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The Spectrum of Scandium, and Its Relation to Solar Spectra

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III. *The Spectrum of Scandium, and its Relation to Solar Spectra.*

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INTRODUCTORY.

THE present investigation of the spectrum of scandium was undertaken in connection with the work on the spectra of sunspots and solar prominences with which I have been occupied during the past few years. The presence of scandium in spots and prominences was already well known, but all the desired information with respect to the positions and characteristics of the various lines could not be gathered from published tables.

THALÉN'S observations of the spark spectrum* extend from 4247 to 6305, but though his intensities give a useful term of comparison in some cases, the wave-lengths lack the precision necessary for use with modern solar tables, and a considerable part of the red is omitted. A few of the Fraunhofer lines were identified with scandium by ROWLAND,† but, probably for want of suitable material for the production of the scandium spectrum, the comparison was far from complete. More extensive observations of the arc and spark spectra have been made by EXNER and HASCHEK,‡ but, as they extend no further into the visible spectrum than 4744, they scarcely enter the region in which the spectra of spots and prominences are best known. The arc spectrum has been further studied by LOCKYER and BAXANDALL,§ but here again the region from 5718 to the red end was not included, and but little attempt was made to classify the lines.

Attention was specially drawn to the need for the re-determination of some of THALÉN'S wave-lengths in the course of a discussion of some observations of the spectra of sunspots in the region C to D,‖ when it was suggested that two very

* 'WATT'S Index of Spectra,' p. 125.

† 'Preliminary Table of Solar Spectrum Wave-lengths,' Chicago, 1896.

‡ 'Wellenlängen-Tabellen' (Leipzig und Wien, 1904).

§ 'Roy. Soc. Proc.,' vol. 74, p. 538 (1905).

‖ 'Monthly Notices, R.A.S.,' vol. 65, p. 211 (1905).

prominent spot lines recorded at 6210·90 and 6306·02 might be due to scandium. THALÉN's wave-lengths for strong scandium lines near these positions were 6210·0 and 6304·0—or 6211·0 and 6305·1 when corrected to ROWLAND's scale—and the identifications seemed probable in consequence of the undoubted presence in spots of the scandium line 5672·05. The wave-length 6306·02 was adopted by Father CORTIE and myself because the spot line could not be distinguished from the telluric oxygen line in that position with the instruments employed, but with greater dispersion MITCHELL* and NEWALL† subsequently identified the spot line with ROWLAND's solar line 6305·88. Observations for checking these identifications were long delayed on account of the difficulty of obtaining a specimen of scandium with which to produce the spectrum, but a few months ago, after an examination of several minerals reputed to contain rare earths, a strong scandium spectrum was obtained from a piece of South African euxenite. The spectrum obtained in this way was admixed with lines and bands of calcium, yttrium, and other substances, but it was quite adequate for the re-determination of wave-lengths, assuming the lines to have been correctly attributed to scandium by THALÉN. Measurements of photographs of the arc spectrum of the mineral removed all doubt as to the precise correspondence of the spot lines 6210·90 and 6305·88 with strong lines of scandium first tabulated by THALÉN.

The scandium lines came out so clearly in the spectra of some of the fragments of euxenite that I was induced to carry the inquiry a stage further, in view of the peculiar selection of lines for representation in the solar spectrum and in sunspots. As I have previously remarked:‡ "The scandium lines which appear in the spots are among the strongest in the arc spectrum, while the possible coincidences with the fainter lines are so few as to be probably accidental. At the same time there are some strong arc lines which are not intensified in the spots; it is a noticeable fact that these are more intense in the solar spectrum than those which appear in the spots, and the probability is that all of them, like 5527·03, are related to the enhanced-line class." There is a similar selection of lines in the chromospheric spectrum, as also remarked by LOCKYER and BAXANDALL, but the lines are different from those which appear in spots.

Similar differences of behaviour have been noted in the case of other elements, but scandium appeared to be rather an extreme example, and further study of the varying intensities of its lines promised to be of value, not only in identifying particular lines with scandium, but in helping to establish the principles to be followed in assigning solar lines of different classes to metallic origins.

On comparing the euxenite spectrum with the scandium arc recorded by LOCKYER and BAXANDALL it was at once evident that the intensities assigned in the two cases were often widely different. For example, the two lines 5527 and 5672 are given as

* 'Astrophys. Jour.,' vol. 22, p. 27 (1905).

† 'Monthly Notices, R.A.S.,' vol. 67, p. 167 (1906).

‡ 'Trans. Int. Sol. Union,' vol. 1, p. 228 (1906).

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10 and 9 respectively in the scandium arc, while in the euxenite arc the former was less than half the intensity of the latter. Such differences as this are no doubt to be accounted for by differences in the conditions of experiment. LOCKYER and BAXANDALL worked with scandium oxalate, and probably obtained what may be properly considered the arc spectrum of the element. In euxenite, on the other hand, the presence of calcium and other substances tended to produce the condition of a "flaming arc," and the scandium lines doubtless appeared with intensities approximating to those proper to the "arc-flame" or "flame" spectrum. That is, in euxenite the presumably "enhanced lines"* were notably weakened as compared with their intensities in the true arc spectrum. Further evidence that these weakened lines were enhanced lines was given in some cases by comparison with the spark intensities of THALÉN.

Although a comparison of intensities estimated by different observers is often apt to be misleading, the "inversions" in the case of several scandium lines were sufficiently pronounced to support the previous deduction, from the behaviour of other elements, that flame lines were strengthened and enhanced lines weakened in spots, while the enhanced lines might appear alone in the upper chromosphere.

At this stage of the investigation I was fortunate enough to receive the valuable assistance of Sir WILLIAM CROOKES. In reply to an inquiry about two years ago Sir WILLIAM CROOKES informed me that scandium was extremely scarce, and that, although he had been carefully collecting residues for some time, he had not then obtained sufficient for a satisfactory examination of the spectrum. By the end of last year, however, when I acquainted him with the results obtained from euxenite, he not only informed me that he had succeeded in collecting and purifying a considerable amount of scandia (Sc_2O_3), but very generously placed half a gramme of the substance at my disposal. It thus became possible to make a much more complete catalogue of scandium lines, and a more satisfactory investigation of the behaviour of the lines under varying experimental conditions. As Sir WILLIAM CROOKES was himself occupied with the spark spectrum, the electric arc was exclusively employed in my own work, but the conditions were varied so as to give in some cases an approach to the spark spectrum, and in others to the flame spectrum.

The Spectrograph Employed.

The photographs were taken with a spectrograph of Littrow form, having a lens of 12 feet focal length, and one prism of 60° for which μ_D is 1·6467. The plates are 12 inches in length, and show satisfactory definition throughout, the region covered being 3930 to 4670, or 4670 to 6600, according to the position of the mirror which

* "Enhanced lines" are lines which are relatively strengthened in passing from the arc to the spark (LOCKYER).

returns the light through the prism. At 6600 the linear dispersion is 12·7 tenth-metres to the millimetre, while at 3930 it increases to 1·8 tenth-metres per millimetre.

The determination of wave-lengths was made in the usual manner with the aid of the Cornu-Hartmann interpolation formula for prismatic spectra, a separate equation being computed for each region of 100 to 200 tenth-metres. Lines in a comparison spectrum of iron, slightly overlapping that of scandium, were used as standards, ROWLAND'S solar wave-lengths for corresponding lines being adopted. Numerous iron lines were included in the measures, and small corrections, depending upon the degree of agreement between the computed and observed values of these extra lines, were applied to the resulting wave-lengths for scandium.

On comparison with LOCKYER and BAXANDALL'S wave-lengths, it was found that there were small systematic differences in some parts of the spectrum which persisted after repeated measurements of different plates. It was accordingly thought desirable to take another photograph in which iron was mixed with scandia, so that there should be no possibility of a relative displacement of the comparison lines. The previously deduced wave-lengths were fully confirmed by this procedure.

For all but the weakest lines it is hoped that in the part of the spectrum more refrangible than D the wave-lengths are correct to within two or three hundredths of a tenth-metre, while on the red side of D, in consequence of the smaller dispersion, the errors may be somewhat greater.

The Arc Spectrum.

The arc spectrum was produced in the ordinary manner by introducing a small quantity of scandia between carbon poles, the current being obtained from the 110-volt lighting circuit. The P.D. between the poles was about 40 volts, and the current 8 amperes. The scandia did not volatilise very readily, and with the small amount of material that one felt justified in using, carbon flutings were also present in the spectrum and tended to conceal some of the fainter metallic lines. Better results were obtained by mixing a little silicate of soda or silicate of potash with the scandia, the carbon flutings being then practically eliminated, and a good spectrum secured with a very small amount of scandia. The few impurity lines introduced in this way were readily recognised, and were less objectionable than the multitude of lines composing the carbon flutings. To avoid unnecessary waste of so rare a substance, the arc was usually enclosed in a glass globe, so that the residues might be collected and the scandia subsequently separated by chemical treatment.

A list of the arc lines between K and C is given in Table I., at the end of this paper. The intensities are on a scale such that 10 corresponds to the brightest lines, and 1 to lines which are just well visible on negatives taken with moderate exposures; very faint lines, which only appeared clearly on strong photographs, are indicated, on ROWLAND'S plan, by 0 and 00. The estimates of intensity are based on an examination of several negatives made with varying exposures, as there is a tendency for small differences in the brighter lines to be effaced by long exposure. It should be understood, however, that the intensities estimated in this way indicate little more than the relative brightnesses of the lines in the same part of the spectrum.

The enhanced lines, of which 5527·0 may be taken as a type, fluctuated considerably in intensity in the arc and appeared differently on different photographs. Nevertheless, all the lines of this class varied together, so that there was no change in the intensities of the enhanced lines with respect to each other, but only with respect to the arc lines.

The flutings which occur in the arc spectrum are dealt with under a separate heading.

The Arc in Hydrogen.

The well-known experiments of CREW* and others† have shown that, when the arc is surrounded by an atmosphere of hydrogen, the spectrum changes in the direction of that given by the spark. Flame lines are relatively reduced and enhanced lines increased in intensity.

Photographs of the scandium arc in hydrogen, at a pressure of about 75 mm., were taken, and the enhanced lines were readily identified by their strengthening when observed in this way. The use of the arc in hydrogen probably does not reveal anything more than the spark as regards the line spectrum, but is sometimes a convenient method of arriving at the same result. Scandia, however, was rather refractory under this treatment, and it was not found possible to avoid the presence of carbon flutings in the photographs.

An interesting result of this experiment was the complete disappearance of the scandium flutings which form such a striking feature of the arc in air.

Although the enhanced lines as a whole were brightened when the arc was passed in hydrogen, their relative intensities were not appreciably different from those found in the ordinary arc. It would therefore serve no useful purpose to give separate estimates of the intensities of the lines in hydrogen. Following LOCKYER's notation, the enhanced lines are indicated, in the second column of Table I., by the letter "p" following the intensity number, p being an abbreviation for "proto," so that pSc signifies "protoscandium," and so on.

For the more refrangible part of the spectrum (3930 to 4670) the enhanced lines were identified first by their behaviour in the arc-flame, as explained under the next heading, and checked by reference to a photograph of the spark spectrum which was kindly forwarded to me by Sir WILLIAM CROOKES.

It should be noted that the enhanced lines of scandium differ from those of iron, titanium, and certain other elements, in exhibiting themselves with relatively great

* 'Astrophys. Jour.,' vol. 12, p. 167 (1900).

† 'Roy. Soc. Proc.,' vol. 72, p. 253 (1903).

intensity in the ordinary arc spectrum, as well as in the spark spectrum. Why this should be so is not quite clear, but scandium is not alone in this behaviour, as reference to the spectra of calcium, strontium, and barium will show, though this point has received little attention hitherto. In the case of the iron arc, the enhanced lines are almost insignificant in the integrated light, but they appear with considerable intensity close to the positive pole, and with less intensity near the negative pole.* It would seem that in the case of scandium and the other elements named the region of the arc in which enhanced lines are produced is of greater extent than in the case of such substances as iron. However that may be, the H and K lines of calcium, the lines 4078, 4215 of strontium, the lines 4554, 4934 of barium, and the lines of scandium in question, have all the other characteristics of enhanced lines and may be properly regarded as such. They are weakened in the flame, relatively brightened in the spark, and are isolated from the other lines of the arc spectra when observed in the upper chromosphere and in certain stellar spectra. The enhanced lines are, in fact, to be regarded as forming a distinct spectrum of scandium, which may or may not co-exist with the other lines according to circumstances. A separate list of these lines is given in Table V.

The Arc-Flame Spectrum.

An economical method of producing an approximation to the flame spectrum was suggested by the observations of the spectrum of euxenite, to which reference has already been made. It was felt that the material available was inadequate for the effective use of the oxyhydrogen flame, or even for the comparatively long exposures required for the outer part of the flame of an ordinary arc.

The method of purposely introducing other substances into the arc was therefore adopted, the idea being to produce a "flaming arc" without unduly increasing the number of impurity lines in the spectrum. For this purpose silicate of soda, silicate of potash, and sodium chloride were separately tried and found to be effective if used in sufficient quantity. A very long "arc" was thus obtained (the P.D. between the poles falling to about 30 volts), and photographs were secured in which the enhanced lines, including even the strong line 5527, were reduced to mere traces. In the blue end of the spectrum the strong enhanced lines were much enfeebled in other photographs covering this region, and it might have been possible to abolish these lines also if more material had been available for continued experiments.

It should be mentioned that the spectrum fluctuated considerably, the enhanced lines occasionally coming in as in the ordinary arc, but, so far as possible, the exposures were only made in the intervals when visual observations showed that the enhanced lines were absent from the spectrum. The desired condition could be restored, in a general way, by adding more of the supplementary substance.

* FOWLER, 'Monthly Notices R.A.S.,' vol. 67, p. 154 (1906).

A valuable confirmation of the identification of the enhanced lines was thus obtained, but as regards the remaining lines it can only be said that, within the limits of these experiments, the brighter arc lines survived in the "arc-flame" with little change in their relative intensities.

The arc-flame spectrum may accordingly be regarded as consisting of the brighter lines of the arc spectrum, except that the enhanced lines (indicated by "p" in the second column of Table I.) are entirely absent. Separate estimates of intensities in the arc-flame would therefore be superfluous, and might be misleading. The principal lines of the arc-flame spectrum are brought together in Table IV.

Impurities.

Allowing for the impurities known to be introduced by the use of carbon poles, or by admixture with other substances for the special purposes already mentioned, there is no evidence of any considerable impurity in the scandia so carefully prepared by Sir WILLIAM CROOKES. In the blue end of the spectrum, thanks chiefly to the admirable work of EXNER and HASCHEK, fairly complete data are available for the detection of such impurities, and in this region at least, with the exception of the yttrium line 4883·8, all the probable impurity lines are extremely faint. In the less refrangible parts of the spectrum the existing records do not permit the identification of impurities to the same extent, but from the evidence afforded by the blue end it is unlikely that any but very faint lines will turn out to be due to substances other than scandium.

A list of the lines rejected as impurities (excluding those of calcium, barium, iron, sodium, and potassium introduced in the course of the observations) is given in Table II. It will be seen that the principal impurity lines are attributed to yttrium, ytterbium, thorium, and cerium, while a few lines are probably due to samarium, gadolinium, and europium. Other faint lines at present included in the general list of scandium lines, Table I., may subsequently have to be rejected as impurity lines, more especially those which occur in the region less refrangible than 4700.

As will be seen from Table I., not more than two of the lines given by EXNER and HASCHEK do not occur in Sir WILLIAM CROOKES' scandia, while several of LOCKYER and BAXANDALL's lines have not been found. The scandium oxalate with which the latter observers worked was admittedly impure, and it would appear probable that lines given by them which do not occur in my own list are not due to scandium. As no list of rejected lines was given by LOCKYER and BAXANDALL, it cannot be determined to what extent the additional lines in my table should be attributed to impurities on similar grounds.

As already remarked, impurity lines in my own catalogue are probably only to be expected among those of very low intensity, but several well-marked lines are not recorded by LOCKYER and BAXANDALL. In reply to an inquiry as to three of these lines, 5210·7, 5219·7, and 5375·5, all of which were given as scandium lines by THALÉN, Sir NORMAN LOCKYER has kindly informed me that weak lines in these positions were found on the Kensington photographs, but not included in the published list. The line at 5210·7 was almost masked by the shading from the strong silver line 5209·6 arising from the silver poles employed for the arc, and this probably accounts for its being passed over. In the case of 5219·7 the line was marked on the photograph as an impurity, but the record as to the substance to which it was attributed has been misplaced. The third line, 5375·5, was omitted as being possibly due to thorium, for which THALÉN gives a fairly strong line at 5374·6, or 5375·6 when corrected to ROWLAND'S scale. A photograph of the thorium spectrum, taken for the purpose, shows that the line in question is not truly coincident with the thorium line. There accordingly seems to be no sufficient reason why these three lines should not be regarded as part of the scandium spectrum.

Flutings.

In addition to the line spectrum, all the photographs, with the exception of those of the arc in hydrogen, show a fluted spectrum which is especially strong towards the red end, but extends also into the green and blue-green. Several of these flutings have previously been noted in the spark spectrum by THALÉN, who regarded them as being probably due to the oxide of scandium and not to the metal itself. The complete disappearance of the flutings when the arc is passed in hydrogen tends to confirm THALÉN'S view that they originate in the oxide, but no further research on this point has yet been undertaken.

A list of the flutings, all of which fade away towards the red, is given in Table III. An attempt has been made to include all the fainter heads as well as the bright ones, but some of the heads are rather diffuse and the positions consequently somewhat uncertain.

By far the brightest group of flutings is in the orange-red, beginning at 6017·3, and there are fainter groups beginning at 6408·7 and 5737·2. There are no flutings in the middle green, but three rather feeble flutings, showing structure lines over a long range, begin at 4672·8, 4858·2, and 5133·8. No flutings have been found in the blue and violet.

In the sunspot spectrum there is a hazy line about 6036·6 which may perhaps correspond with the brightest scandium fluting measured as 6036·48, but as the other bright heads cannot certainly be traced (partly on account of Fraunhofer lines) the evidence as to the presence of scandium oxide in spots is very slight.

Comparison with the Solar Spectrum.

Several important additions to ROWLAND'S identifications of solar lines with scandium were made by LOCKYER and BAXANDALL, and other possible coincidences were indicated. The intensities of the solar lines, however, were often disproportionate to those of corresponding lines in the arc spectrum.

If we dealt only with the arc spectrum of the element in relation to the sun, the selection of lines for representation in the Fraunhofer spectrum would certainly be very remarkable. Of two lines in the same part of the spectrum one may be a comparatively strong line in the sun, while the other, although at least equally strong in the arc, may be weak or missing. For example, the strong line 5672 only occurs with intensity 0 in the sun, while 5684, which is much weaker in the arc, appears with intensity 1 in the sun.

These differences, however, become comprehensible when due attention is given to the properties of the different lines. The lines of scandium which appear most prominently among the Fraunhofer lines are, in fact, the enhanced lines, and within the limits of error of estimation they appear with relative intensities which are identical with those in the terrestrial spectrum. Lines other than those which are enhanced, even though strong lines in the arc, occur only as very faint lines in the solar spectrum.

The coincidences between scandium and solar lines, within the limits of error, are numerous, but many of them cannot reasonably be regarded as other than accidental. Even a faint solar line may properly be attributed to scandium if coincident with an enhanced line of corresponding intensity; but if the scandium line be not an enhanced one, the coincidence can only be accepted as significant when the solar line is faint and the scandium line strong.

The solar lines which may be regarded as true identifications with scandium, in accordance with this conclusion, are indicated in Tables IV. and V., one showing coincidences with arc-flame lines, and the other with enhanced lines. It will be seen that, notwithstanding the occasional confusion caused by lines of other elements, the stronger lines of the arc-flame are represented as consistently as can be expected when dealing with very faint lines appearing in such a complex spectrum as that of the sun. The identification of the enhanced lines, as shown in Table V., is much more definite, in consequence of the greater intensities of the corresponding solar lines.

The result of this comparison is of further interest in relation to the structure of the reversing layer. It has already been suggested by JEWELL,* MITCHELL,† and others, that different Fraunhofer lines are produced at different levels, and the discussion of the scandium lines tends to support this view. In the case of iron all the arc lines, down to the faintest, are well represented by dark lines in the sun, and there are no enhanced lines so strongly shown as the stronger arc lines. With scandium it is just the opposite, and the simplest supposition to make is that only a small amount of scandium absorption originates at the level which produces the majority of the Fraunhofer iron lines. Since direct observations show that enhanced

* 'Astrophys. Jour.,' vol. 4, p. 138 (1896).

† 'Astrophys. Jour.,' vol. 22, p. 37 (1905).

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lines, both of scandium and iron, occur in the upper chromosphere (see p. 59), it seems to follow that the greater part of the scandium absorption is produced at a relatively high level, where the conditions are such as to bring about the comparative isolation of the enhanced lines. The same is probably true of strontium and barium, where the enhanced lines are strong in the Fraunhofer spectrum, and in the upper chromosphere, while the arc lines are feeble or missing.

It results that while in the case of some elements solar identifications are to be based chiefly on arc lines, in others it is the enhanced lines which may be expected to show the most important coincidences.

Comparison with the Sunspot Spectrum.

The previous work of HALE* and myself† has shown that in the spectra of sunspots there is a general tendency for Fraunhofer lines of enhanced metallic origins to be weakened, while flame lines are specially selected for strengthening. This difference of behaviour is well marked in the case of scandium, as will be seen from Tables IV. and V. The data for spots given under "HALE" are derived from the Mount Wilson preliminary catalogue of spot lines, extending from 5009 to 5853,‡ and from the recent more detailed list covering the region 4000 to 4500.§ The intensities under my own name have been derived either from the Mount Wilson photographic map of the spot spectrum (4600 to 7200), or from photographs in the region 3930 to 5800 which have been kindly placed at my disposal by Mr. MICHIE SMITH, Director of the Kodaikanal Observatory, India. Several lines which have escaped record in the published catalogues of spot lines are clearly seen to be affected when special attention is directed to them. Some of the lines have also been noted in my own visual observations, and in those of CORTIE and MITCHELL.

Referring first to the enhanced lines of scandium (Table V.), it is evident that in the less refrangible parts of the spectrum there is a distinct weakening of these lines in spots, while in the region more refrangible than F the evidence as to actual weakening is very slight. For the most part there is no definite change of intensity of the enhanced lines in the blue end of the spectrum, but it has already been recognised that, on account of photospheric light diffused over the spot, or from still undetermined causes, the sunspot spectrum as a whole tends to lose its characteristic features in the blue and violet, in so far as it has yet been photographically registered.‖ If the difference in the two parts of the spectrum be real, and independent of the conditions of observation, it may be that the phenomenon is related to that found in

* 'Astrophys. Jour.,' vol. 24, p. 202 (1906).

† 'Trans. Int. Sol. Union,' vol. 1, p. 228 (1906).

‡ 'Astrophys. Jour.,' vol. 23, p. 15 (1906).

§ 'Astrophys. Jour.,' vol. 27, p. 45 (1908).

‖ HALE, 'Astrophys. Jour.,' vol. 25, p. 90 (1907).

some of the Wolf-Rayet stars, where the less refrangible lines of hydrogen are bright and the more refrangible ones dark.*

A general comparison of the unenhanced lines with the spot spectrum shows that all the more prominent lines are considerably strengthened in passing from the sun to the spot. Seeing that the spot spectrum is far more crowded with lines and flutings than the solar spectrum, it is not surprising that there are several apparent coincidences of spot lines with the fainter lines of scandium, but, with our present knowledge, it would be unphilosophical to regard such occasional coincidences as significant. The only scandium lines which can confidently be regarded as intensified in the spot spectrum are, in fact, those which are brightest in the arc-flame spectrum previously described. The strongest line of all is 6305·88, and other prominent lines are 6210·90, 5700·40, 5687·05, and 5672·05; in the blue end, the strengthening of arc-flame lines, like the weakening of enhanced lines, is less marked in the photographs at present available.

The principal lines of the arc-flame spectrum, including all the unenhanced lines of intensity 6 or more from Table I., are brought together in Table IV. and compared with the sun and sunspots. There is a certain amount of confusion with lines of other elements in spots, but it may be reasonably concluded that the intensities of the lines in spots correspond closely with their intensities in the arc-flame. The line 5514·44 does not appear in the spot spectrum as might have been expected, but it is at the lower limit of intensity, and it would be unwise to conclude from the behaviour of a single line that the conditions in spots are very different from those of the arc-flame. It may be supposed that while there is a general increase in the scandium flame absorption, the increase does not suffice to bring the fainter lines to an intensity within the range of observation.

It is quite certain, therefore, that while the enhanced lines of scandium are weakened in spots, the remaining lines are strengthened more or less in proportion to their intensities in the arc-flame, at least in the less refrangible parts of the spectrum. As the relative intensities of the two sets of lines in spots approximate to those found in the arc spectrum, it is possible that there is a descent of scandium vapour from the upper region, where the conditions are such as to produce enhanced lines, to a lower level where the prevailing conditions approximate to those of the arc. Reduced temperature of the spot vapour, accompanying this change of level, perhaps provides the readiest explanation of the difference between the Fraunhofer and spot spectrum, but much further investigation in several directions is necessary before the precise nature of the action in spots can be ascertained.

Comparison with the Chromosphere.

Two principal sources of data relating to the chromosphere are available for

* CAMPBELL, 'Ast. and Astrophysics,' vol. 13, p. 457 (1894).

comparison with terrestrial spectra: namely, eclipse photographs, and visual observations made at ordinary times, the former being especially valuable for the blue end, and the latter for the less refrangible parts of the spectrum. Eclipse records are now numerous, but completely satisfactory discussions of the lines are not yet possible, owing to discordances in the wave-lengths given by different observers, and the inadequate resolving powers of most of the instruments which have been employed. Nevertheless, since identifications usually depend upon apparent agreement in wave-lengths and intensities of several lines of the same substance, there is reasonable certainty as to the origins of many of the lines.

YOUNG'S well-known catalogue of chromospheric lines,* observed without eclipse, remains the principal source of information with regard to the less refrangible parts of the spectrum, though supplementary observations have been made by MITCHELL,† NAGARAJA,‡ and myself.§ Further determinations of the wave-lengths and characters of many of the chromospheric lines, however, are urgently needed. YOUNG'S observations were mostly made before ROWLAND'S photographic map of the solar spectrum became available, and his subsequent revision was only fragmentary, so that many of the wave-lengths cannot be regarded as final. A more complete distinction between "high-level" and "low-level" lines is also greatly to be desired.

A few lines of scandium have been noted by LOCKYER and others in eclipse spectra, and a greater number by DYSON,‖ who pointed out that the intensities agree well with those of the spark. Making due allowance for the lack of highly precise data, the general result of the more complete comparison which is now possible is to show that it is only the enhanced lines of this element which can be regarded as contributing to the chromospheric spectrum. Of the four strongest lines of the arc-flame spectrum, 6305·88, 5672·05, 4023·83, and 4020·55, there is no suggestion of a chromospheric coincidence except in the case of the last; DYSON gives a line at 4020·50 in his eclipse list, but, as there is no indication of the adjacent similar line at 4023, the coincidence may be considered accidental, especially as the wave-length given by EVERSHED¶ is 4020·3.

A complete list of the enhanced lines of scandium is given in Table V., which also shows the corresponding solar and chromospheric lines. For the region more refrangible than 4670, the latter have been taken from DYSON'S tables, while the less refrangible lines, with their "frequencies" and brightnesses, are from YOUNG'S catalogue. All the brighter enhanced lines are obviously present in the chromosphere, but the fainter ones, as might be expected, have not yet been recorded.

* SCHEINER'S 'Astronomical Spectroscopy,' FROST'S translation, pp. 184 and 423.

† 'Astrophys. Jour.,' vol. 24, p. 82 (1906).

‡ 'Astrophys. Jour.,' vol. 26, p. 150 (1907).

§ 'Monthly Not. R.A.S.,' vol. 66, p. 362 (1906).

‖ 'Phil. Trans.,' A, vol. 206, p. 440 (1906).

¶ 'Phil. Trans.,' A, vol. 201, p. 487 (1903).

Apart from the interference of other lines, the intensities correspond closely with those of the terrestrial spectrum.

This result is in good accordance with the work of LOCKYER on eclipse spectra, which has shown that enhanced lines in general are specially developed in the chromosphere. My own observations* have further shown that enhanced lines appear as "high-level" lines in the chromosphere, while arc lines are mostly restricted to the region near the photosphere. In the case of scandium, the enhanced line 5527 is certainly a high-level line, and 5240, according to my recent observations, is of the same type. That the same is true of other enhanced lines in the blue, notably 4247, is indicated by the lengths of the corresponding arcs in photographs of eclipses taken with the prismatic camera. In YOUNG's catalogue high frequency may often be taken as an indication of high level, since lines of the latter class are brought into view by comparatively feeble disturbances, and the lines 5031, 5658, and 5684 may be regarded as of the high-level class from this evidence.

It may therefore be concluded that scandium exists in the higher reaches of the chromosphere, under conditions specially favourable to the production of enhanced lines, while there is no evidence of its presence at lower levels except that afforded by the feebly developed arc lines in the Fraunhofer spectrum.

Summary of Results.

1. The arc spectrum of scandium consists of two distinct sets of lines, which behave very differently in solar spectra. Each set includes both strong and faint lines.

2. Lines belonging to one set correspond with the enhanced lines of other elements, notwithstanding that they appear strongly in the ordinary arc spectrum.

(*a*) These lines are very feeble or missing from the arc-flame spectrum, and are strengthened in passing to the arc, the arc in hydrogen, or the spark.
(*b*) They occur as relatively strong lines in the Fraunhofer spectrum.
(*c*) They are weakened in the sun-spot spectrum.
(*d*) They occur as high-level lines in the chromosphere.

3. The remaining lines show a great contrast when compared with the first group.

(*a*) They are relatively strong lines in the arc-flame.
(*b*) They are very feebly represented in the Fraunhofer spectrum.
(*c*) The stronger lines are prominent in sun-spot spectra.
(*d*) They have not been recorded in the spectrum of the chromosphere.

4. The special development of the enhanced lines in the Fraunhofer spectrum, together with their presence in the upper chromosphere, indicates that the greater

* 'Monthly Not. R.A.S.,' vol. 66, p. 362 (1906).

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part of the scandium absorption in the solar spectrum originates at a higher level than that at which the greater part of the iron absorption is produced.

5. The discussion of scandium lines indicates that while in the case of some elements solar identifications are to be based chiefly on arc lines, in others it is the enhanced lines which may be expected to show the most important coincidences.

6. The flutings which occur in the arc and arc-flame spectra do not appear when the arc is passed in an atmosphere of hydrogen. As suggested by THALÉN, they are probably due to oxide of scandium.

In concluding this paper the author is anxious to express his great indebtedness to Sir WILLIAM CROOKES, without whose aid in providing purified scandia the greater part of the investigation would not have been possible. Valuable assistance in taking the photographs, and in checking some of the determinations of wave-lengths, has also been rendered by Miss L. ALCOCK, A.R.C.S., B.Sc., H. SHAW, A.R.C.S., and A. EAGLE, A.R.C.S.

TABLE I.—Arc Spectrum of Scandium.

FOWLER.		LOCKYER and BAXANDALL.		EXNER and HASCHEK.		Remarks.
Wave-length.	Intensity.	Wave-length.	Intensity.	Wave-length.	Intensity.	
3933·55	3	*		3933·59	6	* Possibly masked by Ca line.
	*			52·43	1	* Photographs rather weak here.
89·18	0			89·18	1	
96·76	6	3996·75	5	96·79	15	ROWLAND gives Sc in sun at 96·68.
4014·65	2p*	4014·66	3	4014·68	6	* Lines marked "p" are enhanced lines.
20·55	9	20·55	8	20·60	20	Strong arc-flame line.
23·40	0			23·36	1	
23·83	10	23·88	8	23·88	30	Strongest line of arc-flame spectrum in blue.
31·53	1			31·51	2	
34·37	0			34·35	2	
37·00	0			36·98	1	
43·98	2			43·97	2	
46·64	1			46·64	2	
47·96	4	47·97	4–5	47·98	10	
50·11	1			50·09	2	
52·00	0			52·00	1	
54·71	6	54·68	3	54·71	10	
56·75	2			56·72	3	
67·17	1			67·15	2	
75·13	1			75·13	2	
78·72	1			78·70	2	
82·59	7	82·59	6	82·60	15	Strong arc-flame line.
86·20	0			86·15	1	
		86·67	2–3			

TABLE I (continued).

Fowler.		Lockyer and Baxandall.		Exner and Haschek.		Remarks.
Wave-length.	Intensity.	Wave-length.	Intensity.	Wave-length.	Intensity.	
4086·81	1			4086·80	3	La ?
87·29	2	4087·26	1	87·28	3	
		94·85	2–3			
95·01	1			95·03	1	
		4106·02	2–3			
4133·18	3	33·10	2	4133·10	4	
40·45	4	40·42	2–3	40·42	5	
		41·78	1			
52·52	4	52·50	3	52·51	8	
		62·85	1			
		63·77	1			
65·37	4	65·38	2–3	65·39	8	
		71·47	1–2			
71·93	2	71·98	2–3	71·92	2	
4218·41	0			4218·43	1	
19·90	0			19·90	1	
22·[illegible]7	0					
		4224·32	1			
25·78	1			25·76	1	
32·09	2			32·13	1	
33·80	2			33·83	2	
37·94	0			37·96	1	
38·25	3	38·25	2	38·21	3	
39·74	0			39·72	1	
46·30	0			46·27	1	
47·00	10p	47·00	10	47·02	50	Strongest enhanced line in blue.
				51·22	1	
59·86	0					
83·74	1			83·71	1	
86·73	1			86·71	1	Er ?
94·94	4p	94·91	4–5	94·94	5	
4305·88	4p	4305·83	4–5	4305·89	8	
14·25	7p	14·25	9	14·31	30	} Strong enhanced triplet.
20·91	7p	20·90	9	20·98	20	}
25·15	6p	25·15	8	25·22	20	}
48·66	0					
54·78	4p	54·74	3–4	54·79	3	
58·85	1			58·85	1	
59·23	1			59·25	1	
59·83	0					
65·11	1					
74·68	8p	74·65	8	74·69	20	Strong enhanced line.
75·34	0			75·32	1	
81·43	1					
84·97	3p	84·99	4	84·98	3	
89·75	1			89·76	1	
4400·56	8p	4400·56	8	4400·63	20	Strong enhanced line.
15·72	7p	15·72	7	15·78	20	" "
20·83	1p	20·82	1–2	20·84	1	
29·08	0					

TABLE I. (continued).

Fowler.		Lockyer and Baxandall.		Exner and Haschek.		Remarks.
Wave-length.	Intensity.	Wave-length.	Intensity.	Wave-length.	Intensity.	
4431·53	1p	4431·56	2–3	4431·52	2	
4542·76	1			4542·74	1	
44·88	2			44·86	1	
57·42	2			57·45	1	
		4563·40	2			
74·20	2			74·20	2	
79·15	1					
4604·94	1			4604·88	1	
09·71	0					
10·16	0					
10·59	0					
70·59	6p	4670·59	7	70·59	5	
80·68	2					
82·16	0					
4707·10	2					
09·51	2			4709·53	1	
11·90	0					
14·03	1					
14·52	1					Ce ?
16·44	1					
17·21	0					
19·48	1					
20·95	0					
28·95	2			29·00	1	
29·39	5	4729·39	3	29·43	2	
32·46	1					
34·28	5	34·31	3–4	34·31	3	
35·27	1					
37·82	6	37·88	4	37·86	3	
41·20	7	41·24	5	41·23	4	
43·98	8	44·04	6	44·01	5	
46·32	1					
49·15	1			(Record	ends.)	
				Thalén (spark).*		
53·35	6			4753·8	1	
59·11	1					
63·25	3					
71·60	1					
79·53	6					
83·69	0					
84·46	0					
91·69	2					
93·14	0					
		4820·52	2–3			

* Corrected to Rowland's scale.

TABLE I. (continued).

Fowler.		Lockyer and Baxandall.		Thalén (spark).		Remarks.
Wave-length.	Intensity.	Wave-length.	Intensity.	Wave-length.	Intensity.	
4821·65	0					
27·47	4			4827·8	1	
33·85	4			33·8	1	
		4837·27	2–3			
39·63	4			38·8	1	
40·62	0					
41·00	0					
47·84	3					
52·86	4					
59·35	0					
64·95	1					
75·50	0					
78·36	2					Not Ca 78·31 or Fe 78·41.
80·90	1					
90·55	1					
93·15	1					
4906·88	2					
09·89	3			4909·5	1	
23·00	2			22·5	1	
34·39	1					Not Ba 34·24.
35·95	1					Yb ?
		4937·29	2–3			
41·49	2					
51·46	1					Er ?
54·22	4	54·12	1–2	54·5	1	
73·82	3			73·9	1	
80·50	4	80·49	1	80·4	1	
83·59	2					
		87·26	1–2			
92·07	4	92·06	1–2	91·8	1	
95·18	1					
		5009·68	2			
5014·32	1					
18·59	2					
20·30	2					
21·67	2					
31·20	6p	31·20	8	5031·1	10	Strong enhanced line.
32·88	1					
64·50	3	64·35	2	64·1	2	
68·98	1					
70·39	4	70·34	3–4	70·6	4	
75·99	3	75·85	1–2	76·1	1	
		79·79	1			
80·26	0					
81·75	8	81·68	6	81·6	6	} Strong arc-flame lines.
83·88	7	83·77	5	83·6	5	}
85·71	5	85·64	4	85·6	4	
87·17	7 {	87·06	3 }	87·0	5	
	{	87·18	2 }			
90·07	3	89·95	2	90·1	1	

TABLE I. (continued).

Fowler.		Lockyer and Baxandall.		Thalén (spark).		Remarks.
Wave-length.	Intensity.	Wave-length.	Intensity.	Wave-length.	Intensity.	
5092·54	0					
96·90	3	5096·81	2	5097·0	1	
99·38	4	99·28	3–4	99·1	4	
5101·26	3	5101·21	2	5101·1	1	
		04·43	1			
		05·60	2–3			
09·20	2	09·09	1			
		10·85	<1			
13·00	2	12·87	1			
16·86	3	16·73	2	17·6	2	
		21·60	1			
		31·14	<1			
		47·08	2			
		48·28	2			
5210·68	5			5210·8	2	
11·48	0					
19·06	0					
19·75	5			19·3	2	
39·99	5p	5239·99	5–6	39·8	8	Strong enhanced line.
58·49	5	58·46	2–3	58·3	4	
		69·65	1–2			
85·15	1					
85·90	5	85·88	2	85·5	4	
5302·12	2					
		5307·83	1			
14·91	1					
15·77	1					
18·52	2p	18·41	2	5318·3	2	
23·26	0					
23·94	0					
		25·14	2			
		28·05	1			
31·98	1					
34·43	0					Yb ?
39·58	2			40·0	1	
41·21	2			41·0	1	
43·13	2			42·5	1	
49·47	5	49·32	3	49·5	6	
49·91	2					
50·44	1					
56·26	6	56·14	3–4	56·0	6	
57·38	0					
		58·69	2–3			
75·55	5			75·6	4	Not Th.
		89·89	1–2			
92·30	6	92·12	3	92·5	6	
5416·43	3					
25·80	3					
29·62	3					
33·43	4					

TABLE I. (continued).

Fowler.		Lockyer and Baxandall.		Thalén (spark).		Remarks.
Wave-length.	Intensity.	Wave-length.	Intensity.	Wave-length.	Intensity.	
5438·54	1					
39·26	2					
42·84	3					
46·37	5			5446·5	4	
47·66	0					
51·58	4			52·0	1	
55·51	2					
65·40	1					
68·64	4					
72·42	4					
74·92	1					
		5478·66	2			
82·20	6	82·18	4	82·1	6	
84·83	6	84·81	3–4	85·1	6	
5514·44	6	5514·40	4	5514·6	6	
20·73	7	20·70	4–5	20·7	6	
27·03	10p	27·03	10	27·2	12	Strongest enhanced line in green.
36·60	2					
41·28	4					
46·63	1					
49·90	0					
50·64	0					
52·05	1					
53·84	2					
61·34	0					
65·06	3			65·2	2	
71·48	0					
79·96	0					
91·58	3	91·44	2	91·7	2	
93·60	2					
5604·40	2					
10·33	1					
24·08	2					
31·24	1					
35·10	0					Not carbon.
41·21	4p			5641·2	6	
46·60	1					
47·78	0					
49·80	2					
58·10	7p	5658·10	7	57·7	8	Strong enhanced line.
58·56	2p	58·56	3–4			
61·86	0					
67·40	3p	67·40	3–4	67·0	4	
69·28	4p	69·25	4	68·8	4	
72·05	10	72·05	9	72·3	8	Strong arc-flame line.
80·38	0					
84·43	5p	84·44	4	84·5	4	
87·05	9	87·07	8	87·3	8	Strong arc-flame line.
91·55	0					
5700·40	8	5700·38	7	5700·8	8	Strong arc-flame line.

TABLE I. (continued).

Fowler.		Lockyer and Baxandall.		Thalén (spark).		Remarks.
Wave-length.	Intensity.	Wave-length.	Intensity.	Wave-length.	Intensity.	
5708·85	5			5708·8	4	
11·97	8	5711·98	6	11·8	4	Strong arc-flame line.
17·51	5	17·54	3	17·3	4	
21·20	0	(Record	ends			
24·30	5	here.)		24·8	4	
35·40	0					
39·53	0					
41·56	1					
5894·83	2					
5919·21	3					
31·35	2					
40·70	2					
52·42	3					
61·65	3					
68·44	4					
69·37	4					
88·60	4					
6021·92	0					
26·36	3					
49·02	1					
6146·50	3					
93·94	3					
98·68	2					
6210·90	7			6211·0	8	Strong arc-flame line.
39·95	7			39·1	6	,, ,,
45·85	4p			47·1	6	Strongest enhanced line in red.
50·16	3					
59·15	6			59·1	2	
62·48	3					
73·37	0					
76·47	3					
79·95	3p			80·1	2	
84·66	3					Probably double.
93·24	2					
98·00	0					
6300·85	1p					
05·88	10			6305·1	10	Strongest arc-flame line.
10·15	2p					
21·06	2p					
22·96	0					
45·04	1					
79·02	6					
6413·54	6					
48·42	1					
86·56	0					
95·53	1					
6525·84	3					
58·28	3					

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TABLE II.—Impurity Lines omitted from Table I.

Wave-length.	Intensity.	Probable origin.	Wave-length.	Intensity.	Probable origin.
3988·10	00	Yb	4306·87	00	Ce
4077·52	0	Y	4309·81	0	Y
4143·01	0	Y	4352·30	0	Sa
4205·20	0	Eu	4364·82	0	Ce
4222·77	00	Ce	4375·10	0	Y
4231·83	0	U, Zr	4382·03	0	Th
4235·49	0	Mn	4391·30	0	Th
4248·82	0	Ce	4391·85	0	Ce
4270·90	0	Ce	4398·17	0	Y
4280·09	0	Sa	4863·36	0	Th
4282·25	0	Th	4883·86	2	Y
4290·12	0	Ce	4920·00	0	Th
4296·89	0	Ce	5402·94	0	Y
4306·46	00	Gd	5477·86	0	Yb

TABLE III.—Flutings occurring in the Arc Spectrum of Scandium Oxide. (All fade away towards the red.)

FOWLER.		THALÉN.*		Remarks.
Wave-length.	Intensity.	Wave-length.	Intensity.	
4672·85	3			Head of blue fluting } Structure traced to 4850.
4707·10	2			Probable sub-head
4858·25	4			Head of blue-green fluting } Structure traced to 5000.
4893·15	2			Sub-head
5133·86	2			Head of green fluting } Structure traced to 5300.
5171·30	1			Sub-head
5737·20	2	5737·5		Beginning of yellow group.
5761·35	1			
5764·70	2			
5773·10	3	} 5773·0		
5775·55	3			
5797·75	2			
5801·70	2	5802·4		Wide head line.
5810·15	3	} 5810·0		
5811·82	3			
5836·75	2			
5839·90	2	5843·0		Wide head line.
5848·00	3	} 5849·5		
5849·40	3			
5876·95	1			

* Corrected to ROWLAND'S scale.

TABLE III. (continued).

Fowler.		Thalén.*		Remarks.
Wave-length.	Intensity.	Wave-length.	Intensity.	
5878·15	2	5878·0		Wide head line.
5887·90	3	5887·5		,, ,,
5918·30	3	5919·0		,, ,,
5928·20	3			
5959·30	1			Wide head line.
5968·90	2			Confused with adjacent Sc lines in some photos.
6002·58	1			
6017·32	4	6017·0	4	Beginning of orange group.
6036·48	10	6038·0	10	
6055·40	2			
6064·54	9	6065·1	8	
6072·90	8	6072·6	8	
6079·60	8	6080·1	10	
6092·70	1			
6102·07	6	6101·5	6	
6110·17	5			
6116·31	6	6115·9	8	
6140·60	5	6141·1	4	Wide head line. λ rather uncertain.
6148·93	3	6146·1	2	
6154·27	4	6154·1	6	Wide head line.
6180·71	3			,, ,,
6188·35	2			
6193·20	4	6193·4	2	Wide head line.
6220·55	3			
6229·70	2			
6233·30	2			
6408·7	2			Beginning of red group.
6420·2	1			
6437·4	1			
6446·8	2			
6458·2	1–2			
6477·0	1–2			
6485·8	3			
6496·5	1			
6517·8	1			
6526·1	2			
6535·7	2			
6567·3	1			
6576·2	1			

* Corrected to ROWLAND'S scale.

TABLE IV.—Principal Arc-Flame Lines of Scandium compared with Sun and Sunspots.

Sc arc flame.		Sun (ROWLAND).		Sunspots.		Remarks.
Wave-length.	Intensity.	Wave-length and origin.	Intensity.	HALE.	FOWLER.	
3996·76	6	−96·75*	00		0	* ROWLAND attributes 96·68 (00) to Sc.
4020·55	9	Sc 20·55	1	(+Fe) 3	*	* Fe 20·64 strengthened on violet side.
4023·83	10	Sc 23·83	2	3	3–4	
4054·71	6	Sc 54·71	00	*	2	* Close double with Zr 54·59 (0). Strengthened on red side.
4082·59	7	{Sc, Fe, Ti} 82·59	3	4	4	Compound line in sun and spot.
4737·82	6	Fe ? 37·82	1		2–3*	* Probably not wholly Sc.
4741·20	7	Fe ? 41·26	1		2–3*	* ,, ,, ,,
4743·98	8	−44·01	000		1	
4753·35	6				0	
4779·53	6				*	* Fe 79·63 strengthened on violet side.
5081·75	8	−81·76	000	00	0	
5083·88	7	−83·88	000	00	0	
5087·17	7				*	* Ti 87·24 strengthened on violet side.
5356·26	6	−56·27	000	00	0	
5392·30	6				0	
5482·20	6	−82·20	0000		1–2*	* Combined with Ti 82·08.
5484·83	6	−84·85	000	00–0	0	
5514·44	6	−14·43	0000			
5520·73	7	−20·73	00	1	1	
5672·05	10	Sc 72·05	0	2	2	
5687·05	9	−87·06	000	1–2	1–2	
5700·40	8	−00·40	00	2–3*	2–3*	* H gives Cu ? 00·51 as spot line, but Sc line is included and is the more affected of the pair.
5711·97	8				*	* Fe 12·10 strengthened on violet side.
6210·90	7	−10·90	00		4	
6239·95	7	−39·98	0000		2*	* Partly masked by band lines.
6259·15	6	−59·14	0000		2	
6305·88	10	−05·88	0000		6	
6379·02	6				2–3	Falls on band of calcium hydride in spot.
6413·54	6				2	

TABLE V.—Enhanced Lines of Scandium.

Compared with Sun, Spots, and Chromosphere.

Scandium (FOWLER).		Sun (ROWLAND).		Sun-spots.		Chromosphere (DYSON).		Remarks.
				HALE.	FOWLER.			
Wave-length.	Intensity.	Wave-length.	Intensity.	Intensity.	Intensity.	Wave-length.	Intensity.	
4014·65	2	(Fe 14·68)	5		n.c.	Sc, Fe, 14·77	1	Compound line in Sun.
4247·00	10	Sc 47·00	5	6	n.c.*	Sc 47·00	10	* n.c. indicates "no change."
4294·94	4	Zr 94·94	2		n.c.	– 95·2	1	
4305·88	4	– 05·87	2		n.c.	Sr, Ti 05·83	3	Compound line in chromosphere.
4314·25	7	Sc 14·25	3	3–4	n.c.	Sc 14·31	2	
4320·91	7	Sc 20·91	3		n.c.	Sc, Ti 20·98	4	Compound line in chromosphere.
4325·15	6	Sc 25·15	4		n.c.	Sc 25·25	1	
4354·78	4	– 54·78	1		n.c.	– 54·61	1	
4374·68	8	Sc, Fe ? 74·63	3		n.c.	(Y 75·14)	7*	* Includes Sc 74·68, pTi 74·90, and pY 75·10 (LOCKYER).
4384·97	3	– 84·99	0		*			*Masked by strengthened V 84·87.
4400·56	8	Sc 00·56	3	3–4	n.c.	Sc 00·67	3	
4415·72	7	– 15·72	3	2–3	n.c.	Sc 15·65	2	
4420·83	1	– 20·83	00		oblitd.			
4431·53	1	– 31·53	0	0–1	*			* Strengthening probably due to Ti 31·46.
4670·59	6	– 70·59	2		? *	Sc 70·45	2	* Somewhat strengthened on red edge, probably due to line of another element.
						YOUNG.		
						Wave-length.	Fr. Br.*	* "Frequency" and "brightness."
5031·20	6	– 31·20	3		1–2	5031·3	4 3	
5239·99	5	– 39·99	1		00	5240·0 *	3 2	* High-level line (FOWLER).
5318·52	2	– 18·53	00		oblitd.			
5527·03	10	– 27·03	3		2	5527·0 *	40 5	* High-level line. YOUNG'S line 5525·9 (A°) identified with this by MITCHELL and FOWLER, wrongly corrected to 5528·64 in SCHEINER.
5641·21	4	– 41·21	1		0	5641·66*	1 1	* Probably wrongly corrected from 5640·2 (A°).
5658·10	7	– Y 58·10*	2	1–2	1–2	5658·10	8 3	* Y not given by THALÉN or KAYSER.
5658·56	2	– 58·56	0		000			
5667·40	3	– 67·37	0		00	5667·7 *	1 1	* Probably wrongly corrected from 5666·0 (A°).
5669·28	4	– 69·26	1	0	0	5669·2	2 2	
5684·43	5	– 84·42	1		0	5684·7 *	5 3	* This is a line of Si in Sun, but λ may have been wrongly corrected from 5683·5 (A°) or may be mistaken identification with solar line.
6245·85	4	– 45·83	1		00			
6279·95	4	– 79·95	0		*			* Probably weakened, but difficult on account of air line 80·11.
6300·85	1	– 00·90	000		1*			* Spot line probably not Sc.
6310·15	2	*						* Confused with air line 10·10 (2).
6321·06	2	– 21·07	00		oblitd.			