NEW MEASURES OF THE WAVE-LENGTHS OF THE CALCIUM LINES K AND H.

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In *Monthly Notices*, 90, 189, the wave-length of K and H in the carbon-iron arc at atmospheric pressure was determined from the nearest secondary standards of iron as follows :—

K 3933·663, H 3968·470.

The close accordance of the different series of measures, including both prism and grating spectra, appeared to show that these values could not be in error by as much as one unit in the third decimal, and no change exceeding this would seem possible unless the secondary standards of iron published by the International Astronomical Union in 1928 should be revised.

These values, however, are not in good agreement with the interferometer measures of the lines made in 1932 by the late Mr. C. V. Jackson at the Imperial College.* In this work the calcium lines were produced by a small quantity of $CaCo_3$ in a carbon arc *in vacuo*, and the measures were referred to the krypton standards between λλ 4273 and 4502. The mean values from 15 sets of observations, when corrected to atmospheric pressure, were

K 3933·666, H 3968·472.

The successful working of the liquid prism spectrograph, using ethyl cinnamate as the dispersing medium, has yielded arc spectra of iron and calcium on a scale of about 2 mm. to the angstrom with two transmissions through the prism, and between 3 and 4 mm. with four transmissions. The refracting angle of the prism is 63°, and the effective aperture for this part of the spectrum about 8 cm. The calcium lines in these spectra are very narrow, and the iron lines also are narrow and well defined, excepting the four strong lines near K, which have a central narrow absorption line. I have measured these spectra with a re-designed micrometer to see if any modification of the figures quoted above would result from the increased resolving power and scale of the spectra, and with improved methods of measuring.

The Micrometer consists of a Hilger screw mounted on an iron base-plate and furnished with a long self-adjusting nut. The screw has a millimeter pitch, which is uniform throughout the length used of about 10 cm., and there appear to be no sensible periodic errors. Attached to the nut is a brass plate, 12 by 6 cm. : of this, 4 cm. of its width overhangs the nut on the outer side, and in this portion a slot is cut, 10 cm. long by 1 cm. wide. Below this is an equally long mirror, reflecting light upwards through the slot. The glass negative to be measured is stuck to the plate by three small lumps of optical

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* *M.N.*, 93, 98, 1932.

cement, the spectrum image being placed centrally along the slot and adjusted parallel to the screw.

To prevent the nut rotating when the screw is turned either way a round steel arm is attached to it directed downwards, and bearing against a straight edge fixed on the base-plate and adjusted parallel to the screw. It is held against the straight edge by a 100-gramme weight at the end of a short arm, also attached to the nut. The end of the screw is polished flat, and bears against an optically worked sapphire thrust block. It is held against this by a spring acting on a shoulder on the screw shaft at the drum end of the screw, according to the design of Messrs. Hilger.

It will be seen from this short description that friction is reduced to a minimum. The screw simply moves the nut carrying the photograph, the only friction other than the screw bearings and the nut itself is the sliding of the steel arm against the straight edge. The result is that backlash on reversing the motion is very nearly abolished, and wear on screw and nut is inappreciable.

The rest of the instrument is designed to facilitate measuring by the positive on negative method, or by the usual scheme of bisecting the spectrum lines with a fine straight line or lines engraved on glass. For either purpose an adjustable frame is attached to solid cast-iron supports above the screw, and this can be raised or lowered rapidly through 2 cm. screw movements being provided for fine adjustments. This frame carries alternatively either the positive spectrum plate attached with optical cement, or a glass reticule on which two parallel fine lines are engraved, ½ mm. apart and 7 mm. long.

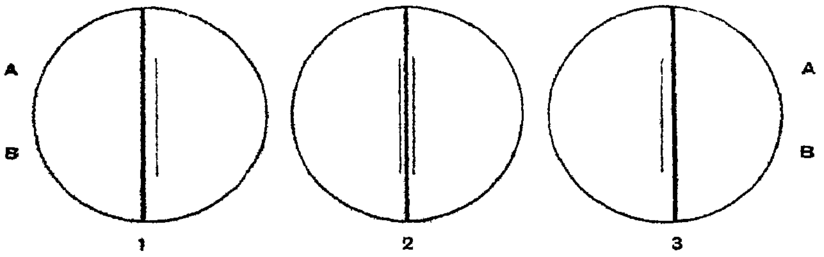
For the wave-length measures the glass reticule is used, and this is lowered to within about 0·3 mm. of the negative, and carefully adjusted by means of the appropriate screws until the engraved lines are as nearly as possible parallel with the spectrum lines.

The viewing microscope consists essentially of a telescope of 22 cm. focus, fitted with an additional object-glass of the same focal length to form a collimator. This gives a flat field of excellent definition, and the small difference of focus of the reticule and the negative (0·3 mm. on a focal distance of 220 mm.) is of no account. The two are seen in perfect focus together. This optical combination is shortened, and the eyepiece brought to a convenient angle for viewing the spectrum, by a right-angle prism and a small plane mirror. The glass reticule when adjusted is clamped firmly above the negative : the microscope therefore does not need to be immovably fixed, as would be the case were the reticule placed as is usual in the focus of the eyepiece. It is in fact mounted on a slide, and can be moved about by hand parallel to the screw for the purpose of adjusting the negative accurately parallel before beginning the measures.

Method of Measuring.—The positive on negative method is inconvenient for wave-length measures because of the very large intervals involved. The screw would need to be twice the usual length to deal effectively with the intervals. I have therefore adopted the following scheme for reducing to a minimum the errors involved in bisecting a spectrum line with the engraved line of the reticule.

The lines in these prismatic spectra are very nearly straight, the curvature being compensated by an appropriate curvature of the spectrograph slit.

In the diagram, 1, 2, and 3 represent three successive positions of a spectrum line with reference to the shorter lines of the reticule. A movable mask in the eyepiece of the microscope allows one to concentrate attention first at A, where readings are taken at each successive position; then, moving the mask, a similar set of readings is made at B. The number of settings for each position is usually three. Consequently the final position of a line depends on the mean of 18 settings. The spectrum is, however, always measured twice, red to the right and red to the left, or 36 settings altogether for each line.



It is a very great advantage to have the engraved lines shorter than the spectrum lines, and not occupying more than one-third the diameter of the field of view of the microscope, for then it is possible to measure very faint and narrow lines which would be completely hidden when covered by the engraved line; but it is easy to see the line projecting beyond the engraved line, and to place it in alignment in positions 1 and 3, and to place it central in position 2 with very considerable accuracy. I find it an advantage also in bisecting the stronger lines to observe the alignment at the same time.

Methods of Reduction.—In all prismatic spectra hitherto measured, including those obtained with glass prisms or with ethyl cinnamate as the dispersing agent, it is found that the rate of increase of scale with decrease of wave-length is very nearly constant over a range of 60 angstroms. In other words, $\frac{\delta\lambda}{\delta m}$ plotted against λ is sensibly a straight line. In measuring a low-dispersion solar spectrum, extending over many hundreds of angstroms, and plotting this relation over the whole range, it becomes apparent that the curvature over even 100 A. is inappreciable. I have therefore adopted a linear relation for converting measured intervals into wave-length. The wave-length of K and H is in this way derived from the nearest secondary standards, one on either side of these lines. These were

$$\begin{matrix}3930\cdot299\\3935\cdot815\end{matrix}\ \text{for K and}\ \begin{matrix}3967\cdot423\\3969\cdot261\end{matrix}\ \text{for H.}$$

Professor Fowler has suggested to me that it would be more satisfactory to adopt the Cornu-Hartmann interpolation formula in reducing the measures, for the results would then depend on all of the secondary standards measured, and not merely the two nearest lines; also, as the straight-line formula can only be approximate, the error might be appreciable in the case of K, where the nearest secondary standard on the violet side is over 3 A. distant. With Professor Fowler's kind advice and assistance, several sets of measures have been reduced by both methods, but with no appreciable differences in the values obtained; and it was shown also that with the straight-line formula no error would be introduced in the wave-length of K as great as 0·001 A.; and in H, where the two lines used in the simpler method are very close to the calcium line, the error would be much smaller. The Hartmann formula would, however, be of use in checking or improving the relative wave-lengths of all the secondary standards measured, and in this connection we found that the only line which appears to require a small correction is the line tabulated at 3940·882.

As a further check on the two methods of reduction I measured ten prominence spectra, selected for the excellent quality of the comparison arc lines of iron and calcium. These were obtained with solid glass prisms of 10 cm. effective aperture, and have a scale between H and K of 1·2 mm./A., or about 1/3rd the dispersion obtained with four transmissions through the liquid prism.

The measures were reduced using the simpler method, and independently by Dr. Comrie using the Hartmann formula, which involves 8-figure logarithms, and a very considerable amount of computation. In this case the following secondary standards of iron were measured, the constants in the formula being determined from those marked with an asterisk:—

3920·260*
3930·299
3935·815
3940·880
3948·779*
3949·958
3956·681
3966·066
3967·423
3969·261
3977·745*

In Table I, I give the results of this comparison. The columns headed C and E are the fractional wave-lengths determined respectively by Comrie using the Hartmann formula, and the writer using a large scale graph to find the required conversion factors.

In addition to K and H, I measured a faint *Fe* line at λ 3932, which does not appear to be subject to pole effect, and the line at 3940 which appeared to require a correction. At the foot of each column I give the mean values of the two methods and the probable errors derived from the residuals of the individual measures. The mean values from all the 10 plates reduced by the Hartmann formula have been tested by means of an error curve in the usual way, but the only line requiring an appreciable correction is H, which required to be increased by 0·0025 A., making it equal to my value.

Two points are to be noted in this table: first, the agreement of the two methods of reduction, and, second, the very much larger range of values for the H line computed by the Hartmann formula compared with the simpler method depending only on the two neighbouring lines. This results in a probable error for H nearly three times larger for the Hartmann method.

TABLE I

No.	3932 C	3932 E	K 3933 C	K 3933 E	3940 C	3940 E	H 3968 C	H 3968 E
1	·628	·626	·663	·661	·883	·881	·466	·470
2	·630	·630	...	...	·880	·881	·462	·469
3	·628	·631	·660	·662	·880	·880	·464	·467
4	·629	·631	·663	·663	·880	·879	·467	·469
5	·625	·626	·662	·662	·878	·878	·466	·467
6	...	...	·662	·662	·883	·882	·459	·465
7	·629	·630	·662	·662	·883	·882	·466	·471
8	·629	·630	·659	·660	·882	·882	·466	·469
9	·628	·628	·665	·665	·882	·882	·474	·468
10	·630	·633	·663	·663	·882	·881	·469	·473
Means	·628	·629	·662	·662	·881	·881	·466	·469
P.E. ±	·0003	·0005	·0004	·0003	·0002	·0001	·0011	·0004

This difference is not due to errors of computation, as the wave-lengths showing the largest discordances have been checked.

On the whole, I consider this series of measures gives reliable mean values of wave-length, notwithstanding the comparatively small scale of the spectra. The greatest deviation from the mean for K is 0·003 A., and for H in column E it is 0·004 A. In Jackson's interferometer measures of 15 plates the greatest deviations are also 0·003 A. for both K and H. A slight instability in these lines appears to be indicated.

TABLE II

Mean Results of New Measures of K and H in Iron-carbon Arc in Air

Series	No. of Measures	K	H
1	Mean of 6 spectra, approx. scale 4 mm./A.	3933·663 ± ·0004	3968·468 ± ·0001
2	Mean of 10 spectra, approx. scale 2 mm./A.	·663 ± ·0001	·469 ± ·0002
3	Mean of 10 spectra, approx. scale 1·2 mm./A.	·662 ± ·0004	·469 ± ·0004
	Adopted values	3933·663	3968·469
	Previous values, *M.N.*, 90, 189, 1929	·663	·470

In Table II, I have collected the mean values from all the new measures without giving individual results. In series 1 and 2 with high dispersion, the separate values are rather more accordant than those shown in Table I, as was to be expected. In series 1 the greatest deviation from the mean for K is 0·002 A., and for H it is less than 0·001; and for series 2 it is 0·003 for K and 0·002 for H. These variations are larger than can be accounted for by errors of measurement. In series 2, the plates giving the lowest and highest values for K were re-measured with results not differing at all in the third decimal. Such small differences may of course be due to the gelatine film on drying not recovering the exact form it had before development. If, however, it is a real variation in the relative positions of the calcium and iron lines, then one would expect H to vary in the same direction as K in any single photograph. This is in fact usually the case, though H is less affected than K, as the following comparison of mean values indicates:—

		K	H
	High Dispersion Spectra		
Mean of 9 measures, K exceeding	3933·6630	3933·6642	3968·4696
Mean of 6 measures, K less than		3933·6620	3968·4688
	Difference	·0022	·0008
	Low Dispersion Spectra		
Mean of 3 measures, K exceeding	3933·6630	3933·6638	3968·4700
Mean of 7 measures, K less than		3933·6615	3968·4688
	Difference	·0023	·0012

Approximately, therefore, when K increases in wave-length by 0·002 A. H increases by 0·001 A. Assuming the secondary standards of iron to be perfectly stable lines, it may be that K and H are very slightly subject to pole effect. In working the iron-carbon arc for these spectra the lower pole is of steel, and the upper one a rod of carbon, 5 mm. thick, which contains sufficient traces of calcium to give very narrow lines, but the length of the arc cannot easily be controlled; it may vary from a few mm. to 1 or 2 cm. with 5 to 6 amperes on a 100-volt circuit. It follows that some of the spectra may have been obtained with a short arc very near to the poles, and others near the centre of a long arc.

The mean values of the three series in Table II are in quite satisfactory agreement, and they confirm the values previously published, the only difference being a correction to H of −0·001 A. The difference between these results and the interferometer measures already referred to is 0·003 A. for both K and H, the interval 34·806 A. between the two lines being the same in both.

If the lines are subject to pole effect, I can only suggest that in Jackson's work the pole pieces were very close together in the vacuum arc, for this might tend to give larger values, but the difference may also be connected with the different standards used.

If the adopted mean values are corrected by subtracting the pressure shift of one atmosphere, and are then compared with the measures of these lines in the Revision of Rowland, the following differences are obtained:—

Arc reduced to vacuum	K 3933·661	H 3968·467
Centre of Sun (1928 scale)	·684	·494
Sun − vacuum arc	+0·023	+0·027

My direct measures of the shift of the solar lines gave K +0·020 and H +0·023.

I may once more call attention to this large shift of the high-level calcium lines at the centre of the Sun, approximately three times the Einstein effect, whilst at the limb it is reduced to +0·015 A., according to my direct measures.

Supplementary Measures.—In addition to K and H a few other lines were measured in these spectra. The mean wave-lengths are given in Table III as follows :—

TABLE III

Mean λ	Element	Number of Measures	Greatest Deviation from Mean
3928·091	*Fe*	2	0·000
3932·628	*Fe*	9	0·002
3933·602	*Fe*	3	0·002
3940·881	*Fe*	10	0·003
3944·014	*Al*	6	0·002
3949·957	*Fe*	5	0·001
3961·529	*Al*	6	0·002

The lines 3932 and 3940 are from Table I. 3933 is a faint iron line very close to K, and only measurable in three plates where the iron lines are strong and K very weak. The aluminium lines show in these spectra as well-defined narrow lines.

Summary.—High dispersion spectra in the H and K region obtained with the liquid prism spectrograph, and others of less dispersion obtained with glass prisms, have been measured with a newly designed micrometer for the accurate determination of the wave-lengths of the calcium and other lines in the open arc, and for comparison with interferometer measures of H and K.

A description is given of the micrometer and of the method of measurement. The computation of wave-lengths was made by the Cornu-Hartmann interpolation formula for many of the measures and compared with a simpler graphical method.

Tables are given showing the results for calcium, aluminium and some of the iron lines. The wave-lengths of the calcium lines are in very close agreement with those previously published by the author, but differ appreciably from the interferometer measures by the late C. V. Jackson. Possible causes of this difference are mentioned.

The adopted wave-lengths of K and H reduced to zero pressure are compared with the values given in the Revision of Rowland's Table for the Sun, showing a shift to red of these lines at the centre of the Sun which is three times the Einstein effect.