III. *On the Atmospheric Lines of the Solar Spectrum, illustrated by a Map drawn on the same scale as that adopted by* KIRCHHOFF.

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Communicated by Professor STOKES, *Sec. R.S.*

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THE spectroscopic observations hereafter discussed were made with instruments belonging to the Royal Society, and in accordance with certain suggestions which a Committee were good enough to make in connexion with my letter to Sir EDWARD SABINE, President, dated 13th February, 1866. In view of my residence at a considerable height, and the exceedingly clear atmosphere prevailing at some periods of the year, it was suggested that the locality was peculiarly favourable for comparing the solar spectrum when the sun was high with the corresponding spectrum at sunset; any differences between these aspects which might appear were to be noted on KIRCHHOFF'S well-known maps. Accordingly I set to work with the spectroscope first supplied to me (hereafter distinguished by the prefix *old*), and during the autumns of 1868 and 1869 I mapped the differences in question from the extreme red to D: these results appeared in the 'Proceedings of the Royal Society,' No. 123, 1870, the Map being marked vol. xix. pl. 1; it is unnecessary, therefore, to dwell on this portion of my labours, excepting to add that the definitions and general procedure there adopted have been retained in the remarks which follow.

2. The observations hereafter noticed were always taken in the *autumn*, when, the rainy season having passed away, the atmosphere on these mountains is exceedingly clear, so that the sun, the object of inquiry, is bright even to his setting, and a spectrum may therefore be then obtained through a long stretch of terrestrial atmosphere corresponding to the height of the station of observation; on the other hand, with the sun about the meridian, the height of station places the observer *above* a relative amount of atmosphere, so that the spectrum obtainable at this time and about sunset are highly eligible for the comparison in view. Accordingly the two spectra are given in the accompanying map (Plate 25); and for easy comparison they are placed in juxtaposition. By "sun high" is to be understood any position for the sun within a couple of hours of the meridian; by "sun low" that the sun was within 3 or 4 diameters of his *setting* and yet quite bright. Indeed it is only when *very* near sunset that the marked alterations in the lines appear; so that the spectrum required is not only *rarely* obtainable, but it hardly lasts beyond 10 minutes of an evening. In this short period (when, moreover, the observer is fatigued with previous watching) changes from the *sun-high* spectrum must first be detected; then their position must be identified, and, failing this, found by measurement; next,

the appearance should be drawn, and finally the drawing should be compared with the original: under these conditions a week may be easily absorbed by a single group. It is also to be borne in mind that no human eye will endure, without at least temporary injury, protracted watching of the bright solar spectrum for more than four or five weeks at a time; indeed, though I habitually used both eyes as a relief to one another, they both invariably suffered, and continued to do so for several weeks after every autumn. The following facts may be here mentioned:—

In 1870,	commencing	October	17,	I observed	17	sunsets.
„ 1871,	„	„	5,	„	20	„
„ 1872,	„	„	10 (about),	„	20	„
„ 1873,	„	„	6,	„	35	„

3. In the autumns of 1870 and 1871 I continued to work with the *old* spectroscope, mapping from D to F, in extension of the Map already published; but all desire for publication of these results was naturally suppressed when Professor STOKES gratified me by announcing that the Royal Society had ordered a new spectroscope for my use. This instrument reached my residence at Dehra, together with two actinometers, when I was absent with the eclipse expedition in December 1871; and I need hardly add that after my return I lost no time in examining the contents of the package. It appears inevitable that instruments should suffer in travelling; this one did, and the injuries took weeks to repair; but once the spectroscope was fit for use and I was able to judge of its capabilities, the idea of not superseding the map already published, based on my work of 1868 and 1869, or of not suppressing the map in hand from observations 1870 and 1871, was at once relinquished: thus the map now submitted was obtained entirely with the *new* spectroscope. However, I had my old maps as skeletons to begin with; and adopting Professor STOKES'S suggestion to compare, in the first instance, the spectra by the *two* instruments, I set to work *de novo* from the extreme red in the autumn of 1872, and finished the work in November 1873; it was not, however, until the following summer that I was able to forward the map appended, nor have I had it in my power until now to attempt this explanatory paper.

4. As regards my station of observation, it is best known locally by Vincent's Hill *, being a knoll on some property once owned by the late General VINCENT: the site is in N. lat. 30° 27′, E. long. 78° 3′; height above sea 7100 feet; and it commands a complete view of the horizon from S.E. to S.W. by W. The site in question was made available for my purposes through the courtesy of Surgeon-Major R. WHITTALL. Next, of the new spectroscope by GRUBB of Dublin: it mounts three (compound) prisms, which are moved with the telescope by an automatical contrivance for maintaining minimum deviation; the eye-end of the telescope is fitted with a micrometer, and the highest power eyepiece which may be generally employed gives an image of the dispersion about $3\frac{1}{2}$ fifths of that delineated in KIRCHHOFF'S maps at the usual distance of reading:

* On the Himalaya Mountains, N. W. Provinces, India.

the prisms are *beauties*: an object-glass, about 1 inch in diameter, is fitted at the end of a rod, and can be adjusted so as to throw an image of the object on the slit; this provision was exceedingly useful to me. Further description of the instrument appears unnecessary, excepting to state generally that I am much pleased with its good qualities.

5. I now proceed to add a few words as to my reasons for ascribing the differences in certain parts of the solar spectrum, sun high and sun set, in all cases to the influence of the *earth's atmosphere*, believing that I can definitely show the relation between this effect and this cause. I will premise that I now have access to the Philosophical Transactions for 1860, in which the paper by Sir DAVID BREWSTER and Dr. GLADSTONE on the lines of the solar spectrum is given, together with an illustrating map; and I here make allusion to these documents, because, though the Committee were good enough to call my attention to them, I was unable when writing in 1870 to get possession of a copy. I have also access to other volumes of the Philosophical Transactions, including Professor STOKES'S drawings in the volume for 1852, besides various documents on the subject of air-lines, as Report on a Mission in Italy by M. JANSSEN, &c. All these papers contain descriptions or allusions to experiments showing the effect of reflections from various surfaces, and of the passage of light through strata of variable lengths, &c. And in turn I also (in keeping with suggestions by Professor STOKES, for which I am very much obliged) tried certain experiments which I will now briefly allude to. Selecting a bright clear day, I first turned the collimator to the sun about the meridian, and set the slit for good definition of the lines; after this, with the slit as before, I admitted the sun's light reflected from blue or white glass backed with velvet, from ink of various degrees of blackness, from coloured solutions, &c.; and finally I got a reflection from a distant muddy river; but none of these, or other experiments which need not be detailed, produced the smallest approach to the *variable* lines which were the especial aim of these experiments, nor yet, as a matter of fact, to those seen only at sunset that are plainly air-lines. Some of the belts are specially deserving of attention—for instance the huge shadow 1073 to 1155 of KIRCHHOFF'S scale on my Map; this shadow or belt stands out like a *wall* at sunset, and then not only comes into existence itself, but with it come 1108, 1114, and 1121, which *I* could not see sun high, nor has KIRCHHOFF shown.

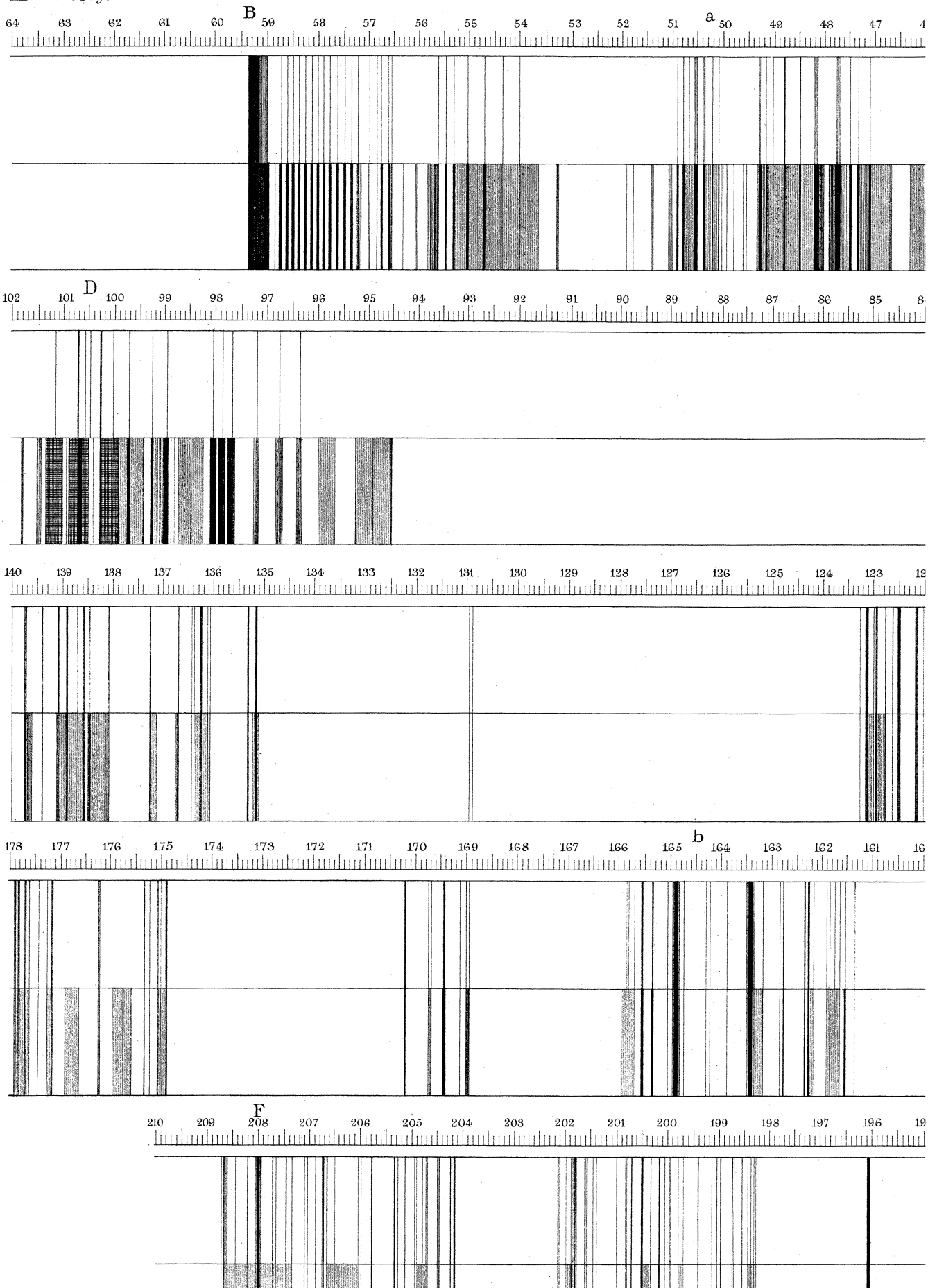
6. I now turn to another fact. When the autumn has well advanced here, there springs up from the plain country, stretching away S.E. and S.W. by W., a kind of haze which becomes visible at sunset, and which grows day by day in height until it attains to perhaps 3° or more above the horizon; this haze, moreover, grows denser daily, until at last it is sufficiently opaque to obscure the sun's rays. I need not in this place enter into the causes which produce this haze; it is sufficient to remark here that I have noticed it year after year, and from its opacity and its formation occurring just before winter, I always call it "the winter bank;" indeed I remember talking about it one evening with the late Archdeacon PRATT, who also had noticed it, in connexion with some other fact. Now this haze bank practically *compelled* the sun to set whenever

the latter sank behind the former; so that in the first autumn of my observations the appearance of the haze obliged me to close work for the season. Subsequently it occurred to me that the gradual growth in height of this haze gave me exactly the very test I required, viz. sunset varying one day with another from a depression of $1\frac{1}{2}^\circ$ to an altitude of some $3\frac{1}{2}^\circ$. Accordingly I watched the corresponding effect on the air-lines, and found beyond all question that as the bank rose and the corresponding sunset occurred higher, the *variable* and *air-lines* all disappeared, each in its turn. This test is of course most effectually applied to lines which require the *lowest* of sunsets to be developed, and the behaviour of all lines is by no means the same. For instance, 813 is almost as good as a clock to me, commencing to change so early as 2 or 3 P.M.; whereas 712 (which is, in fact, the more prominent line *eventually*, and is, I believe, noticed here for the first time) hardly presents the smallest change until the sun is under 1° of altitude or thereabout. Similarly, my air-wall (above noticed) requires a low sunset, but not so low as 712. The test just explained gave a visible connexion between the atmospheric lines and the terrestrial atmosphere; *i. e.* the higher the sunset, the more the air-lines were absent. I state the fact thus briefly, notwithstanding that I tested it day after day, and that I possess abundance of notes on the subject; these notes, however, are in the main repetitions, which have no interest once the fact has been announced, and I therefore refrain from transcribing them.

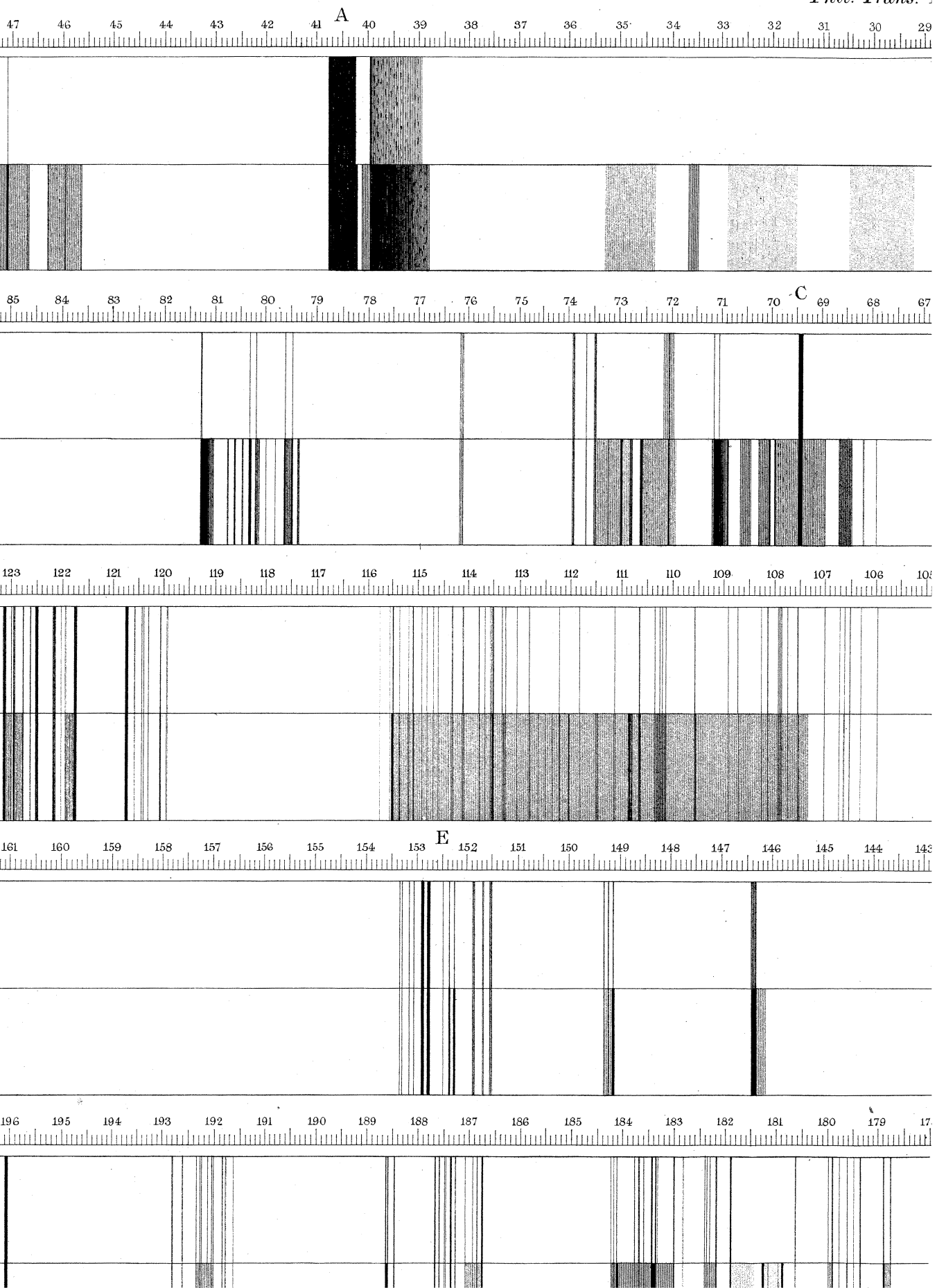
7. It will be seen that in the portion extreme red to D there are some slight discrepancies between my map of 1870 and my present map; these are solely due to the far greater powers of the new spectroscope, and not to any want of care in preparing the earlier map: the *additions* are chiefly due to the same cause, and to some extent are the results of greater skill, which experience may have brought me. Amongst the new lines or bands are group 315–352, the additions about A, 460, 730, 950, and elsewhere, not forgetting 712 (which, I repeat, is a very prominent air-line, but only so at a very low sunset). For further discussion of the map now submitted to the Royal Society, and for comparison with other maps which have preceded it, I must await a more favourable opportunity—merely remarking at present, that while looking for air-lines I happened to detect a few other lines which do *not* vary, but which are *not* given in KIRCHHOFF'S map; of this class are 1006, the pair 1310, and some others. I may repeat my conviction, already stated in my paper dated 25th April, 1870, that besides other changes in the light, as the sun approaches the horizon, there is this peculiarity, that rays of less refrangibility become visible, so that the spectrum appears to be extended towards the red end. My search, as will be seen from the map, has not as yet extended rigorously beyond F; indeed examination of the spectrum beyond this line is hardly practicable for the detection of air-lines without some additional provision for collecting light, which, however, I think I could contrive; with my present means, but little light reaches beyond F when the earth's atmosphere intervenes to a depth which may be expected to produce an effect, the brightest part of the spectrum being the portion that is last visible at sunset.

1. PART OF THE SOLAR
2. PART OF THE SOLAR

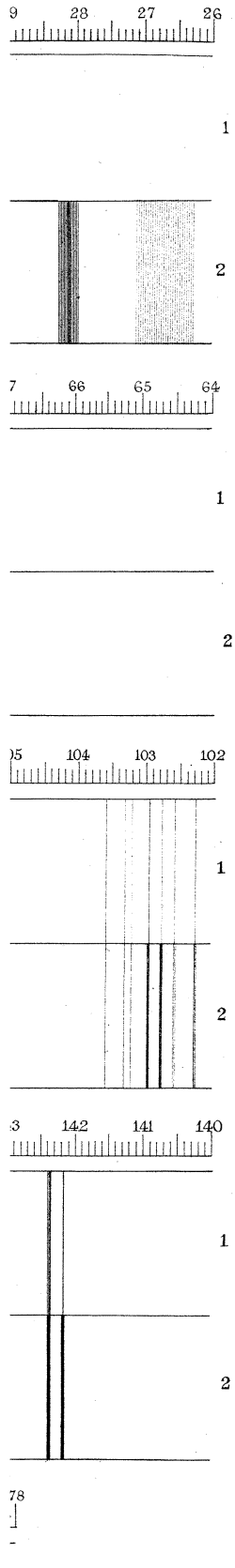
Hennessey.

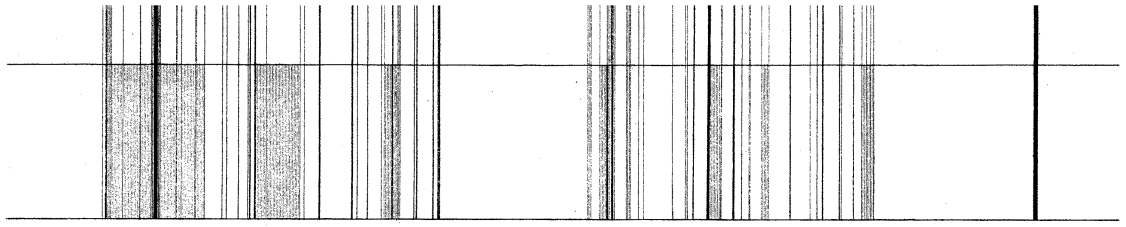


SOLAR SPECTRUM AS SEEN BETWEEN 10 A.M. & 2 P.M.
SOLAR SPECTRUM AS SEEN AT SUNSET.

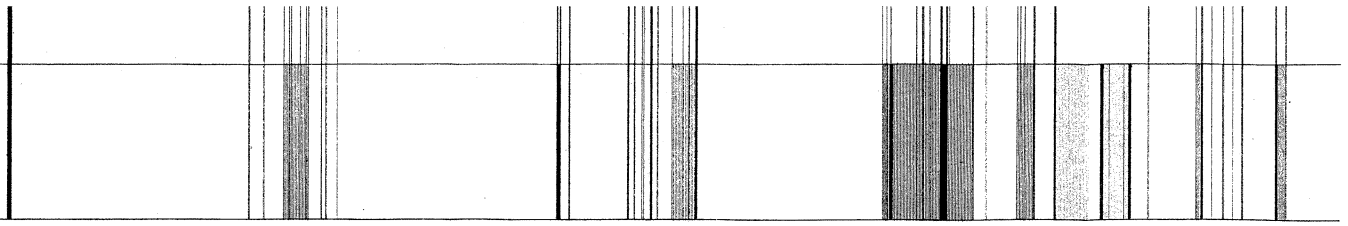


1875. *Plate* 25.





W. We



W. West & Co. lith.

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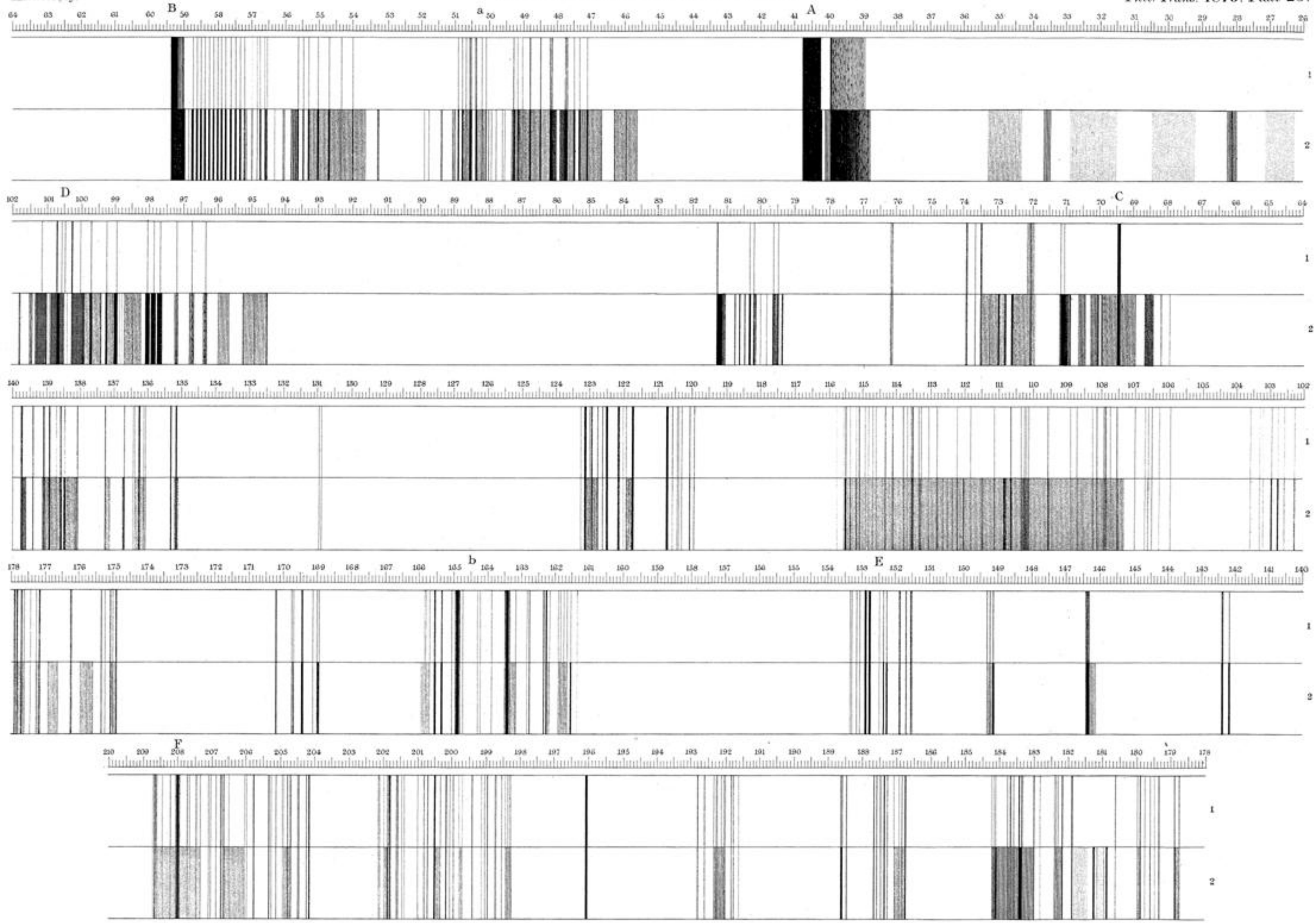
2. PART OF THE SOLAR SPECTRUM AS SEEN AT SUNSET.



W. West & Co. imp.