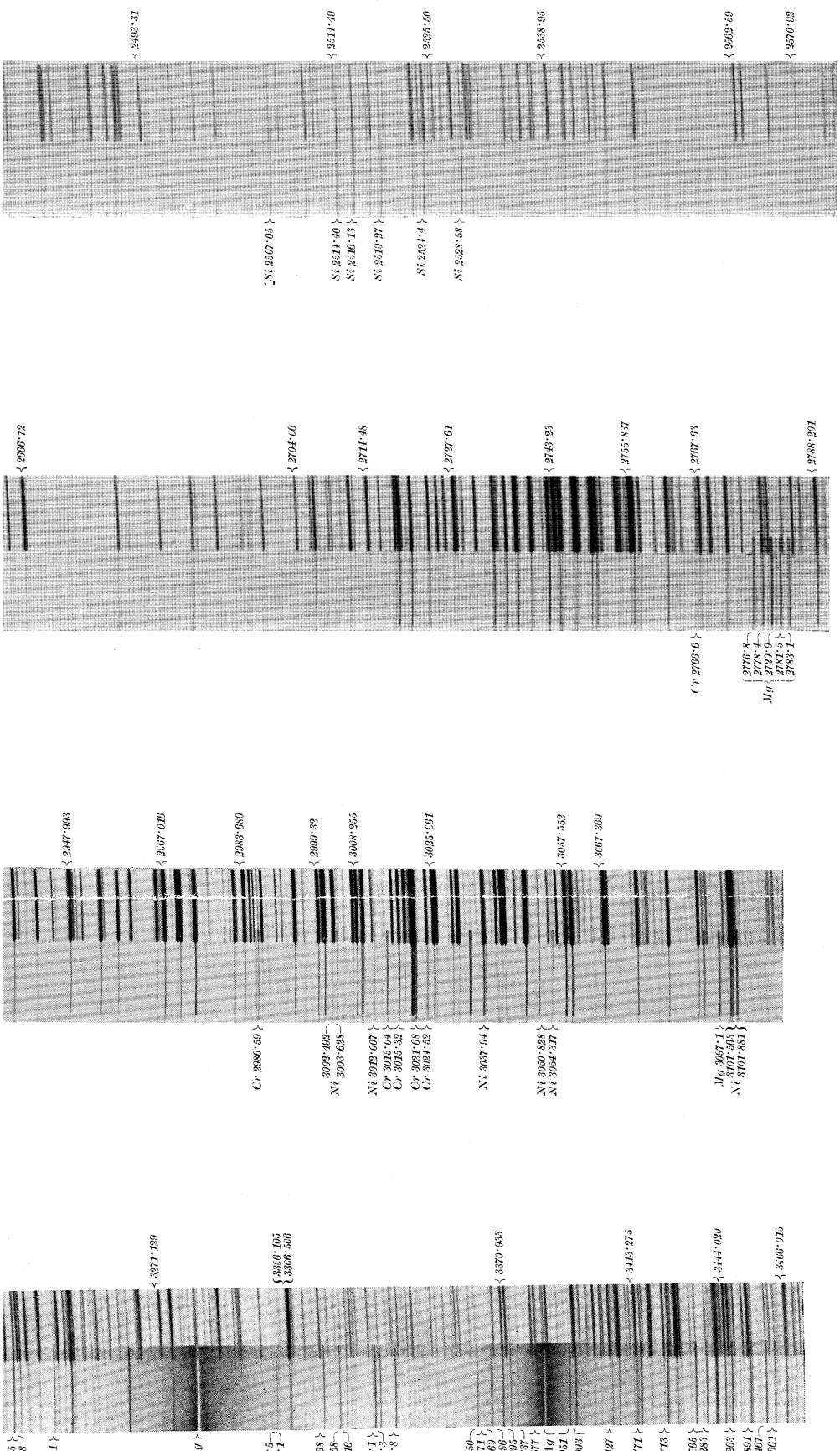
OLITE



OLITE

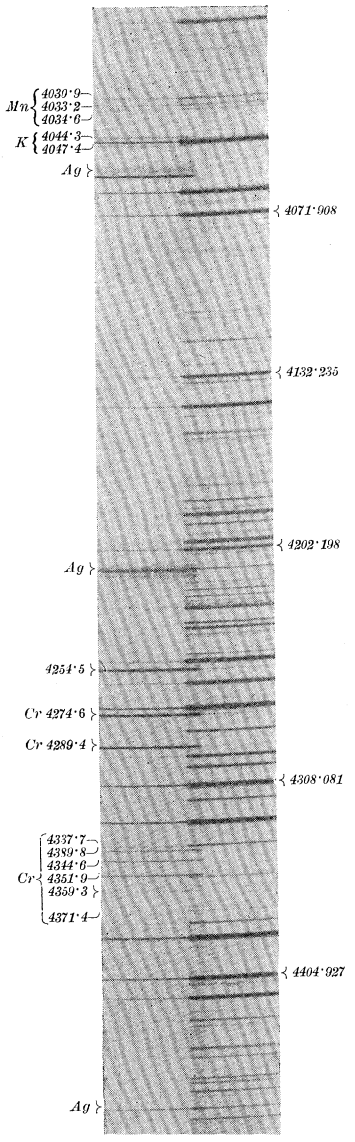


RING (+Ag) COMPARED WITH IRON.

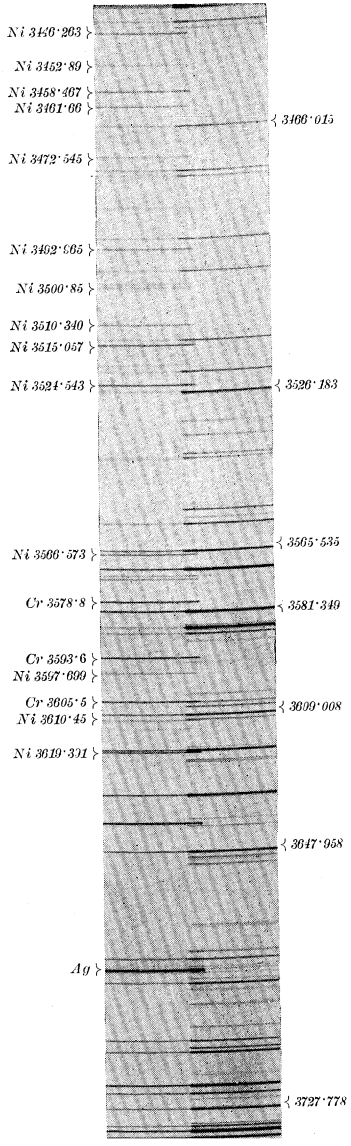


PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

OLITE



OLITE



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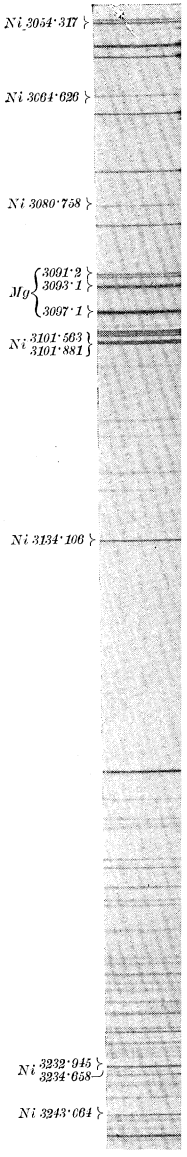
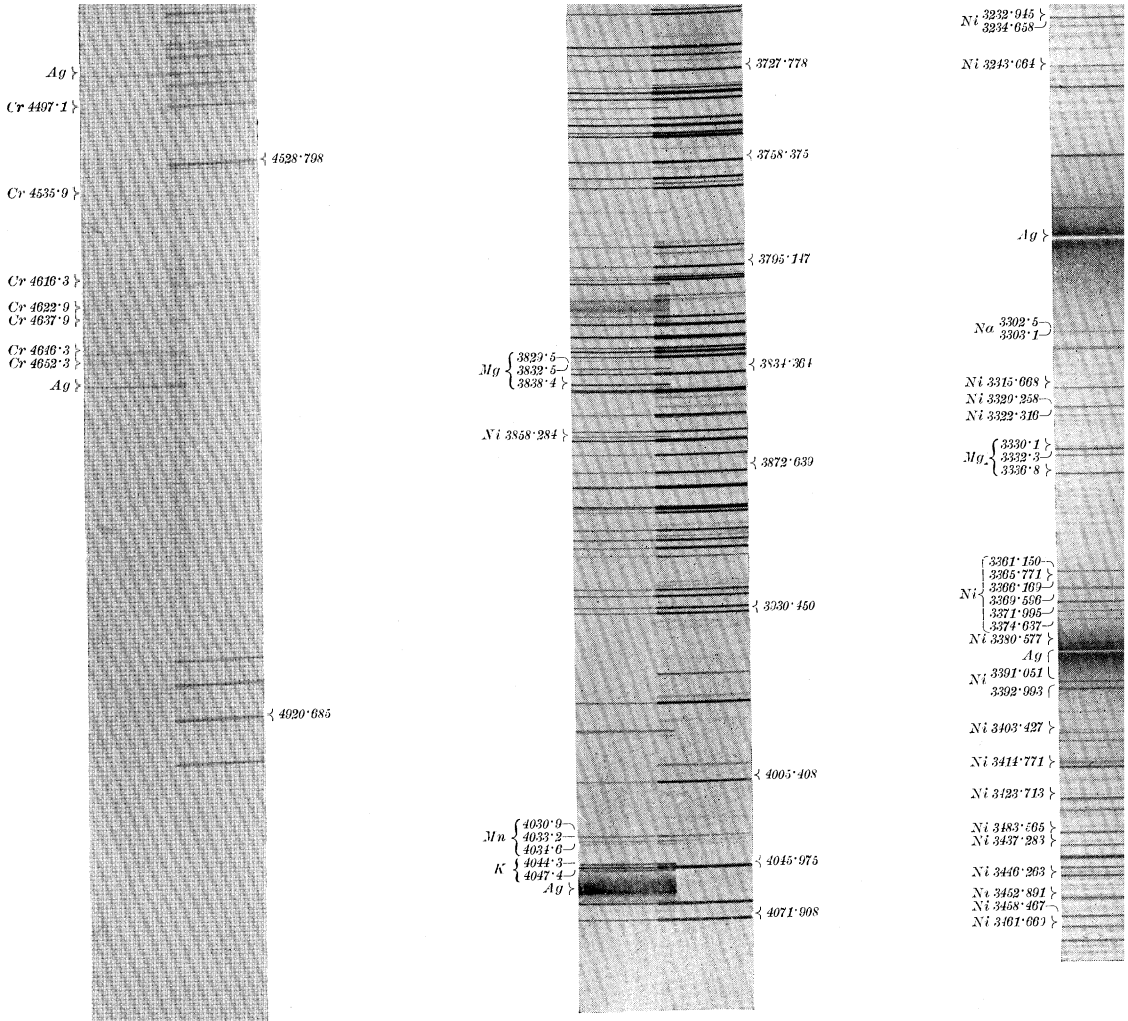


PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES



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Launton (from Bicester, Oxfordshire).

The whole of the 5 grm. of material available quickly burnt out and only short exposures were possible. The photographed spectrum extended from λ 3302 to λ 5896, and includes in addition to the lines of iron 2 aluminium, 2 calcium, 21 chromium, 2 magnesium, 3 manganese, 20 nickel, 2 potassium, 6 sodium.

Mount Brown (from Evelyn County, New South Wales).

The photographed spectrum of this aerolite extends from λ 2599 to λ 6643, and includes in addition to the lines of iron 3 aluminium, 3 calcium, 28 chromium, 11 magnesium, 3 manganese, 55 nickel, 6 sodium.

Mount Dyrring (from Durham County, New South Wales). (See Plate 20.)

The lines found in the photographed spectrum of this aerolite extends from λ 2482 to λ 4652, and includes in addition to the lines of iron 25 chromium, 17 magnesium, 3 manganese, nickel, 2 potassium, 6 silicon, 2 sodium.

Nammianthal (from South Arcot, Madras, India).

The photographed spectrum of this aerolite extends from λ 2716 to λ 4652, and includes in addition to the lines of iron 2 calcium, 23 chromium, 3 magnesium, 3 manganese, 50 nickel, 2 sodium.

Parnallee (from Madras, India).

The photographed spectrum extends from λ 2788 to λ 5896, and includes in addition to the lines of iron 1 aluminium, 24 chromium, 3 magnesium, 3 manganese, 50 nickel, 2 potassium, 6 sodium.

Before discussing in detail the composition of these aerolites as revealed by their arc spectra it is well to record one or two points of general importance. Keeping the current and voltage constant the number of lines recorded in the arc spectrum of a compound substance depends in large measure upon the time-length of the "exposure" and the sensitiveness of the photographic plate. For instance, if in an exposure of say five minutes there are a mass of lines, having some that are very much over-exposed and some that are only just visible, by making another exposure of the same material for double the time the very faint lines would appear stronger, and others that in the shorter exposure were not visible would come into view, and so on. But in practice a limit is fixed, governed partly by the demands of the strong lines and partly by the amount of the material at one's disposal. This latter limitation, the amount of material available, is very potent when dealing with such substances as rare meteoric stones.

From an examination of the whole set of aerolite spectra it appears that the proportion of nickel to iron is generally constant. There is a nickel line at λ 3619·391 and an iron at λ 3618·919; these two lines form a close pair, and in twenty-seven out of the thirty spectra they remain in the same relative intensity,

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being faint or strong according to the general character of the spectrum. But in three, Bustee, El Nakhla, and Aubres, while the iron line shows as usual, the nickel line is either absent altogether or very faint.*

In several of the aerolites in my list, it will be seen that the total number of lines recorded is below the average. The aerolite Bustee is an instance.† The rapidity with which it burnt away in the arc prevented me from giving the length of time for each exposure necessary to bring out many of the fainter lines. A rather interesting point came out in connection with this aerolite.

In the early work my stock of material amounted only to about 2 grm.—and the length of time given for an exposure was necessarily short—it was noticed that although the stronger chromium lines came out in good intensity, the nickel lines were absent. Having obtained more material I was able to get photographs with longer exposures; the nickel lines could then be seen, although as a whole much more faintly than those due to chromium. This gave rise to some experiments upon the relative photographic intensity of the two metals under the conditions in which I was working.

The chromium spectrum is fairly rich in lines. Under the conditions prevailing in these experiments, in addition to a large number of faint lines there are recorded about one hundred strong ones, and of these there are three groups, which might be called the dominant lines of the element; the strongest of these groups is composed of the three lines at λ 4254·50, λ 4274·97, and λ 4289·90; the next strong group is also three lines at λ 3578·840, λ 3593·633, and λ 3605·478, and the faintest consists of two lines, λ 4862·02 and λ 4870·9.

Some pure chromium was taken and reduced to powder, some pure electrolytic nickel was prepared in the same way, and a mixture was made of silver, kaolin, and yttria, with 10 per cent. each of Ni and Cr. This was pressed into a button and the spectrum taken as in the case of the aerolite: it was at once seen that the chromium groups came out in greater intensity than the adjacent nickel lines.

The mixture above referred to is the outcome of many experiments made to find a material capable of carrying small percentages of nickel and chromium, so that when mixed with silver and formed into electrodes for the arc it should behave in a way similar to an aerolite; the yttria was only used as a diluent of known composition.‡

An extensive series of experiments was carried out to throw light upon the

* In connection with this proportionality between the lines of iron and nickel, I have examined the spectra of a number of siderites, and in the majority of instances the proportionality remains constant; but there are a few cases in which the nickel line is fainter than that of iron and others in which it is stronger.

† Through the kindness of the Trustees of the British Museum and of Dr. Prior, three successive portions of this aerolite, making 12·171 grm. in all, were placed at my disposal.

‡ Incidentally, I may say that this is a very convenient method for obtaining the arc spectra of the rare earths.

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photographic effect of known percentages of chromium under the conditions obtaining in the aerolite spectra.

Two electrodes were made as follows :—

Yt_2O_3	70
Kaolin	10
Nickel	15
Chromium	5
	100

And to this was added an equal weight of pure silver powder. The arc spectrum was then photographed under conditions similar to those of the aerolites.

It was seen that the chromium groups were still the most prominent lines in the spectrum, those of nickel being comparatively faint.

Keeping the other ingredients constant and gradually reducing the proportion of chromium several more experiments were made, and it was found that when the chromium had been so reduced that it was only 0·16 per cent., the lines λ 4862·02 and λ 4870·9 were no longer visible ; a further experiment with electrodes containing only 0·1 per cent. chromium distinctly showed the other two groups.

These experiments show that it is easy to detect the presence of chromium in an arc between electrodes that contain only 5 parts Cr in 10,000.

It is not easy to see why in subjecting the two elements nickel and chromium to the heat of the electric arc it should produce so much more intense atomic disturbance in one case than in the other—the melting-points of the two elements are not very different—it may be, however, that the volatilisation points differ. I have pursued this matter in connection with the examination of a large number of meteoric irons (siderites) that will form the subject of a further communication.*

Although these experiments only make it possible to form an approximate estimate of the amount of chromium present in these aerolites it would seem to lie between 0·6 per cent. and 0·1 per cent.

In the previous experiments the proportion of nickel which was kept the same in all mixtures was evidently in considerable excess of that contained in any of the

* Without anticipating this communication on siderites, I desire to point out the remarkable fact that although the chromium lines appear, sometimes very strongly, in all my aerolite spectra they do not appear in any of the siderites I have so far examined—except in one instance, that of "Zacatecas." Although of course the nickel lines are always visible—from the spectroscopic examination of a number of specimens of iron, to which I had added decreasing amounts of chromium, I found that the dominant lines of chromium were quite visible even when the amount present was no more than 0·0175 per cent. This is due to the fact that chromium is absent from the nickel-irons but almost universally present in the aerolites in the form of chromite. In Aubres, &c., there is probably more chromite than nickel-iron. In the magma which produced meteorites all the Cr was converted into oxide or sulphide, giving rise to the mineral chromite or daubreelite and leaving no Cr for the nickel-iron.

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aerolites; the experiments were therefore continued, blocks made in the same way as in the experiments with chromium were used as electrodes for the arc. The proportion of nickel was from 2 per cent. down to 0·04 per cent.—photographs of the spectrum were made under the usual working conditions. The portion of the spectrum taken was that containing the chromium group, λ 3578·840, λ 3593·633, λ 3605·478, and the closely adjacent nickel lines; it was found that when the amount of nickel was reduced to 0·04 per cent. the line 3619·391 was only just visible.

The information gained from these mixtures of chromium and of nickel made it possible to obtain an approximate estimate of the quantities of these elements present in the three aerolites, El Nakhla, Aubres, and Bustee. A mixture containing chromium 0·25 per cent. and nickel 0·04 per cent. gave a photograph which for Cr-Ni was practically identical with that of Aubres.

The estimation made in this way cannot be more than a "good approximation" on account of unavoidable variations, due to intensity of light and time of exposure; also to conditions of photographic development, which cannot be *exactly* controlled, but the indications given by the relative intensities of closely adjacent Ni and Cr lines when they occur on the same film are very much more exact, and the result proves that in these aerolites the element chromium exists in greater abundance than nickel.

To this fact must be added that of the almost total absence of chromium in the familiar nickeliferous irons of the siderites.

In a general survey of the spectrum analyses of the 30 aerolites which forms the subject of this Paper, the most striking fact is their similarity in composition, and the small number of elements represented. Making full allowance for wide differences in the photographic activity of the arc spectra of the elements, it is remarkable that we only see with certainty the lines due to some *ten* bodies, and of these ten, four only—iron, chromium, magnesium, and nickel—appear to be present in quantity. With three exceptions, Bustee, El Nakhla, and Aubres, the proportion between these elements appears to be practically the same in all.

This suggests that these earthy meteorites must have a common origin, and that origin might be due to the disruption of a body in which the process of cosmial evolution has been completed; in short, may we not conclude that the aerolites are fragments of a finished and cooled planet. It is possible that we have in our museums fragments of a world unrealised—a world that at one time had its place between Jupiter and Mars in our planetary system.

From the results of my unfinished notes on the spectrum analyses of meteoric irons, to which I have already referred, it would appear that either the siderites are of a different origin, or that they have constituted the solid nucleus or core, from which by some process at present unknown the chromium and other elements had been separated, leaving the magnetic elements iron and nickel as the familiar ferro-nickel meteorites.

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Nickel.	Intensity.	L'Aigle.	Alfianello.	Aubres.	Baroti.	Barratta.	Bustee.	Chandakapur.	Chantonnay.	Chateau-Renard.	Crumlin.	Dandapur.	Daniel's Kuil.	Dhurmsala.	Durala.	Eli Elwah.	El Nakhla el Baharia.	Futtehpur.	Gilgoin.	Girgenti.	Gnarrenburg.	Hvittis.	Jelica.	Jhung.	Kansada.	Khairpur.	Launton.	Mount Brown.	Mount Dyrring.	Nammianthal.	Parnallee.
2981·652	6	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	+	–	–	+	+	–	–	+	+	–	+	–	+	+
3002·492	10	–	–	–	–	+	–	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+
3003·628	9	–	–	–	–	+	–	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+
3012·007	9	–	–	–	–	+	–	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	–	+	+	+	–	+	+	+	+
3037·940	9	–	–	–	–	+	–	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	–	+	+	+	–	+	+	+	+
3050·828	10	–	–	–	–	+	–	+	–	+	+	–	+	+	+	–	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+
3054·317	8	–	–	–	+	+	–	+	–	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+
3064·626	6	–	–	–	–	+	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–	+	–	–	+	–	–	+	–	+	+
3080·758	6	–	–	–	–	+	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–	+	–	+	–
3101·563	8	–	+	–	+	–	–	–	–	–	+	+	+	+	–	–	–	+	–	+	+	+	+	+	+	–	–	+	+	+	+
3101·881	8	–	+	–	+	–	–	–	–	–	+	+	+	+	–	–	–	+	–	+	+	–	+	+	+	–	–	+	+	+	+
3134·106	10	–	+	–	–	–	–	+	–	–	+	+	+	+	+	–	–	+	–	+	+	–	–	–	+	–	–	+	+	+	+
3197·121	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
3221·661	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
3225·030	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	+	–	–
3232·945	8	–	+	+	+	–	–	+	–	+	+	+	+	–	–	–	–	+	–	+	+	–	+	+	+	–	–	+	+	+	+
3234·658	5	–	+	–	+	–	–	+	–	–	–	+	–	–	–	–	–	+	–	+	+	–	–	–	+	–	–	+	+	+	+
3243·064	8	–	+	–	+	–	–	+	–	+	–	+	+	–	–	–	–	+	–	+	+	–	+	+	+	–	–	+	+	+	+
3315·668	7	–	+	–	+	–	–	+	–	+	–	+	–	+	+	–	–	+	+	+	+	–	+	+	+	+	–	+	+	+	+
3320·259	5	–	+	–	+	–	–	–	–	–	–	+	–	–	+	–	–	+	–	+	+	–	+	+	+	+	–	+	+	+	+
3322·316	5	–	+	–	+	–	–	–	–	–	–	+	–	–	+	–	–	+	–	+	+	–	+	–	+	–	–	+	+	+	+
3361·550	5	–	+	–	+	–	–	+	–	+	–	+	+	+	+	–	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+
3365·771	4	–	+	–	+	–	–	+	–	+	–	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+
3366·169	5	–	+	–	+	–	–	+	–	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+
3369·576	10	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	–	+	+	+	–	+	+	+	+
3371·995	5	–	+	–	+	–	–	–	+	–	–	+	+	+	+	+	–	+	+	+	+	+	+	+	+	–	–	+	+	+	+
3374·637	5	–	+	–	+	–	–	+	–	+	–	+	+	+	–	–	–	+	+	+	+	+	+	+	+	–	–	+	+	+	+
3380·577	10	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	+	–	–	–	+	–	–	+	+	+	+	–	–
3391·051	7	+	+	–	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3392·993	10	+	+	–	+	+		+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3403·427	3	–	+	–	–	–	–	–	–	–	–	+	+	–	+	–	–	+	–	+	+	–	–	–	+	–	–	+	+	–	+
3414·771	10	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3423·713	8	+	+	+	–	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+
3433·565	9	+	+	–	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3437·283	6	+	+	–	+	+	–	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+
3446·263	10	+	+	–	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3452·891	6	+	+	–	+	+	–	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+	+	–	–	+	+	+	+
3458·467	10	+	+	–	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3461·660	10	+	+	–	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3467·505	5	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	+	+	–	–	–	+	–	–	+	+	+	–
3469·484	5	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	+	+	–	–	–	+	–	–	+	+	+	–
3472·545	7	+	+	–	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	–	+	+	+	+	–	+	+	+	+	+	+
3485·892	5	+	+	–	+	+	–	+	–	+	+	+	+	–	–	+	–	+	+	–	+	–	+	+	–	+	–	+	–	+	+
3492·965	10	+	+	–	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3500·852	6	+	+	–	+	–	–	–	–	+	+	+	+	+	+	+	–	+	–	–	–	–	–	+	–	+	–	+	+	–	+
3502·609	4	–	–	–	–	–	–	+	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
3510·340	7	+	+	–	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	–	+	+	+	+	+	+
3515·057	9	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+

\+ means present, – means absent.

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	Intensity.	L'Aigle.	Alfianello.	Aubres.	Baroti.	Barratta.	Bustee.	Chandakapur.	Chantonnay.	Chateau-Renard.	Crumlin.	Dandapur.	Daniel's Kuil.	Dhurmsala.	Durala.	Eli Elwah.	El Nakhla el Baharia.	Futtehpur.	Gilgoin.	Girgenti.	Gnarrenburg.	Hvittis.	Jelica.	Jhung.	Kansada.	Khairpur.	Launton.	Mount Brown.	Mount Dyrring.	Nammianthal.	Parnallee.
Nickel (continued).																															
3524·543	10	+	+	+	+	+	−	+	+	+	+	+	+	+	+	+	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3566·373	10	+	+	−	+	+	−	+	+	+	+	+	+	+	+	+	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3597·699	7	+	+	−	+	−	−	+	+	+	+	+	+	+	+	+	−	+	+	−	+	−	−	+	−	+	+	+	+	+	+
3610·45	8	+	+	−	+	+	−		+	+	+	+	+	+	+	+	−	+	+	−	+	−	−	+	−	+	+	+	+	+	+
3612·732	7	+	−	−	−	−	−	+	−	+	+	+	+	−	−	+	−	+	−	−	+	−	−	+	−	+	−	−	+	+	+
3619·391	10	+	+	−	−	+	−	+	−	+	+	+	+	+	+	+	−	+	+	+	+	−	+		−	+	+	+	+	+	+
3775·562	9	+	−	−	+	−	−	+	−	+	+	+	+	−	−	+	−	+	+	−	+	−	−	+	−	+	+	+	+	+	+
3783·51	8	+	−	−	+	−	−	+	−	+	+	+	+	−	−	+	−	+	+	−	+	−	−	+	−	+	+	+	−	+	+
3807·135	8	+	+	−	+	−	−	+	+	+	+	+	+	+	+	+	−	+	+	−	+	−	−	+	−	+	+	+	+	+	+
3858·284	10	+	+	−	+	+	−	+	+	+	+	+	+	+	+	+	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+
6643·657	10	−	+	−	−	−	−	+	−	−	−	−	+	+	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−
Chromium.																															
2663·5	3	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−
2780·97	5	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−
2967·76	3	−	−	−	−	−	−	+	−	+	+	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−
2971·32	2	−	−	−	−	−	−	+	−	+	+	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−
2975·6	3	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−
2980·9	4	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
2986·12	2	−	−	−	−	−	−	−	−	+	+	−	+	−	+	−	−	+	−	+	+	+	+	−	+	−	−	−	−	−	+
2986·59	3	−	−	−	−	−	−	+	−	−	+	−	+	−	+	−	−	+	−	+	+	+	+	−	+	−	−	+	−	+	+
2988·78	4	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	+	−	−	−	−	−	−
3005·17	3	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
3015·04	3	+	+	−	+	+	+	+	+	+	+	+	+	+	+	−	−	+	+	+	+	+	+	+	+	+	−	+	+	+	+
3015·32	4	+	+	−	+	+	+	+	+	+	+	+	+	+	+	−	−	+	+	+	+	+	+	+	+	+	−	+	+	+	+
3018·61	5	+	+	−	+	+	+	−	+	+	+	+	−	+	+	−	−	+	+	+	+	+	+	+	+	+	−	+	+	+	+
3018·92	5	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	+	−	−	−
3021·68	5	+	+	−	+	+	+	+	+	+	+	+	+	+	+	−	−	+	+	+	+	+	+	+	+	+	−	+	+	+	+
3024·47	4	−	−	−	−	+	−	+	+	+	+	−	+	+	+	−	−	+	−	+	+	+	+	−	+	+	−	+	+	+	+
3578·84	10	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3593·63	10	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3605·47	10	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3908·9	4	+	−	−	+	−	−	−	−	−	−	−	−	−	−	+	+	−	−	−	−	−	−	+	−	+	−	−	−	−	+
3919·3	6	+	−	−	+	−	−	+	+	−	−	−	−	+	+	−	+	+	−	−	−	−	−	−	−	+	+	−	−	−	+
3963·9	8	−	−	−	+	−	−	+	+	−	+	−	−	−	−	+	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−
3969·2	6	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−
3976·8	8	−	−	−	−	−	−	+	−	−	+	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−
3984·0	5	−	−	−	−	−	−		−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	+	−	−	−	−	−	−
3991·2	6	−	−	−	−	−	−	+	−	−	−	−	−	−	−	−	−	+	−	−	−	−	−	−	+	−	−	−	−	−	−
4254·50	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4274·97	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4289·90	15	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4337·7	9	−	+	+	+	+	−	+	−	+	+	+	+	−	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4339·8	4	+	+	+	+	+	−	+	+	+	+	+	+	+	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4344·67	9	+	+	+	+	+	−	+	+	+	+	+	+	+	−	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

\+ means present, − means absent.

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	Intensity.	L'Aigle.	Alfianello.	Aubres.	Baroti.	Barratta.	Bustee.	Chandakapur.	Chantonnay.	Chateau-Renard.	Crumlin.	Dandapur.	Daniel's Kuil.	Dhurmsala.	Durala.	Eli Elwah.	El Nakhla el Baharia.	Futtehpur.	Gilgoin.	Girgenti.	Gnarrenburg.	Hvittis.	Jelica.	Jhung.	Kansada.	Khairpur.	Launton.	Mount Brown.	Mount Dyrring.	Nammianthal.	Parnallee.
Chromium (continued).																														
4351·96	10	+	+	+	+	+	–	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+	+	+	+	+	–	+
4359·8	6	–	+	–	+	+	–	+	–	+	+	+	+	+	–	–	–	–	+	–	+	+	–	–	–	+	+	+	+	–
4371·45	10	–	+	–	+	+	–	+	–	+	+	+	+	+	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+
4497·03	10	+	+	–	+	+	–		–	+	+	+	+	+	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+
4530·9	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	+	–	–
4540·6	8	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
4544·7	4	–	–	–	–	–	–	+	–	–	–	–	+	–	–	–	–	+	–	–	+	+	–	–	–	–	–	+	–	–
4546·13	8	+	+	–	+	+	–	+	–	+	+	+	+	+	–	–	–	+	+	+	+	+	+	+	–	+	+	+	+	+
4591·57	6	–	–	–	–	+	–	+	–	+	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
4600·9	10	–	–	–	–	+	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
4616·3	8	+	+	–	+	+	–	+	–	+	+	+	+	+	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	–
4622·1	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	–	–	–	–	–
4622·6	6	+	+	–	+	+	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–
4622·9	6	–	–	–	–	–	–	+	–	+	+	+	+	+	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	–
4637·9	3	–	+	–	+	+	–	+	–	+	+	+	+	+	–	–	–	+	+	+	+	+	+	+	+	+	+	+	+	–
4646·33	10	+	+	–	+	+	–	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4652·33	10	+	+	–	+	+	–	+	+	+	+	+	+	+	+	–	–	+	+	+	+	+	+	+	+	+	+	+	+	+
5348·5	10	–	–	–	–	–	–	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
5410·0	10	–	–	–	–	–	–	+	–	–	–	–	+	+	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–
Magnesium.																														
2776·8	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
2778·4	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–
2779·9	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	+	+	–	–
2781·5	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
2783·1	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	+	–	–
2795·6	8	–	–	+	–	–	+	+	–	–	–	–	–	+	+	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
2802·8	8	–	–	+	–	–	+	+	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
2852·2	10	–	–	+	–	+	+	+	–	–	–	–	–	+	+	–	–	+	+	+	–	+	+	–	+	+	–	+	+	+
3091·2	5	–	–	–	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
3093·1	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
3097·1	8	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
3330·1	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
3332·3	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
3336·8	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
3829·5	10	+	–	+	–	–	+	–	–	–	–	–	+	–	–	–	–	+	–	–	–	–	–	+	–	+	–	+	–	–
3832·5	10	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+
3838·4	10	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+
Silicon.																														
2507·00	8	–	–	+	–	–	–	+	–	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	+	–	–
2514·40	6	–	–	–	–	–	–	+	–	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	+	–	–
2516·13	8	–	–	+	–	–	–	+	–	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	+	–	–
2519·27	6	–	–	+	–	–	–	+	–	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	+	–	–
2524·11	6	–	–	–	–	–	–	+	–	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	+	–	–
2528·58	8	–	–	+	–	–	–	+	–	–	–	–	–	–	–		–	–	–	–	–	–	–	–	–	–	–	+	–	–

+ means present, – means absent.

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	Intensity.	L'Aigle.	Alfianello.	Aubres.	Baroti.	Barratta.	Bustee.	Chandakapur.	Chantonnay.	Chateau-Renard.	Crumlin.	Dandapur.	Daniel's Kuil.	Dhurmsala.	Durala.	Eli Elwah.	El Nakhla el Baharia.	Futtehpur.	Gilgoin.	Girgenti.	Gnarrenburg.	Hvittis.	Jelica.	Jhung.	Kansada.	Khairpur.	Launton.	Mount Brown.	Mount Dyrring.	Nammianthal.	Parnallee.
Sodium.																														
3020·5	6	+	+	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
3303·1	6	+	+	−	+	+	+	+	+	+	+	+	+	+	+	−	+	+	+	+	+	+	+	+	+	+	+	+	+	+
5682·9	5	+	+	−	−	−	−	+	+	+	+	−	+	+	−	−	−	+	+	−	+	−	−	+	−	−	+	−	+	+
5688·3	5	+	+	−	−	−	−	+	+	+	+	−	+	+	−	−	−	+	+	−	+	−	−	+	−	−	+	−	+	+
5890·1	100	+	+	+	+	−	−	+	+	+	+	+	+	+	+	−	+	+	+	+	+	+	+	+	+	+	+	−	−	+
5896·1	100	+	+	+	+	−	−	+	+	+	+	+	+	+	+	−	+	−	+	+	+	+	+	+	+	+	+	−	−	+
Manganese.																														
4030·9	30	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4033·2	30	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
4034·6	20	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Potassium.																														
4044·3		+	−	−	+	−	−	−	+	+	−	+	−	+	+	−	+	+	+	+	+	−	+	+	−	+	+	−	−	+
4047·4		+	−	−	+	−	−	−	+	+	−	+	−	+	+	−	+	+	+	+	+	−	+	+	−	+	+	−	−	+
Aluminium.																														
3082·3		−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	−	+	−	−
3944·3		−	−	−	+	+	−	−	+	−	+	−	−	−	−	−	−	+	−	+	+	−	−	+	−	+	+	+	−	−
3961·6		−	+	−	+	+	−	+	+	−	+	−	+	−	−	−	−	+	−	+	+	−	−	+	−	+	+	+	−	+
Calcium.																														
3933·82		−	−	−	+	+	−	+	−	−	−	−	−	+	−	−	−	+	+	−	+	−	−	+	−	+	+	+	−	−
3968·62		−	+	−	−	−	+	+	−	+	−	−	−	−	+	−	−	+	+	+	+	−	−	+	−	−	−	+	−	−
4226·87		−	+	−	+	+	+	+	+	+	−	+	−	+	+	−	−	+	+	+	+	+	+	+	+	+	+	+	−	−

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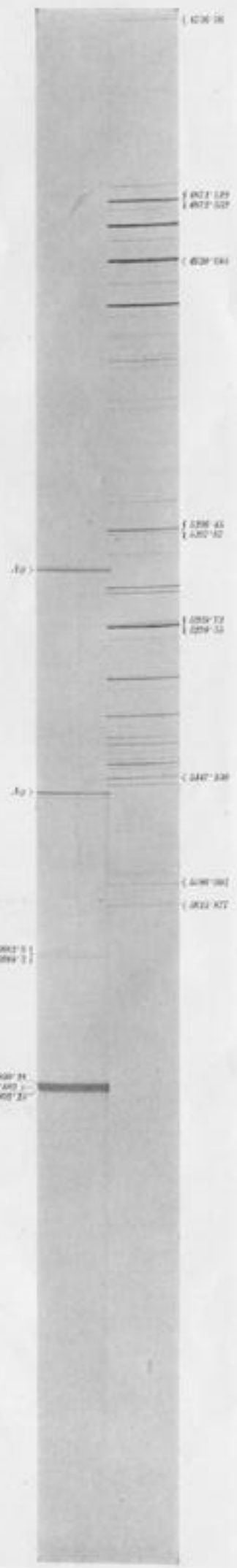

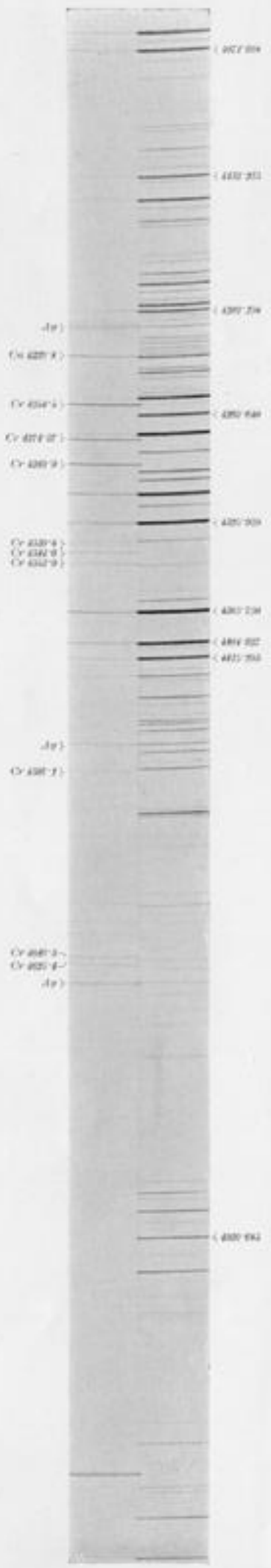

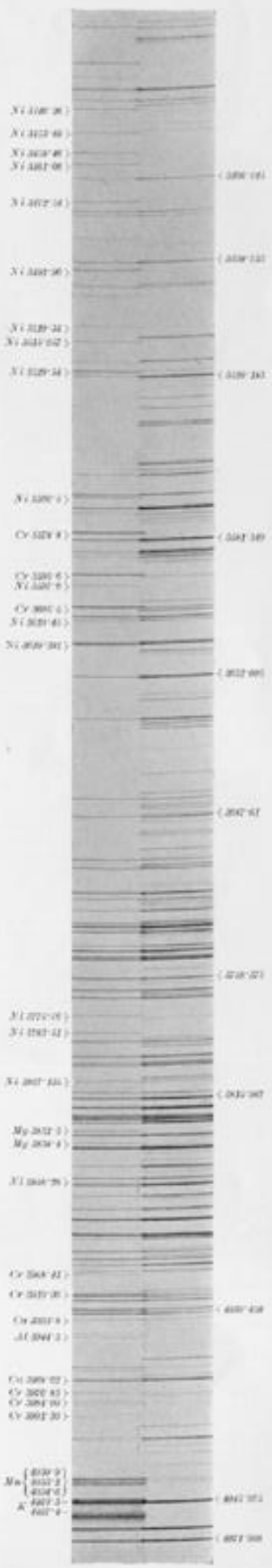

Crookes.

THE ARC SPECTRUM OF THE AEROLITE KHAIRPUR (+ Ag) COMPARED WITH IRON.

Phil. Trans., A, vol. 217, Plate 19.

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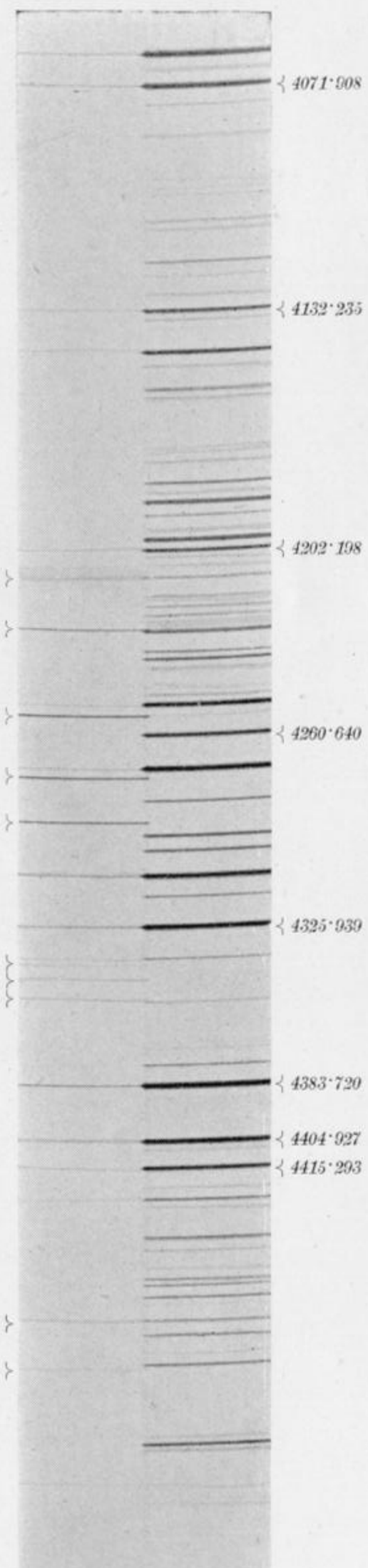
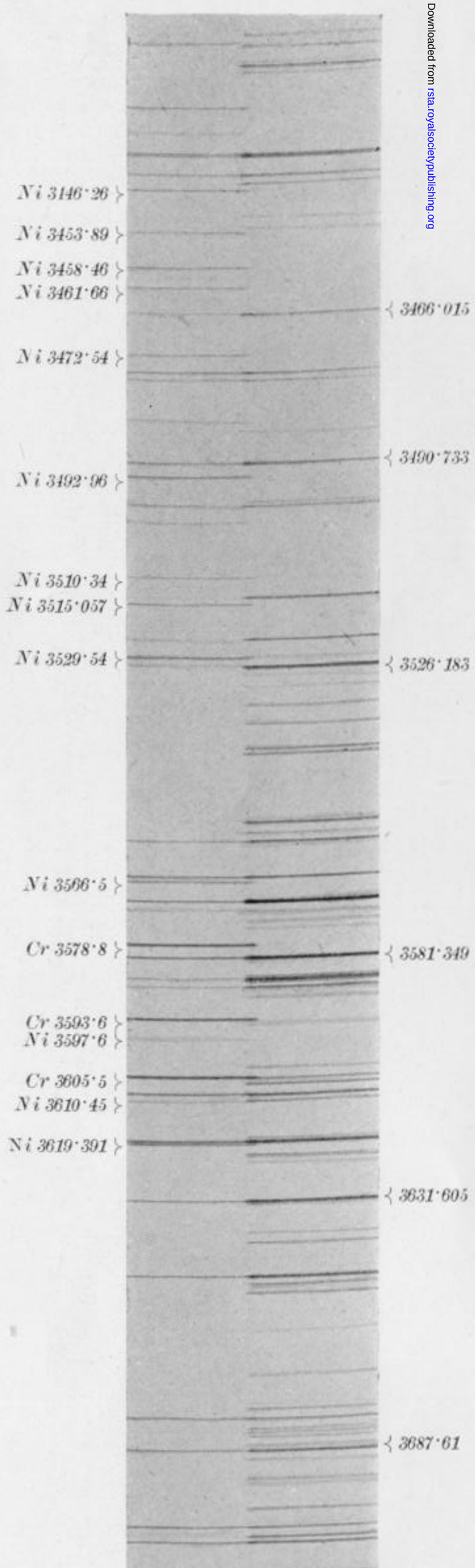
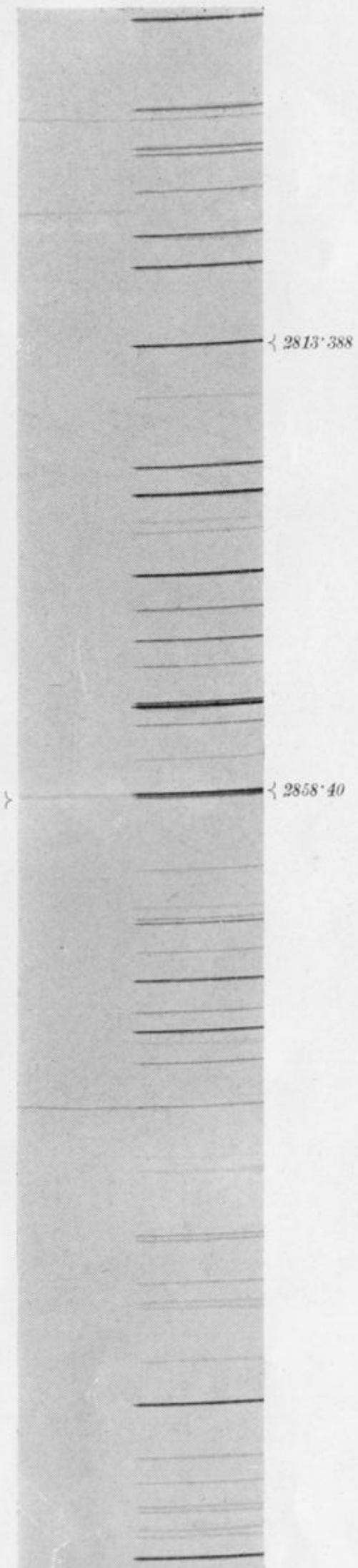
The Arc Spectrum of the Aerolite Khairpur (







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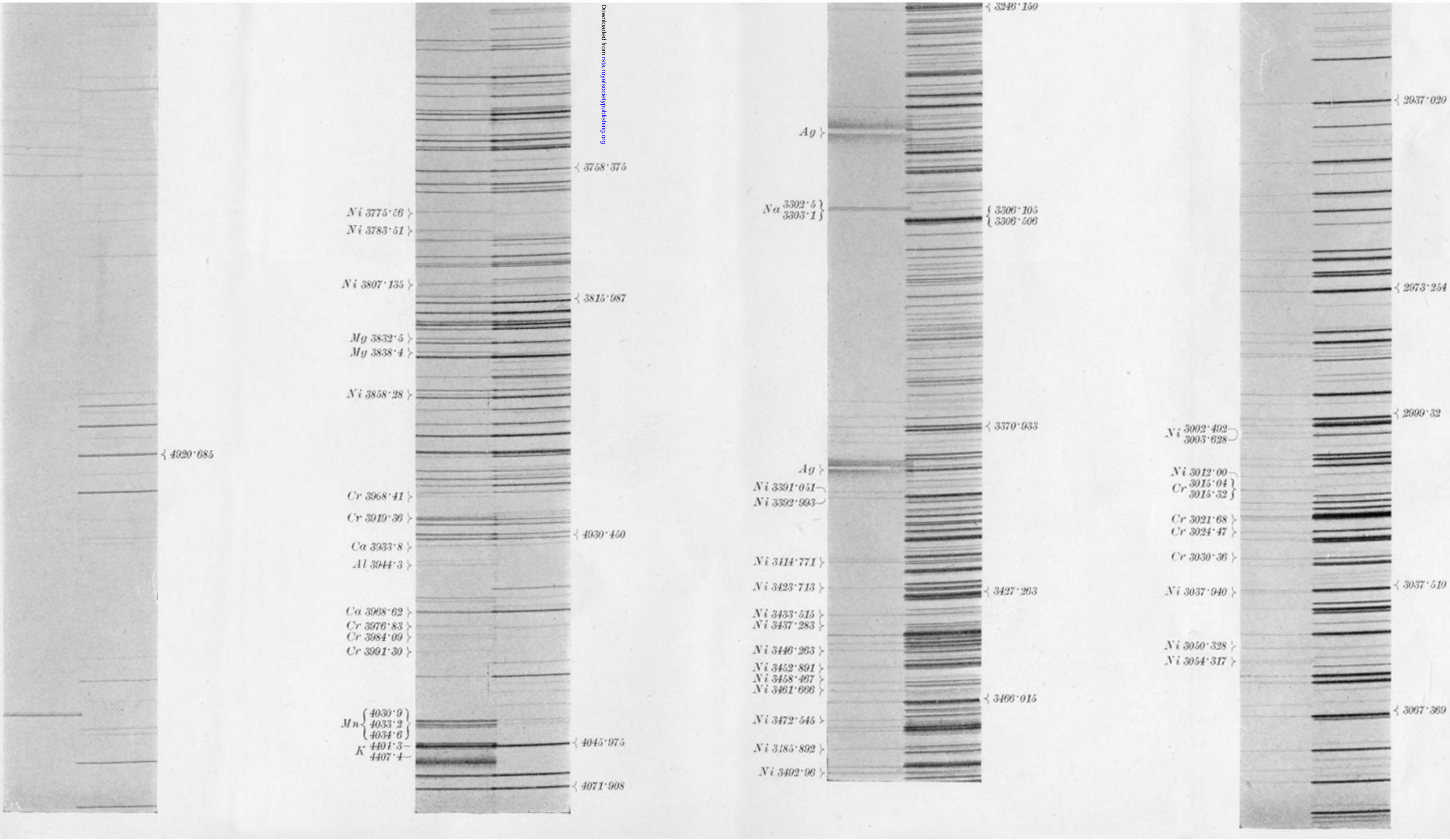
Phil. Trans., A, vol. 217, Plate 19.

PUR (+Ag) COMPARED WITH IRON.



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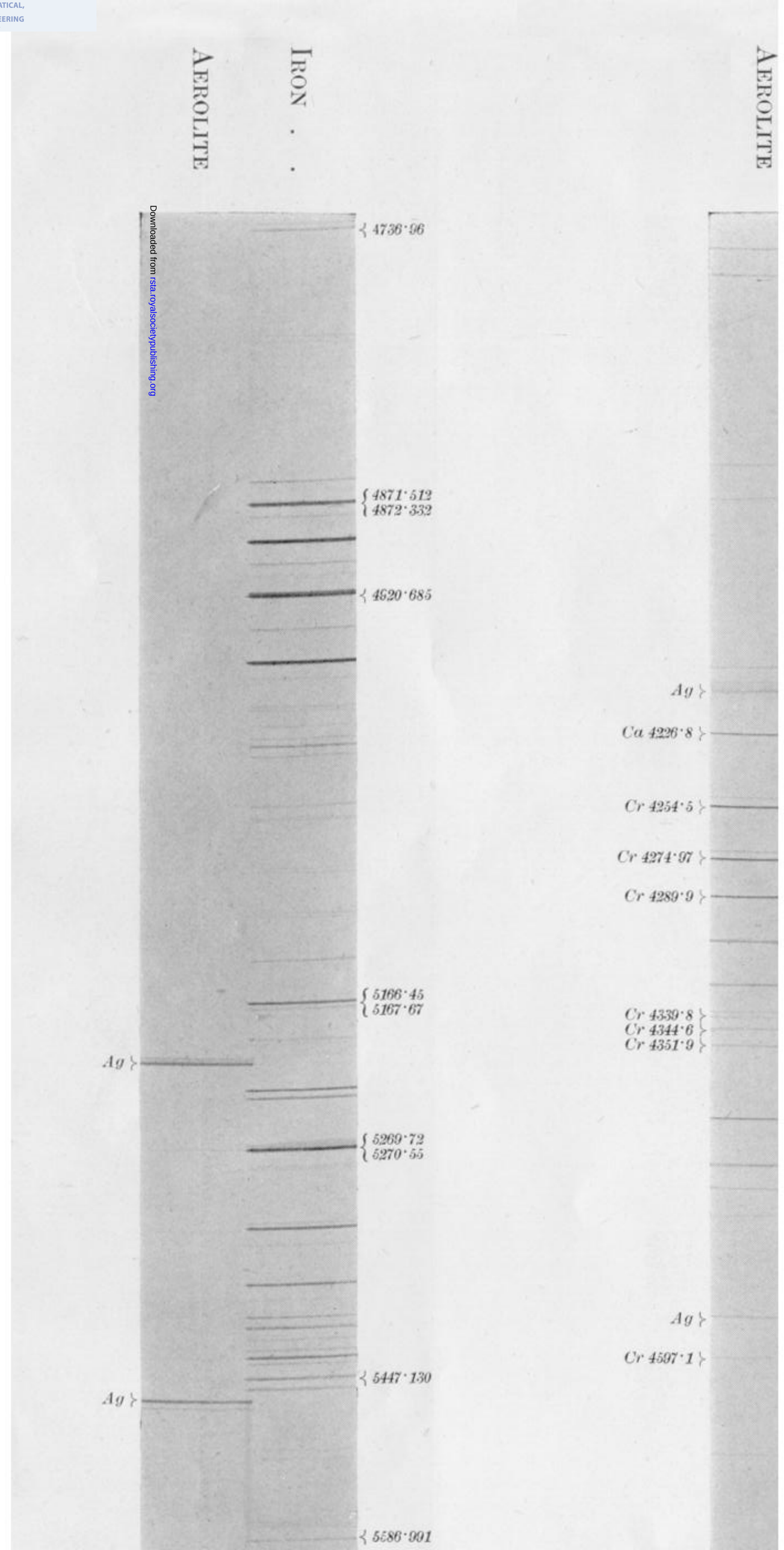

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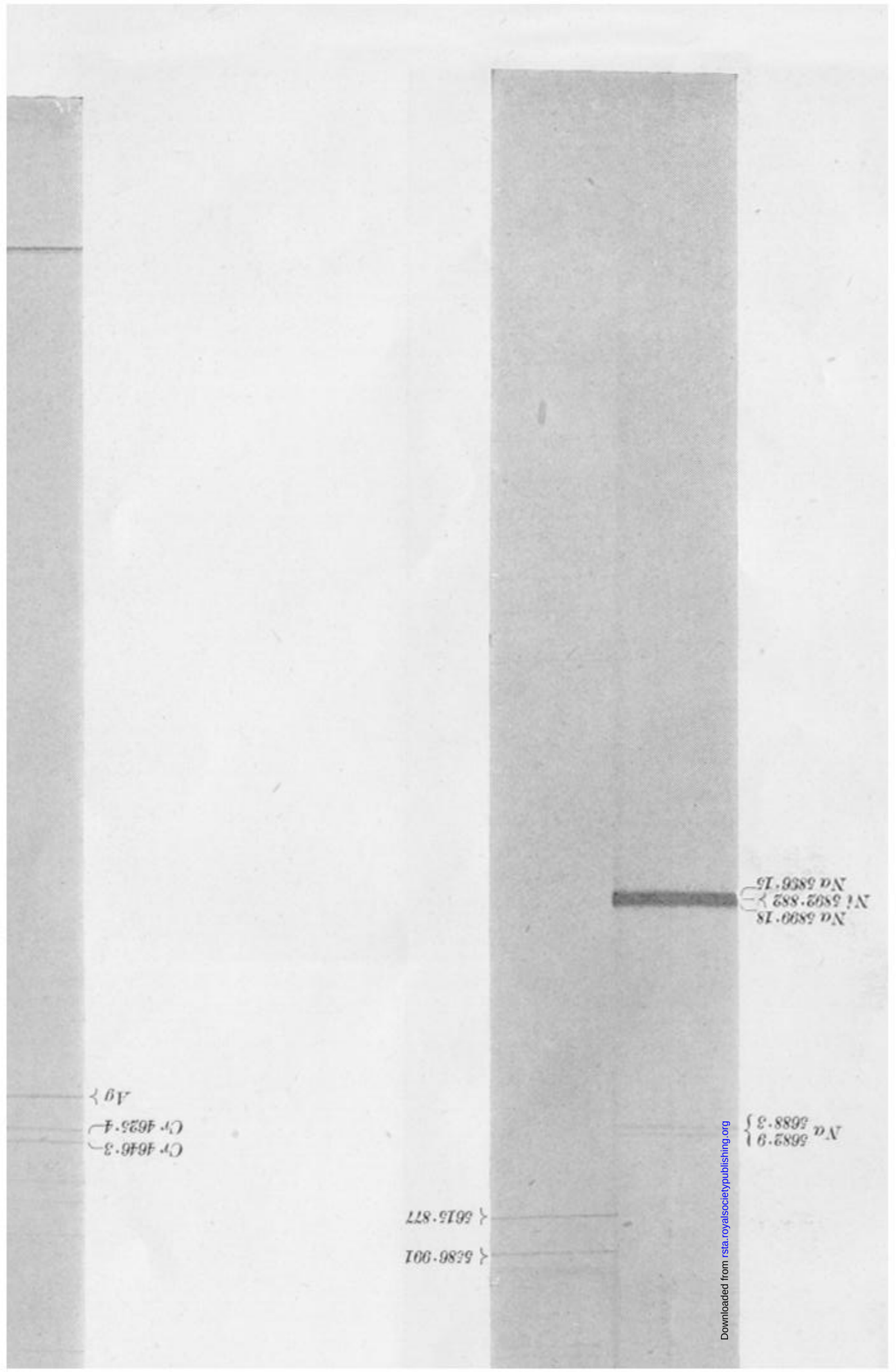

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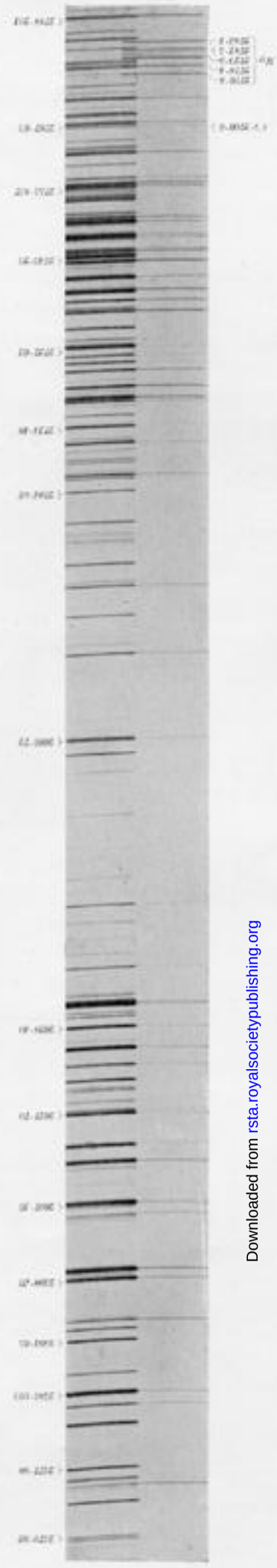
THE ARC SPECTRUM OF THE AEROLITE MT. DYRRING (+Ag) COMPARED WITH IRON.



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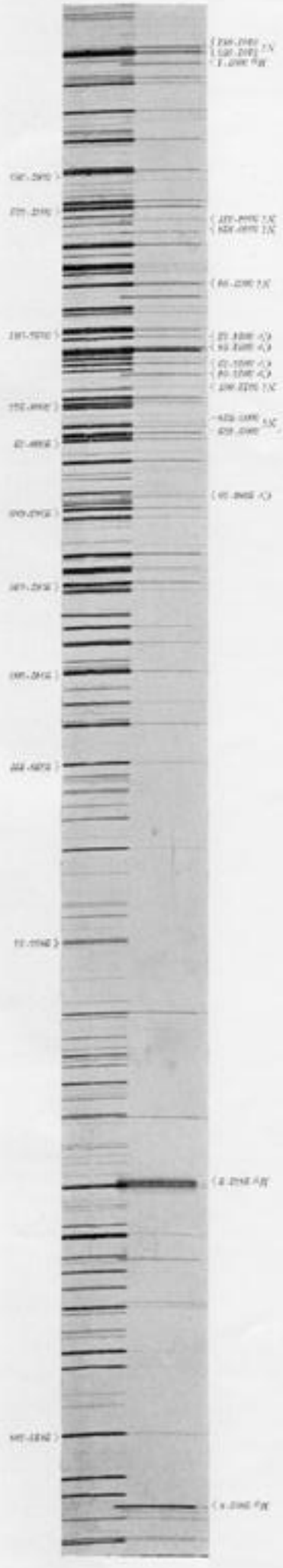

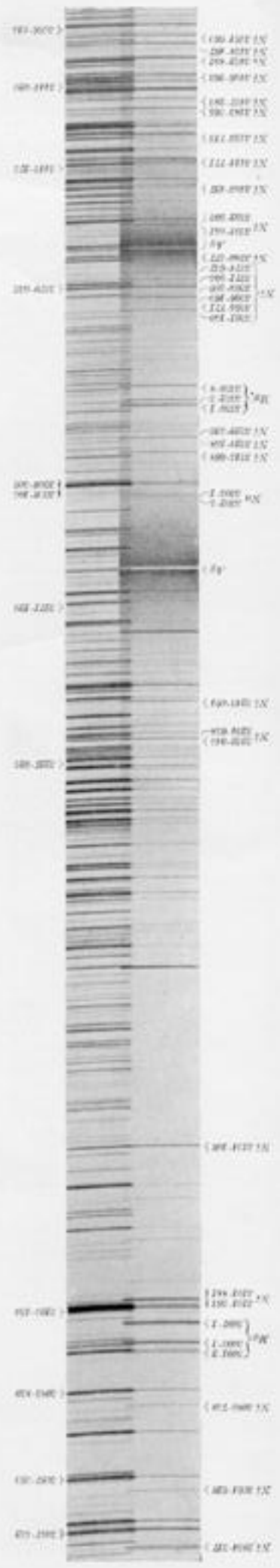

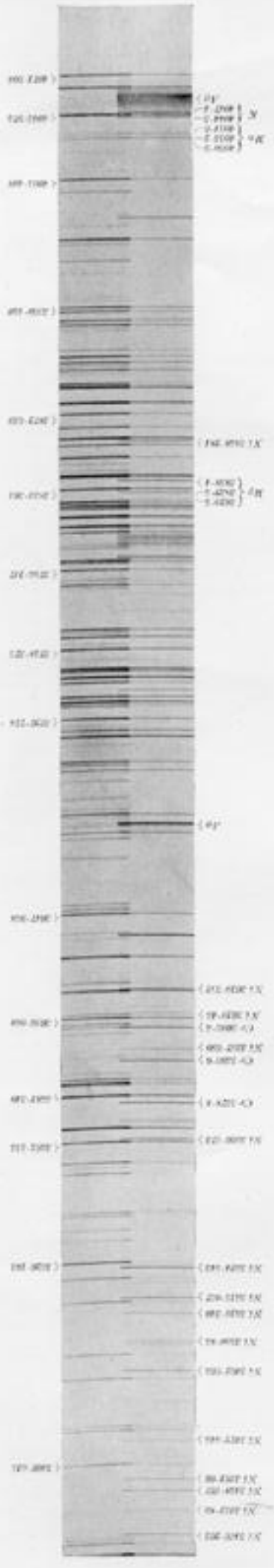

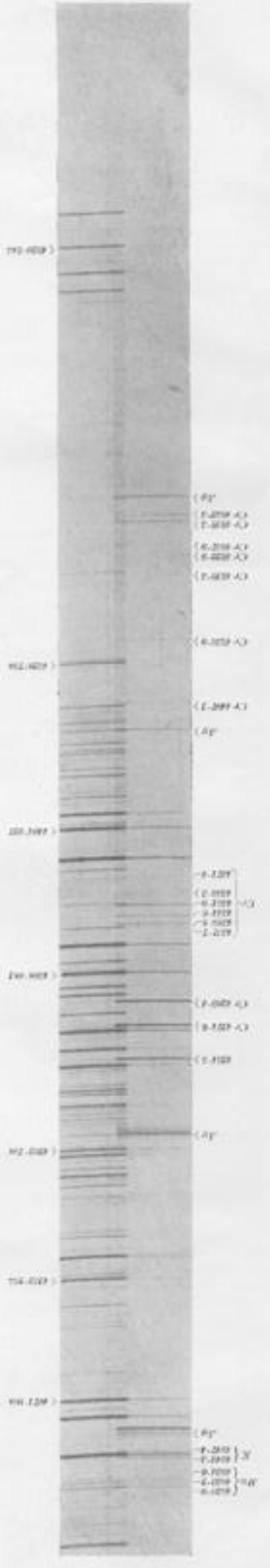

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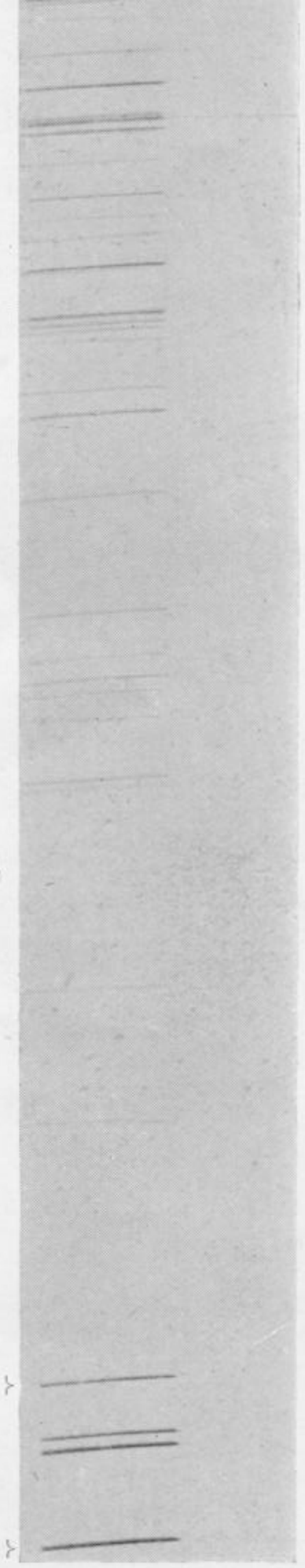
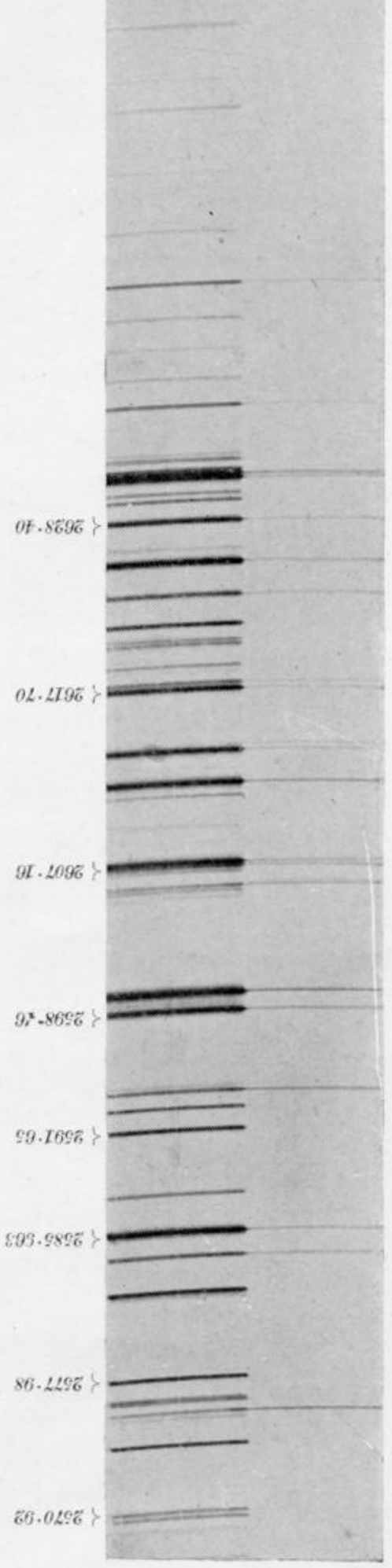
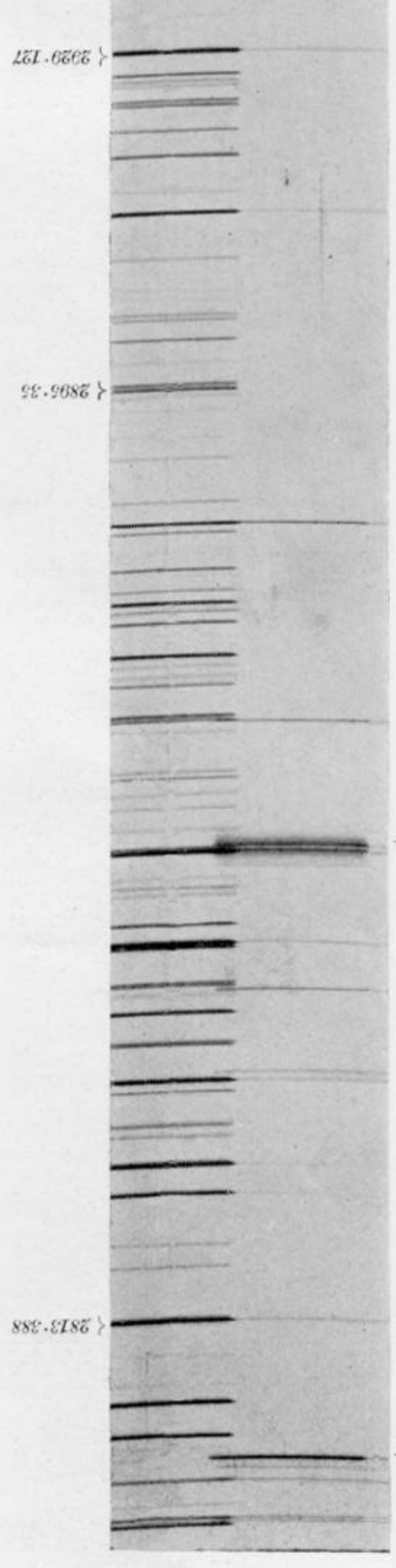
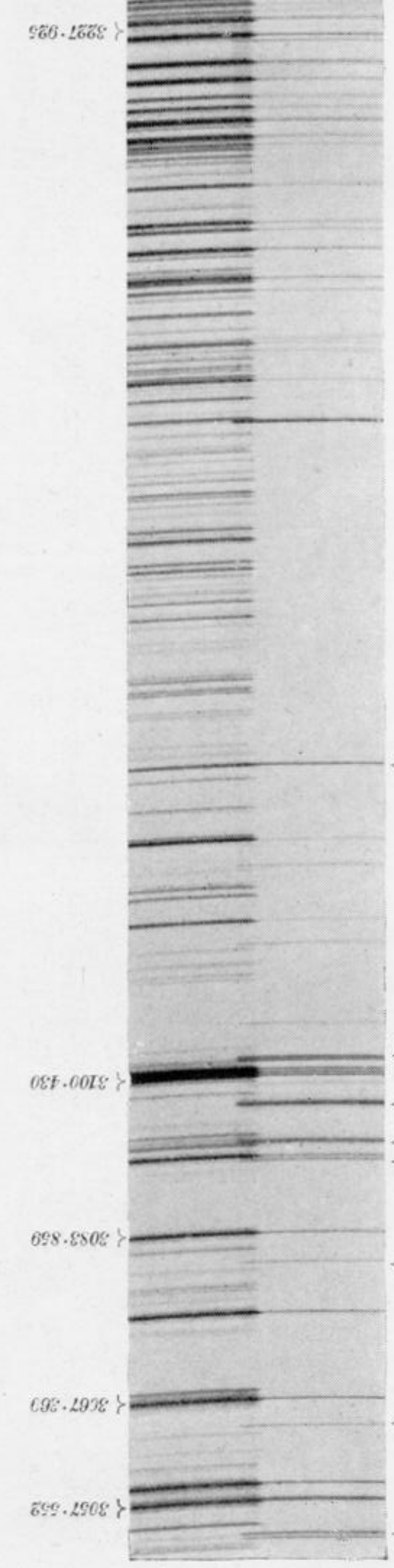
THE ARC SPECTRUM OF THE AEROLITE Mt. DYH









Mr. Crookes.

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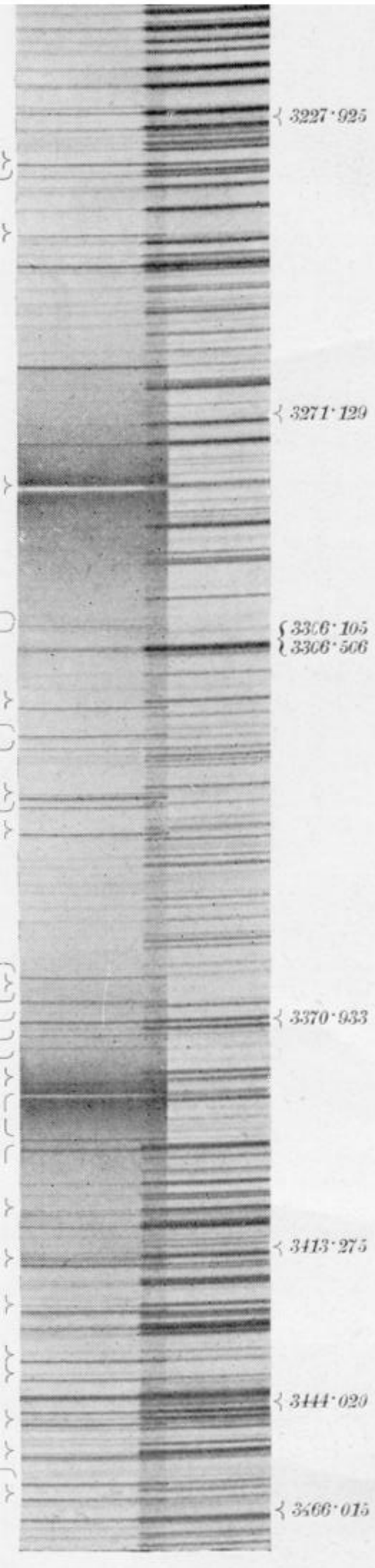

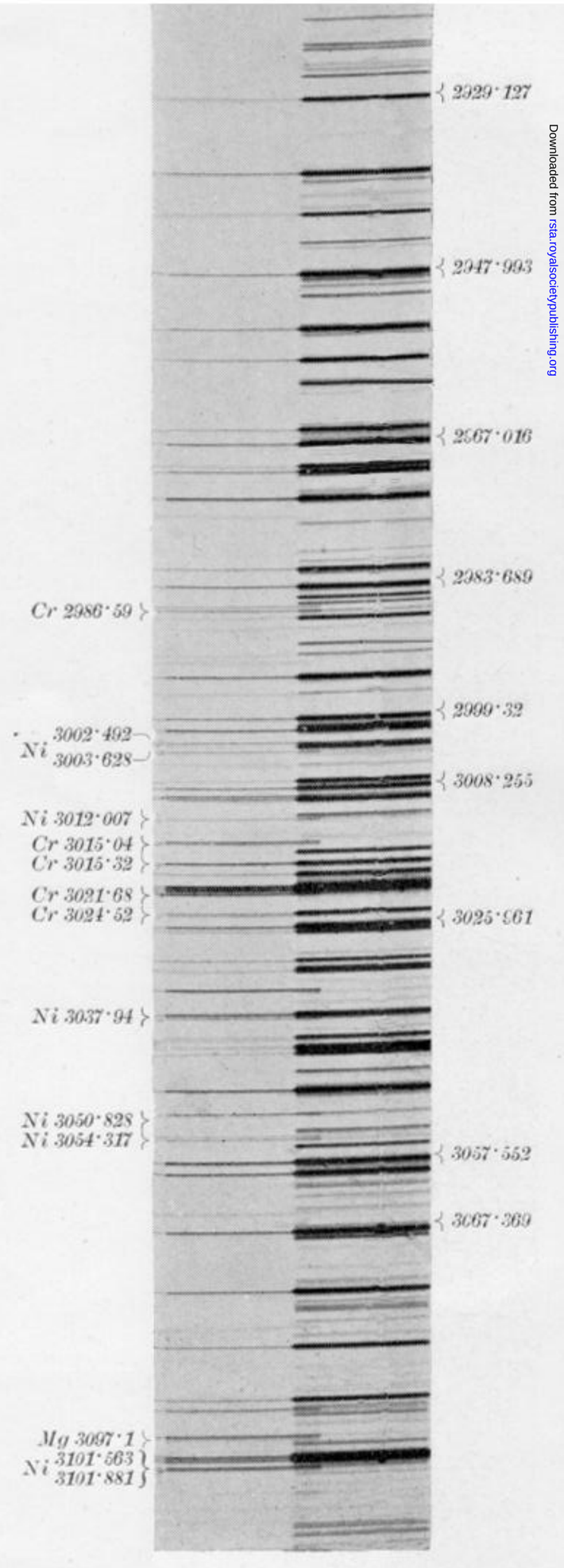

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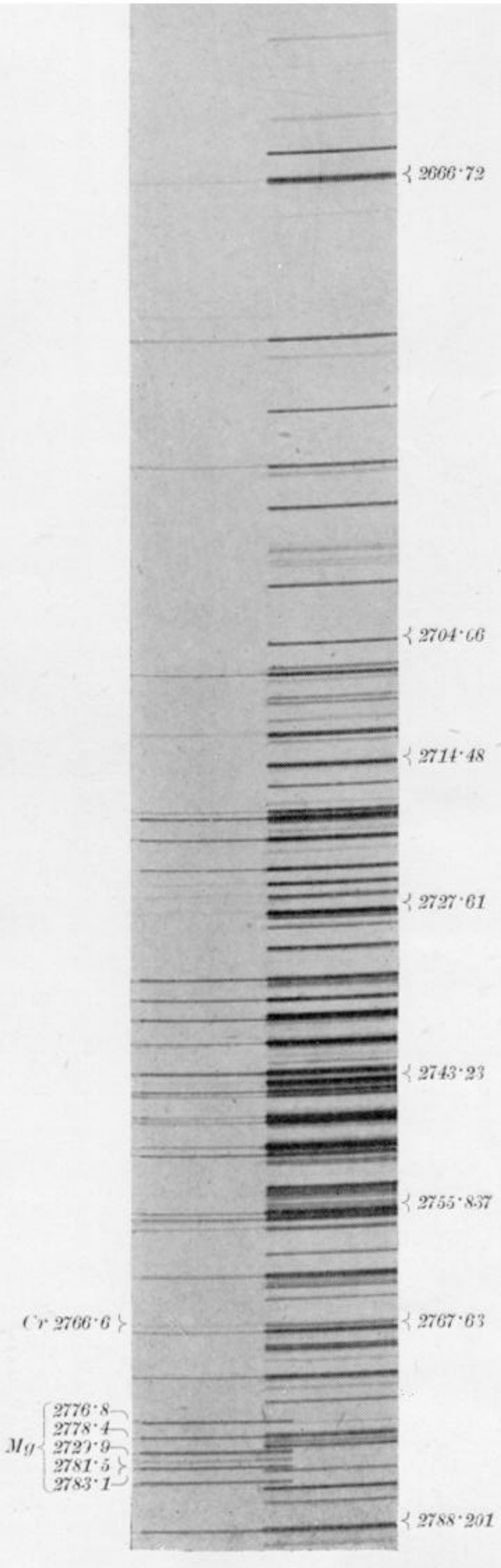

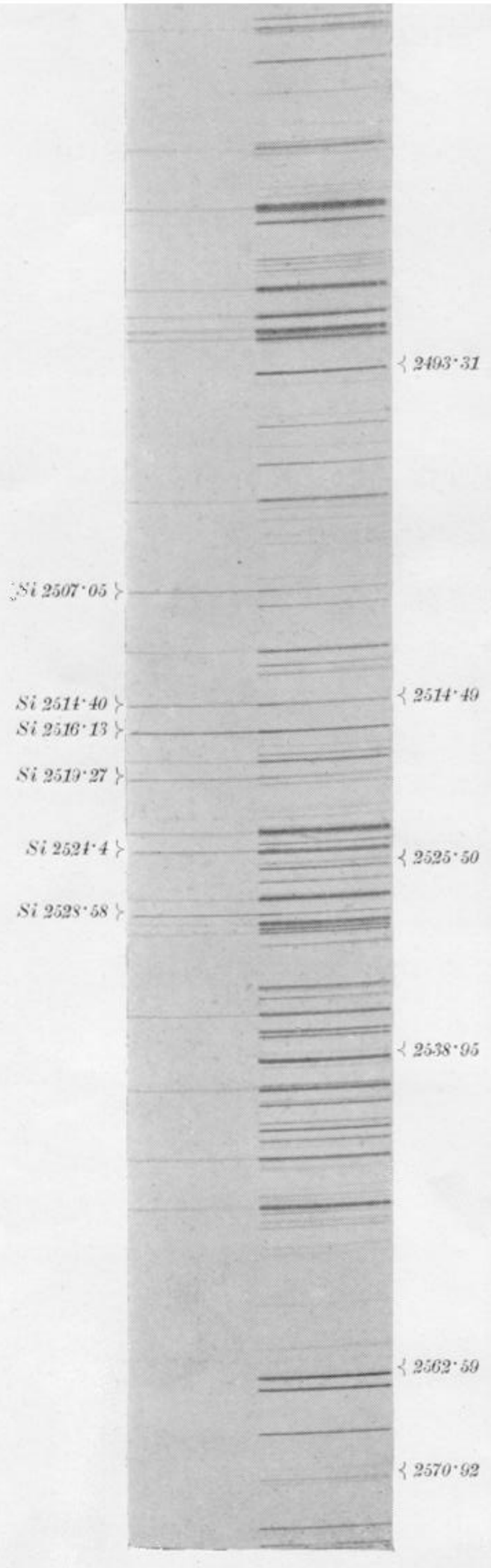

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T. DYRRING (+Ag) COMPARED WITH IRON.

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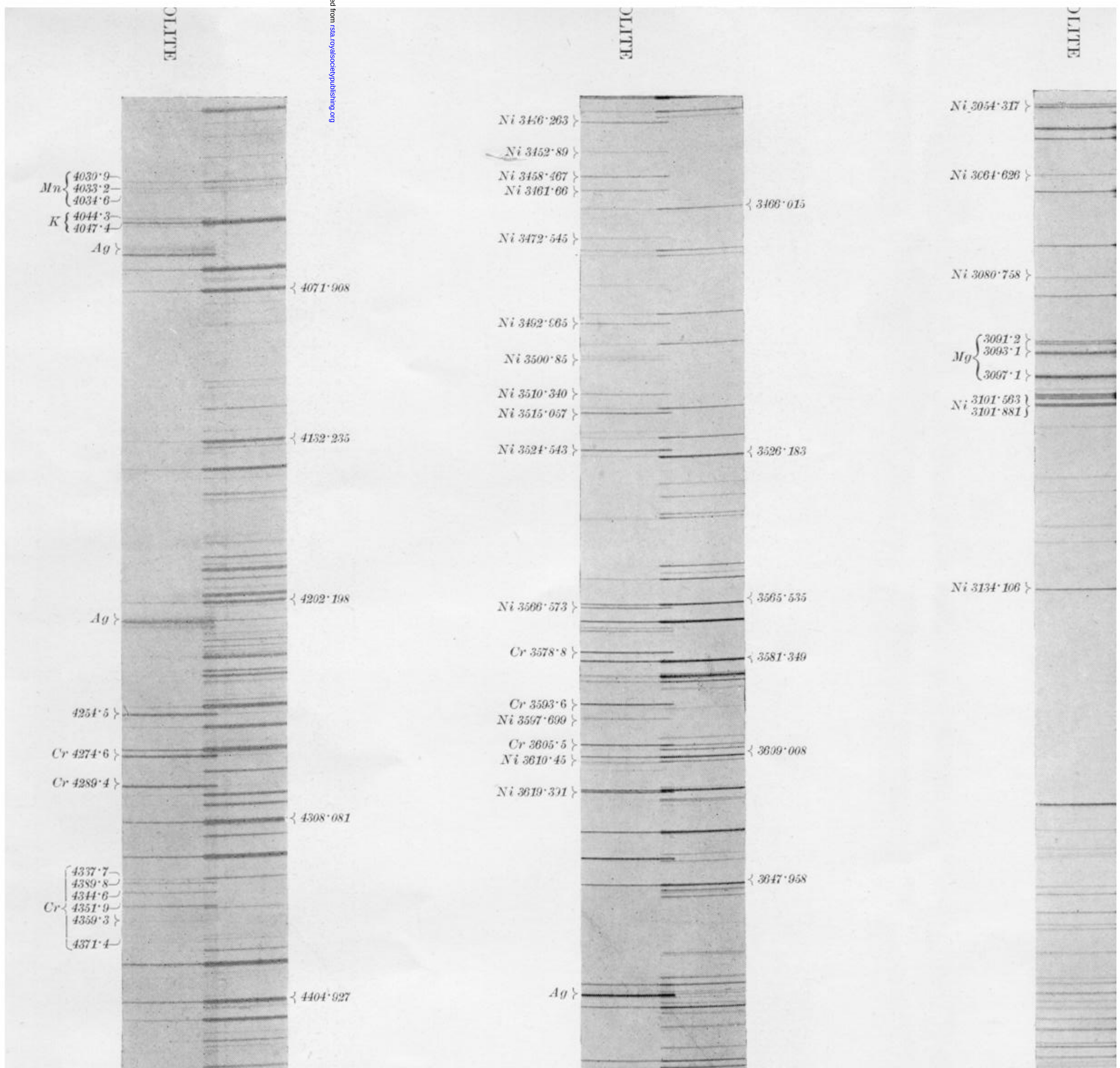

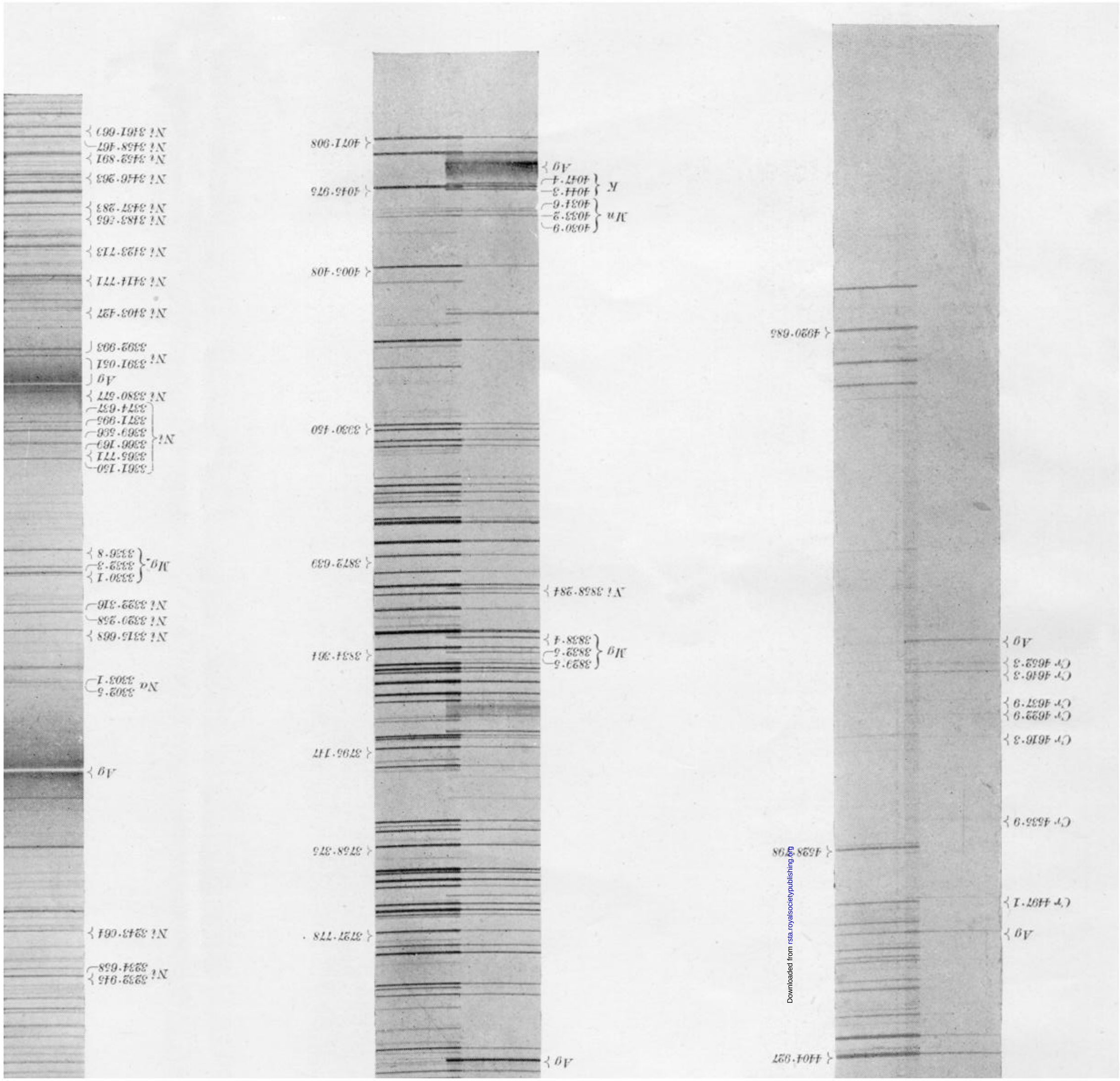

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