XIV. *On the Photographic Spectra of some of the Brighter Stars.*

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[PLATES 26–30.]

CONTENTS.

I. INTRODUCTION.

In the Bakerian Lecture for 1888* I brought together the various observations of the spectra of stars, comets, and nebulæ which had been made up to that time, and showed that the discussion suggested the hypothesis that all celestial bodies are, or have been, swarms of meteorites, and that the difference between them is one of condensation only. The new classification of the heavenly bodies according to their spectra, rendered necessary by this hypothesis, differed from previous ones inasmuch as the line of evolution followed, instead of locating the highest temperature at its commencement as demanded by LAPLACE'S hypothesis, placed it much later. Hence bodies of increasing temperature were demanded as well as bodies of decreasing temperature.

These conclusions were necessarily based on observations made by others, for the reason that my own work up to that time had been chiefly directed to the Sun.

So soon, however, as my solar work rendered it necessary to determine the Sun's true place among the stars in regard to its temperature and physical conditions, arrangements were made both at Kensington and Westgate-on-Sea to photograph the spectra of stars and nebulæ.

The present communication gives an account of certain parts of this inquiry so far as they have been carried; it is based upon 443 photographs of 171 of the brighter stars.

Having this new and accurate basis of induction, the objects have been to determine :—

(1.) Whether the hypothesis founded on eye observations is also demanded by the photographs.

(2.) In the affirmative case to discover and apply new tests of its validity, or otherwise.

The results as yet obtained are not sufficient to permit a discussion of all points bearing upon the hypothesis, but since most of the crucial ones are covered by the photographs already obtained, it appears desirable that the publication of the work done during the last two years should be no longer delayed.

* 'Roy. Soc. Proc.,' vol. 44, p. 1.

II. METHODS OF WORK.

(1.) The Objective Prisms.

At Kensington arrangements have been made for photographing the spectra by means of objective prisms. This method was originally suggested and employed by Fraunhofer, in 1814, for observing stellar spectra. For photographic purposes the method, which is obviously the best, has been revived with conspicuous success by Professor Pickering, of Harvard College.

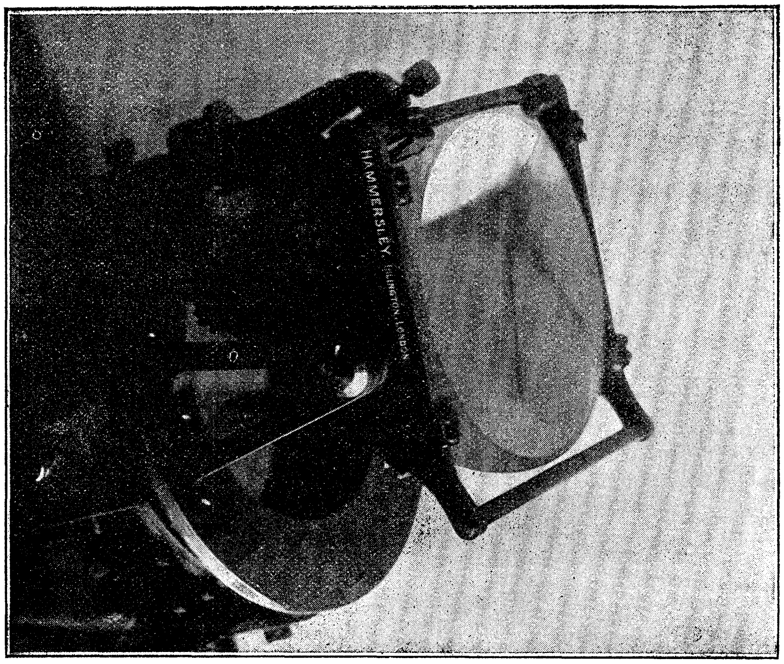
An ordinary telescope with a prism in front of the object-glass becomes a complete star spectroscope, the rays coming from a star being already parallel, so that both slit and collimating lens can be dispensed with. As the image of a star is a point, the spectrum thus obtained will have no breadth, and for eye observations it is necessary to use a cylindrical lens in conjunction with the eye-piece of the telescope. For photographic purposes, however, a different method is adopted. The prism is so placed that its refracting edge lies in a parallel of declination, and then it is only necessary to allow the driving clock to be slightly in error in order to obtain the necessary width.

Instrument A.—The main instrument employed in the work at Kensington has been a 6-inch refracting telescope, with an object-glass made and corrected for G by the Brothers Henry. This was at first used in conjunction with a prism of $7\frac{1}{2}°$ by Hilger, and, for convenience, this combination will be afterwards referred to as *Instrument A.* The object-glass and prism are fixed at the end of a wooden tube, which is attached to the side of the 10-inch equatorial, at such an angle that the spectrum of a star falls on the middle of the photographic plate when its image is at the centre of the field of the larger instrument. The camera is arranged to take plates of the ordinary commercial size, $4\frac{1}{4} \times 3\frac{1}{4}$ inches. The spectra obtained with this instrument are 0·6 inch long from F to K. An excellent photograph of the spectrum of a first magnitude star can be obtained with an exposure of 5 minutes.

Instrument B.—A 6-inch prism, with a refracting angle of 45°, was obtained from the Brothers Henry in May last, and, since then, this has been in constant use with the Henry 6-inch object-glass. The combination will be referred to as *Instrument B.* The spectra obtained with this instrument are 2 inches long from F to K, and the definition is exquisite. In some photographs the calcium line at H is very clearly separated from the line of hydrogen, which occupies very nearly the same position. It is unnecessary to swing the back of the camera in order to get a perfect focus from F to K. The deviation of the prism is so great that it would be very inconvenient to incline the tube which supports it at the proper angle to the larger telescope. When photographing the spectrum of a star, the star is therefore first brought to the centre of the field of the large telescope, and the proper deviation is then given by reading off on the declination circle. This method has been found to work quite satisfactorily.

With this combination the exposure required for a first magnitude star is about 20 minutes. The method of mounting the prism is shown in fig. 1.

Fig. 1.



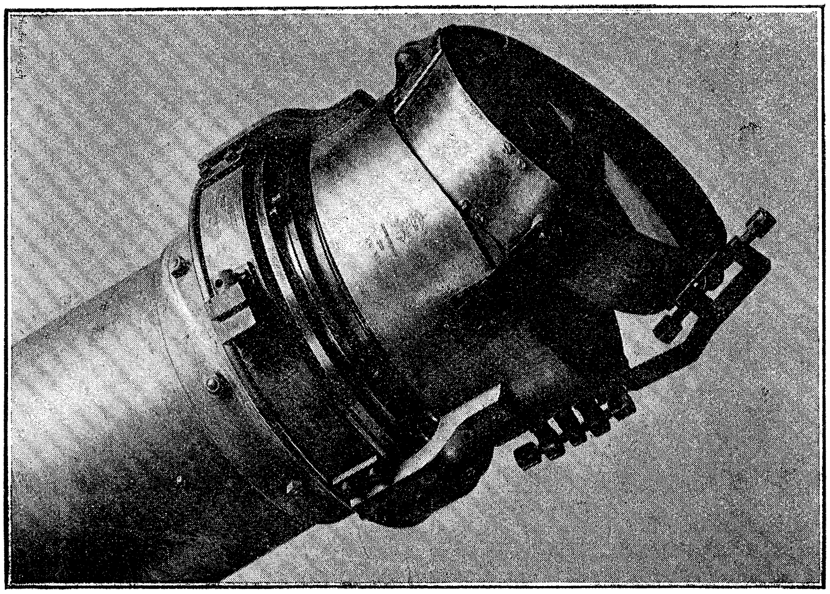
Objective prism of 45° fitted to 6-inch object-glass.

Instrument C.—Two prisms of $7\frac{1}{2}°$ each and 10 inches clear aperture have been provided for use with the 10-inch Cooke refractor, but, as this telescope is required for the instruction of students during the greater part of the year, they have not been largely employed. The prisms are circular in form, and are fitted in cells provided with adjusting screws. A camera taking plates $4\frac{1}{4} \times 3\frac{1}{4}$ inches replaces the eyepiece of the telescope.

To facilitate the adjustment of the spectrum, the 3-inch finder can be inclined to the body of the telescope, so that when a star is brought on the cross-wires its spectrum falls in the proper place on the photographic plate. The focal length of the 10-inch objective is about 11 feet, and the spectra obtained are about $1\frac{1}{2}$ inches long from F to K. With this dispersion and aperture, a normal first magnitude star, like Altair, requires an exposure of about 10 minutes on a fairly good night to give a fully exposed spectrum $\frac{1}{10}$th of an inch wide. The results so far obtained with this instrument do not equal those obtained with Instrument B. Fig. 2 shows the way in which the prisms are attached to the cell containing the object-glass.

Instrument D.—For the fainter stars, the 6-inch prism of $7\frac{1}{2}°$, which was dismounted from Instrument A, has been adapted to a Dallmeyer rectilinear lens of 6 inches aperture and 48 inches focal length, the tube with its appendages having been mounted in place of the tube of the Dallmeyer photoheliograph. This, also, is fitted with a finder inclined at an angle to correct for the deviation of the prism. The spectra taken with this instrument are only 0·3 inch long from F to K, and the time of exposure is reduced in proportion. Even a fifth magnitude star may be photographed in 30 minutes.

Fig. 2.



Objective prisms of $7\frac{1}{2}°$ each attached to 10-inch object-glass.

The Clock Rate.

The proper regulation of the clock error and consequent "trail" of the spectrum across the plate parallel to itself are essential to the success of photographs taken by the objective prisms. The spectrum of a bright star must obviously be made to trail more quickly than that of a fainter one, and a shorter exposure is sufficient. Since for the same clock error, and in the same time, a star near the pole will give a shorter trail than one nearer the equator, declination must also be taken into account. Keeping a constant clock error, equal widths of spectrum for stars of different declinations may be obtained by lengthening the time of exposure for stars away from the equator, but in that case, the stars near the pole would be over-exposed in relation to those nearer the equator.

The exposure given to stars of equal magnitudes should evidently be the same, no matter in what part of the sky they may be situated, and the clock error should, therefore, be increased in proportion to the secant of the angle of declination.

The light-ratio of stars being $2·512^n$, where n expresses the difference in magnitude, the time of exposure must vary in the same proportion, and the clock error in inverse proportion. Thus, where 5 minutes' exposure is sufficient for a first magnitude star, 31 minutes is required to obtain a fully-exposed spectrum of a star of the third magnitude. This law, however, only applies to photographic magnitudes, and must be modified according to the type of spectrum or the colour of the star.

For conveniently adjusting the exposures, tables have been constructed which show at a glance the position of the regulator for a star of given magnitude and declination.

It is obvious that with an instrument of high dispersion, the number of stars it is possible to photograph is very limited, as the long exposures required for the fainter stars are impracticable, and, even if possible, the definition of the lines would be destroyed by atmospheric tremors.

Hence, it is at present only possible to photograph the spectra of the faint stars on a very small scale. With an objective of 8 inches aperture and 44 inches focal length, and a prism of 13° refracting angle, Professor PICKERING has photographed the spectra of stars down to the eighth magnitude. These spectra are about one centimetre long and a millimetre broad, and though they do not show a very great amount of detail, they are sufficient to reveal the type of spectrum.

With an instrument capable of photographing faint stars, a large number of spectra may be taken at one exposure; but, with the instruments of larger dispersion, this is not generally the case, as there are few bright stars of nearly equal magnitude sufficiently close together.

The red stars, being much weaker in blue and violet rays than the yellow or white stars, require much longer exposures than white stars of equal magnitude. To obtain a spectrum of β Pegasi extending to the K line, for example, at least three times the exposure required by a white star of similar magnitude must be given.

Electrical Control.

In consequence of the great accuracy required in the driving of the telescope when long exposures are necessary, the 10-inch equatorial has been fitted with a simple and inexpensive form of electrical control. This is a modification of that designed by Mr. RUSSELL, of the Sydney Observatory.* The existing driving gear has been altered so that the driving rod performs its revolution in a second, and the motion is then communicated to the driving screw through a small worm wheel. The driving rod is vertical and in two parts, the lower portion ending in a faced ratchet wheel, 3 inches in diameter, and with 200 teeth. The upper part of the rod ends in an arm at right angles to itself, and this arm carries a ratchet of suitable shape held down by an adjustable spring. An electro-magnet, connected with the controlling pendulum, is arranged so as to only permit the ratchet to pass it once a second (see fig. 3). If the clock be driving too quickly, the ratchet is held until the stop is raised by the

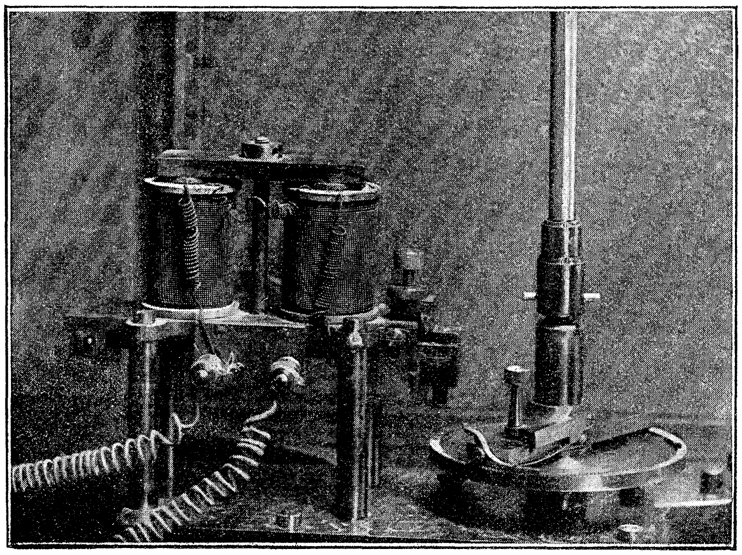
* 'Monthly Notices,' vol. 51, p. 43, 1890–91.

pendulum. When held in this way the ratchet is lifted out of the teeth, and the driving clock itself is not affected.

In order that this form of control may be effective, it is essential that the clock should be going too quickly, as it is only capable of retarding the driving rod.

The controlling pendulum is, of course, regulated to the rate required for the particular star which is being photographed.

Fig. 3.



Electrical control for 10-inch equatorial.

In Mr. RUSSELL's form of control the two parts of the driving rod are connected by friction plates. It was found, however, on testing this arrangement, that when the upper portion was held by the electro-magnet the rate of the governors was seriously retarded. I therefore asked Messrs. HAMMERSLEY (who carried out the necessary alterations of the driving clock), to provide some more efficient substitute, and the ratchet wheel was the result.

(2.) THE 30-INCH REFLECTOR.

Instrument E.—Before the erection of the 3-foot reflector, the arrangements at Kensington did not provide for the use of a very large aperture, and I was led to erect a 30-inch reflector at Westgate-on-Sea, having received grants in aid from the Government Grant Fund. The mirror, which is a very fine one of 11 feet 3 inches focus, was figured and presented to me by my friend Dr. COMMON; for the flat (7 inches in diameter) I am indebted to other friends, the Brothers HENRY, and I am anxious to take this opportunity of expressing my great obligations to them for this magnificent help in my work.

The Slipping-plate.

The telescope is of the Newtonian form, the eye end being provided with a slipping-plate, which is a modification of that designed by Dr. COMMON for use with his 5-foot reflector.* This is adapted to take a plate holder for photographing direct images, and also for use with eye-pieces and spectroscopes. The advantage gained by its use is that a small amount of motion can be given to the photographic plate or spectroscope without in any way disturbing the large mass of the whole telescope. The slipping-plate is so arranged that one screw corrects any small error in right ascension, and the other in declination. A small eye-piece is used as a follower when photographing directly. It is capable of adjustment so that it may be used to observe any small star near the edge of the field, and being provided with cross wires illuminated by a small incandescent lamp it enables the observer to correct any small errors in right ascension or declination.

The Slit Spectroscopes.

In addition to a Maclean star spectroscope and a small direct vision spectroscope, two others have been employed. One is by HILGER, and is fitted with one prism of 60° and two half prisms. This is provided with the usual arrangements for observing and photographing the spectra of celestial bodies. The other is a four-prism spectroscope by HAMMERSLEY, and is arranged so that one or two prisms may be removed at pleasure. It is provided with an automatic adjustment for minimum deviation, and is supplied with a bright line micrometer, which is illuminated electrically. A small telescope for observing the spectrum by reflection from the surface of the second prism, a camera to replace the eye-piece, and arrangements for comparison spectra, complete the instrument. The whole spectroscope can be rotated round the axis of the collimator. In order to reduce the weight of the spectroscope the more massive parts are made of aluminium. The weight of the whole instrument, with the four prisms, is only eight pounds.

A grating spectroscope, which has been obtained for the solar work, can also be adapted to the reflector for special investigations. The grating is one of ROWLAND'S, with 14,438 lines to the inch.

(3.) ENLARGEMENTS OF THE NEGATIVES.

Many of the negatives taken have been enlarged about nine times on glass, and further copies have been taken on bromide paper, bringing the enlargement up to about 25 times the size of the original.

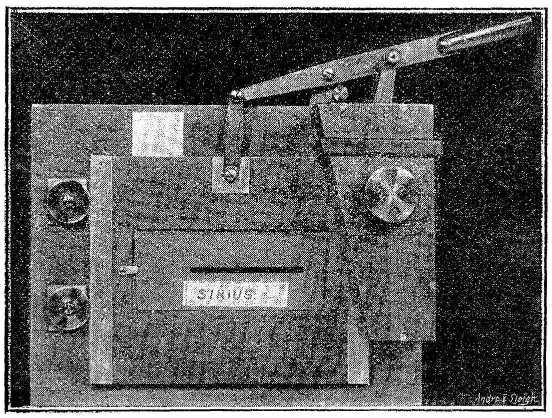
Owing to various causes the photographic spectra obtained by the method of trails

* 'Monthly Notices,' vol. 49, p. 297, 1888–89.

show irregularities resembling the lines along the spectrum observed when the slit of a spectroscope is partly clogged with dust. It has been noticed that the period of the irregularities is equal to the time of revolution of the main driving screw of the telescope, and hence they may be accounted for by supposing the driving gear to be mechanically imperfect. In that case some of the parallel lines which, by their juxtaposition form the broadened spectrum, are superposed, while others are drawn apart, thus giving rise to dark and bright lines parallel to the length of the spectrum. These lines are more apparent in the case of bright stars than fainter ones. If the telescope were driven with perfect regularity and the atmosphere were quite steady, we should obtain a spectrum of uniform intensity along its width. This condition has very nearly been obtained in some cases.

The irregularities above described are eliminated in the enlarged negatives by giving them an up-and-down motion during exposure in a direction parallel to the lines of the spectrum. This was originally done by hand, but a negative holder has been constructed in which the necessary motion is given to the negative by a small driving clock.

Fig. 4.



Negative holder used in enlarging.

A diagram of the arrangement is given above. The only drawback to this method is that defects of the film are apt to produce, by a succession of their images on the enlarging plate, lines (generally very faint) which have a semblance of the true spectrum lines.

To distinguish the real lines from the artificial ones, a direct enlargement of the spectrum is made on the same plate alongside the other, the to-and-fro motion being dispensed with. By a comparison of the two enlarged strips, one can see at a glance which are the true lines of the spectrum, and which are those produced by small irregularities on the film. It may be stated that Dr. SCHEINER has also used a somewhat similar method to the one described, the only difference being that he caused the plate on which the enlargement was to be taken to have the oscillating motion, instead of the original negative. The method employed at Kensington, though no account of it had been published, had been in use for some time before Dr. SCHEINER's method was announced.*

III.—LISTS OF SPECTRA PHOTOGRAPHED.

My object has not been so much to obtain photographs of the spectra of a large number of stars, as to study in detail the spectra of comparatively few. Hence many of the stars have been photographed several times with special exposures and foci for different regions of the spectrum.

The following lists of 443 photographs of the spectra of 171 stars will show what material has been available for discussion. The stars are arranged in each table in the order of their right ascension.

(1.) STARS photographed with Instrument A (6-inch prism of $7\frac{1}{2}^{\circ}$).

Name of star.	Number of photographs.	Name of star.	Number of photographs.
α Andromedæ	1	α Canis Minoris	2
β Cassiopeiæ	1	α Hydræ	1
γ Pegasi	1	α Leonis	4
α Cassiopeiæ	2	γ Leonis	1
γ Cassiopeiæ	19	θ Leonis	1
β Andromedæ	2	β Ursæ Majoris	1
δ Cassiopeiæ	1	α Ursæ Majoris	1
β Arietis	1	δ Leonis	3
γ Andromedæ	1	γ Ursæ Majoris	1
α Arietis	2	γ Virginis	1
α Ceti	5	ε Ursæ Majoris	1
β Persei	1	α Virginis	2
α Persei	1	ζ Ursæ Majoris	1
The Pleiades	1	η Ursæ Majoris	1
α Tauri	3	α Bootis	16
α Aurigæ	16	ε Bootis	1
β Orionis	5	β Ursæ Minoris	1
β Tauri	1	α Coronæ	1
Nova Aurigæ	6	α Herculis	1
γ Orionis	2	α Ophiuchi	1
δ Orionis	3	γ Draconis	2
λ Orionis	1	α Lyræ	2
ι Orionis	1	β Lyræ	12
ε Orionis	2	γ Lyræ	2
ζ Tauri	1	α Aquilæ	4
ζ Orionis	1	δ Cygni	1
κ Orionis	1	γ Cygni	1
θ Aurigæ	1	α Cygni	2
α Orionis	9	ε Cygni	1
μ Geminorum	6	α Cephei	1
γ Geminorum	2	ε Pegasi	2
α Canis Majoris	4	η Pegasi	1
β Canis Minoris	1	β Pegasi	5
β Canis Majoris	1	α Pegasi	1

* 'Nature,' vol. 42, p. 303, 1890.

(2.) STARS photographed with Instrument B (6-inch prism of 45°, and 6-inch Henry object-glass).

Name of star.	Number of photographs.	Name of star.	Number of photographs.
α Andromedæ	1	α Orionis	3
γ Cassiopeiæ	6	α Canis Minoris	1
β Andromedæ	1	α Canis Majoris	2
γ Andromedæ	1	α Virginis	1
α Arietis	1	α Bootis	11
β Persei	1	α Ophiuchi	1
α Persei	1	α Lyræ	2
α Tauri	1	β Lyræ	7
α Aurigæ	5	γ Lyræ	1
β Orionis	3	α Aquilæ	5
γ Orionis	1	γ Cygni	3
ε Orionis	1	α Cygni	3
ζ Orionis	1	β Pegasi	2

(3.) STARS photographed with Instrument C (two 10-inch prisms of $7\frac{1}{2}°$).

Name of star.	Number of photographs.	Name of star.	Number of photographs.
γ Cassiopeiæ	6	α Geminorum	1
α Arietis	1	α Canis Minoris	3
β Persei	1	β Geminorum	2
α Tauri	2	α Leonis	2
α Aurigæ	2	α Ophiuchi	2
β Orionis	7	χ Virginis	1
β Tauri	1	α Bootis	4
γ Orionis	4	α Coronæ	2
δ Orionis	2	α Lyræ	15
ε Orionis	1	α Aquilæ	5
ζ Orionis	1	α Cygni	2

(4.) Stars photographed with Instrument D (6-inch prism of $7\frac{1}{2}°$ on 6-inch Dallmeyer lens).

Name of star.	Number of photographs.	Name of star.	Number of photographs.
ζ Cassiopeiæ	1	α Serpentis	1
β Ceti	1	π Scorpii	1
η Ceti	1	δ Scorpii	1
α Ursæ Minoris	1	β Scorpii	1
τ Ceti	1	δ Ophiuchi	1
γ Ceti	1	ε Ophiuchi	1
α Ceti	1	σ Scorpii	1
ρ Persei	1	γ Herculis	1
κ Persei	1	α Scorpii	2
ν Persei	1	β Herculis	2
The Pleiades	1	λ Ophiuchi	1
ζ Persei	1	τ Scorpii	1
ε Persei	1	ζ Ophiuchi	1
48 Persei	1	ζ Herculis	1
α Aurigæ	1	η Herculis	1
γ Orionis	1	ι Ophiuchi	1
β Aurigæ	1	κ Ophiuchi	1
α Canis Minoris	1	ε Herculis	1
α Lyncis	1	η Ophiuchi	1
ε Hydræ	1	δ Herculis	1
ρ Hydræ	1	π Herculis	1
ζ Hydræ	1	θ Ophiuchi	1
ε Leonis	1	ρ Herculis	1
α Leonis	2	β Ophiuchi	2
ψ Ursæ Majoris	1	μ Herculis	2
12 Comæ Berenicis	1	γ Ophiuchi	1
13 Comæ Berenicis	1	ν Ophiuchi	1
14 Comæ Berenicis	1	67 Ophiuchi	1
16 Comæ Berenicis	1	70 Ophiuchi	1
δ Corvi	1	72 Ophiuchi	1
17 Comæ Berenicis	1	ο Herculis	1
γ Virginis	1	η Serpentis	1
α Canum Venaticorum	2	σ Sagittarii	1
δ Virginis	1	ζ Aquilæ	1
ε Virginis	1	ν Aquilæ	1
α Virginis	2	σ Cygni	1
ζ Virginis	1	29 Cygni	1
η Bootis	1	P Cygni	1
α Bootis	3	ζ Delphini	1
λ Bootis	1	β Delphini	1
λ Virginis	2	α Delphini	1
γ Bootis	2	δ Delphini	1
ε Bootis	1	γ Delphini	1
α Libræ	2	α Cygni	4
β Bootis	1	ζ Cygni	1
β Libræ	1	δ Capricorni	1
β Coronæ	1	ζ Aquarii.	1
υ Bootis	1	ζ Pegasi	1
θ Coronæ	1	μ Pegasi	1
γ Coronæ	2		

(5.) SPECTRA taken with Instrument E.

Name of star.	Number of photographs.	Name of star.	Number of photographs.
Orion Nebula	5	α Aquilæ	1
α Orionis	2	α Boötis	1
α Coronæ	1	α Aurigæ	1

IV.—TABULATION OF SIMILAR SPECTRA.

As in the case of stellar spectra observed in the usual way, the photographic spectra vary very considerably in passing from star to star, and well-marked groups may be recognised.

In the classification of stars which has been adopted from a consideration of the visual observations, only the broader differences in the spectra have been taken into account. Professor PICKERING, however, has suggested a provisional classification in connection with the Henry Draper Memorial photographs of stellar spectra, but this chiefly relates to photographs taken with small dispersion. Now that it has become possible to obtain large dispersion photographs of the spectra, much more detail is revealed, and it becomes necessary to deal with the presence or absence of individual lines to a greater extent than by Professor PICKERING.

Hence, in the first instance, I have arranged the various stars of which the spectra have been photographed at Kensington in tables, without reference to any of the existing classifications, and taking into account the finer details.

The basis upon which the first grouping is founded is the extent of the continuous spectrum. Such a distinction was not possible in the case of eye observations, and it is only by a consideration of the photographs that the classification from this point of view can be made.

Some spectra show a remarkable continuous absorption either in the ultra-violet or violet, in others this absorption extends to about K, whilst in a third class it reaches as far as G. This practically amounts to the same thing as classifying the spectra according to the thickness of the hydrogen lines, for it is found that where the continuous absorption is least the hydrogen lines are broadest. But it must not be forgotten that the broadness of these lines depends, to an as yet undetermined extent, upon the time of exposure, and it may further be that other causes besides temperature may be effective in producing the broadening.

(1.) TABLE A.—Stars in which there is no remarkable continuous absorption either in the ultra-violet or violet. In these stars the hydrogen lines are broad.

(α.)	(β.)	(γ.)	(δ.)
The spectra differ widely from the solar spectrum. There is only a small number of lines, and the hydrogen lines are not of extreme thickness.	The spectra do not differ very widely from the solar spectrum. There is a large number of lines, but the hydrogen lines are not of extreme thickness, though much thicker than in the solar spectrum.	The spectra show very broad hydrogen lines, and, in addition, faint representatives of some of the lines seen in stars of sub-division α.	The spectra show very broad hydrogen lines, and, in addition, faint representatives of the lines seen in stars of sub-division β.
γ Pegasi	β Cassiopeiæ	α Andromedæ	θ Aurigæ
ζ Persei	α Canis Minoris (Procyon)	ζ Cassiopeiæ	γ Geminorum
ϵ Persei	δ Cassiopeiæ	β Persei (Algol)	α Geminorum
β Orionis (Rigel)	ν Persei	48 Persei	α Canis Majoris (Sirius)
β Tauri	β Arietis	β Aurigæ	γ Ursæ Majoris
γ Orionis (Bellatrix)	α Persei	β Canis Minoris	α Canum Venaticorum
δ Orionis	δ Leonis	η Leonis	α Coronæ
λ Orionis	12 Comæ Berenicis	α Leonis	α Lyræ (Vega)
ι Orionis	13 Comæ Berenicis	β Ursæ Majoris	
ϵ Orionis	14 Comæ Berenicis	ι Ophiuchi	
ζ Tauri	γ Virginis	δ Capricorni	
ζ Orionis	γ Herculis	γ Lyræ	
κ Orionis	α Ophiuchi	α Pegasi	
β Canis Majoris	α Aquilæ (Altair)	The Pleiades	
η Ursæ Majoris	α Cephei		
α Virginis	ζ Aquarii		
π Scorpii			
δ Scorpii			
β Scorpii			
σ Scorpii			
τ Scorpii			
ζ Ophiuchi			
67 Ophiuchi			
σ Sagittarii			
δ Cygni			
α Cygni			

Many of the photographs are on too small a scale or are too ill-defined to show more than that there is no remarkable absorption in the violet or ultra-violet, and that the hydrogen lines are broad. These are as follows :—

π Ceti.	θ Coronæ.
γ Ceti.	λ Ophiuchi.
16 Comæ Berenicis.	ϵ Herculis.
δ Corvi.	η Ophiuchi.
17 Comæ Berenicis.	ρ Herculis.

ρ Hydræ.
β Leonis.
ε Ursæ Majoris.
ζ Ursæ Majoris.
ζ Virginis.
λ Bootis.
λ Virginis.
γ Bootis.
α Libræ.
β Libræ.
γ Coronæ.
β Coronæ.
δ Herculis.
γ Ophiuchi.
27 Ophiuchi.
o Herculis.
ζ Aquilæ.
29 Cygni.
ζ Delphini.
β Delphini.
α Delphini.
γ Delphini.
ζ Pegasi.

(2.) TABLE B.—Stars in which there is a continuous absorption in the ultra-violet, extending to about K. In these stars the hydrogen lines are relatively thin.

(α.) The spectra differ considerably from the solar spectrum, although showing a large number of fine dark lines.	(β.) The spectra have a very close resemblance to the solar spectrum.
γ Cygni	α Cassiopeiæ β Ceti α Ursæ Minoris α Arietis κ Persei α Aurigæ (Capella) β Geminorum ε Hydræ ζ Hydræ ε Leonis γ Leonis α Ursæ Majoris ε Virginis α Bootis η Bootis ε Bootis β Bootis ε Ophiuchi β Herculis ζ Herculis η Herculis π Herculis β Ophiuchi μ Ophiuchi ν Ophiuchi 70 Ophiuchi γ Aquilæ ζ Cygni η Pegasi μ Pegasi

(3.) TABLE C.—Stars in which there is a continuous absorption in the ultra-violet or violet, extending to about G. In these stars the hydrogen lines are narrow.

(α.) In the spectra there are indications of dark flutings fading away towards the less refrangible end of the spectrum.	(β.) There are no indications of flutings in the spectra.
β Andromedæ	η Ceti
α Ceti	α Lyncis
ρ Persei	γ Andromedæ
α Orionis (Betelgeux)	α Tauri (Aldebaran)
μ Geminorum	α Hydræ
δ Virginis	ψ Ursæ Majoris
ν Bootis	β Ursæ Minoris
δ Ophiuchi	α Serpentis
κ Ophiuchi	γ Draconis
α Scorpii (Antares)	η Serpentis
α Herculis	o^2 Cygni
β Pegasi	ϵ Cygni
	ϵ Pegasi

(4.) TABLE D.—Stars which are not included in any of the preceding Tables.

γ Cassiopeiæ.
β Lyræ.
P Cygni.
Nova Aurigæ.

It will be seen, on reference to the Tables, that the bright-line stars of the Wolf-Rayet type, and the red stars of Group VI., have not yet been photographed at Kensington. All the stars of these types are very faint, and the dispersion hitherto employed has been too great to successfully cope with them. A larger aperture, with smaller dispersion, appears to be essential; and this has not yet been available. It is intended, however, to utilize the three-foot reflector for this work as soon as possible.

All the stars of Table D show special features in their spectra, and will not be further considered in the present communication.

V.—DISCUSSION OF STARS IN TABLE A.

The stars included in this Table are characterised by the absence of any remarkable continuous absorption either in the violet or ultra-violet, and by the presence in their spectra of broad lines of hydrogen. As already shown, they may be conveniently classified into four sub-divisions, which we may now consider separately. The photographs, which only show the lines of hydrogen, owing to small dispersion or defective definition, will be omitted from the discussion.

(1.) Sub-division α.

Characteristics of the Spectra.

In all the stars in question the hydrogen lines are well marked, though not of such extreme breadth as in stars like Sirius. The total number of lines in the spectra is remarkably small, as compared with the number seen in stars which resemble the Sun. The lines seen in addition to those of hydrogen vary very considerably in passing from star to star, though some lines are common to them all. It will, therefore, be convenient to further sub-divide the stars, according to the presence or absence of individual lines. Such a classification is given in the following Table.

Stars in which there occur strong lines at 4025, 4120·5, 4143, 4388, 4471, in addition to hydrogen lines of moderate breadth.

(1) There are strong lines at 4481, 4233, 4127, and 4130. The lines at 4025 and 4471 are very feeble. A few lines of iron are added.	(2) The lines at 4025 and 4471 are much intensified, the last as strong as 4481. There are no lines of iron.	(3) The lines at 4481, 4127, 4130, are now faint, while 4025 and 4471 are very strong.	(4) The lines at 4025 and 4471 are still very strong, and lines at 4414·5 and 4088 are seen.	(5) The line at 4414·5 is intensified, while that at 4088 is feebler.	(6) Stars which show no lines of importance except the five typical lines.
α Cygni	β Orionis β Tauri 67 Ophiuchi δ Cygni	γ Orionis β Canis Majoris	δ Orionis ι Orionis ϵ Orionis ζ Orionis κ Orionis	ϵ Persei α Virginis γ Pegasi	ζ Persei λ Orionis ζ Tauri η Ursæ Majoris π Scorpii δ Scorpii β Scorpii σ Scorpii τ Scorpii ζ Ophiuchi σ Sagittarii

The preceding Table only refers to the more important lines in the spectra, and in order to facilitate comparisons, the following more complete one has been compiled. The wave-lengths were determined in the first instance from photographs taken with the two 10-inch prisms (Instrument C), and have since been confirmed by photographs taken with the larger dispersion of the 6-inch Henry prism of 45° (Instrument B). The values are believed to be accurate to four figures, and in cases where decimals are added, greater accuracy was attainable. The numbers following the wave-lengths indicate as nearly as possible the intensities of the lines, 6 being the strongest, and 1 the feeblest.

[Note, Aug. 15, 1893.—The wave-lengths have been determined by reference to the lines of hydrogen (marked *H*, *h*, and *G* in the plates), which appear in the spectra of all the stars which have been photographed.]

WAVE-LENGTHS of principal lines in spectra of Stars in Table A, sub-division α.

1.	2.		3.	4.	5.
	Kensington.	Potsdam.			
			3919 (2)		
			3926 (3)		
3933 (6)	3933 (6)		3933 (3)	3933 (1)	3933 (1)
3961 (6)					
	3963 (2)		3963 (3)	3963 (2)	
3968 (6)	3968 (6)		3968 (6)	3968 (6)	3968 (6)
	3994 (1)		3994 (3)	3994 (2)	
	4008 (2)		4008 (5)	4008 (2)	4008 (1)
4024 (2)					
4025 (1)	4025 (3)	4026·6 (6)	4025 (6)	4025 (4)	4025 (4)
			4040 (2)		
			4069 (2)	4069 (2)	4069 (2)
			4071 (2)		
			4075 (2)	4075 (2)	4075 (2)
				4088 (5)	
				4095 (2)	
4101 (6)	4101 (6)	4102·0 (6)	4101 (6)	4101 (6)	4101 (6)
			4104 (2)		
				4114 (4)	
			4119 (2)		
	4120·5 (2)	4121·2 (2)	4120·5 (4)	4120·5 (2)	4120·5 (2)
4121·5 (2)					
4127 (3)	4127 (3)	4128·3 (6)			
4130 (3)	4130 (3)	4131·2 (4)			
4143 (1)	4143 (2)	4143·8 (3)	4143 (5)	4143 (2)	4143 (2)
			4168 (3)		
4172 (4)	4172 (1)		4172 (1)		
4177 (4)	4177 (1)	4179·0 (2)	4177 (1)		
4233 (5)	4233 (2)	4233·3 (3)			
4241·5 (2)			4241·5 (2)		
4246 (2)					
			4253 (2)		
	4267 (2)	4267·7 (2)	4267 (4)	4267 (1)	4267 (1)
4298 (3)					
4302 (3)					
4307 (3)					
4314 (3)				4314 (1)	4314 (1)
4337 (2)					
4340 (6)	4340 (6)	4340·7 (6)	4340 (6)	4340 (6)	4340 (6)
			4345 (2)		
4351 (4)	4351 (1)		4351 (2)	4351 (1)	
4383 (3)					
	4388 (3)	4388·4 (4)	4388 (5)	4388 (2)	4388 (4)
4394·3 (3)			4394·3 (2)		
			4414·5 (2)	4414·5 (1)	4414·5 (3)
4417 (3)			4417 (2)		
		4439·6	4437 (3)		
4471 (1)	4471 (4)	4472·4 (6)	4471 (6)	4471 (5)	4471 (4)
4481 (5)	4481 (5)	4482·2 (6)	4481 (3)		
4541 (2)				4541 (1)	4541 (1)
4549 (4)					
4555·5 (3)			4553 (3)		
4558·5 (3)					

WAVE-LENGTHS of principal lines in spectra of Stars in Table A, sub-division α—(continued).

1.	2.		3.	4.	5.
	Kensington.	Potsdam.			
			4567 (2)		
4571 (2)					
			4574 (2)		
4583 (4)					
			4613 (2)		
4629 (3)			4629 (2)		
			4643 (2)		
			4650 (2)	4650 (6)	
			4714 (3)		

A list of the lines seen in three photographs of the spectrum of Rigel, taken at Potsdam, has already been published by Dr. SCHEINER,* and, allowing for the difference between the Potsdam scale and that of ÅNGSTRÖM, which I have employed, there is a fair agreement between the two series of measures.

The spectra of four typical stars of this sub-division, namely: α Cygni, β Orionis, γ Orionis and ζ Orionis, are shown in Plate 27. Many of the finer lines recorded in the table have been obliterated in the process of reproduction, but all the more important lines are present.

As far as the work has yet gone, sub-division (1) is only represented by α Cygni. The spectrum of this star is a very remarkable one. It shows many more lines than such stars as Rigel, but not nearly so many as stars which more or less resemble the Sun. The hydrogen lines are only of moderate thickness, and there are a few other strong lines, in addition to many fainter ones. On reference to Plate 27, it will be seen that it has many lines in common with Rigel and Bellatrix.

The K line of calcium is common to all the stars in question, but the strong blue line of calcium, at λ 4226, is absent.

With the exception of the K line, the lines of hydrogen, and the high temperature line of magnesium, at λ 4481, all the lines may be said to be at present of unknown origin. Some of the lines fall near lines of iron, but the absence of the strongest lines indicates that the close coincidences are probably accidental.

The Spectrum of γ Orionis.

A very fine photograph of the spectrum of this star was taken on September 17, 1892, with Instrument B. This shows many very fine lines in addition to those

* 'Ast. Nach.,' No. 2923, p. 328.

given in the preceding Tables. A complete list is given below, the intensities being indicated as in the previous tables.

LINES in the spectrum of γ Orionis (Bellatrix).

Wave-length.	Intensity.	Wave-length.	Intensity.
3919	2	4267	4
3926	3	4271	1
3933	3	4276	1
3963	3	4340	6
3968	6	4345	2
3982	1	4351	2
3994	3	4373	1
4008	5	4388	5
4025	6	4394·3	2
4040	2	4414·5	2
4069	2	4417	2
4071	2	4437	3
4075	2	4442·5	1
4088	1	4447	1
4101	6	4471	6
4104	2	4475·5	1
4119	2	4481·2	3
4120·5	4	4517	1
4127	1	4528·0 } 4530·5 }	2 { a broad faint band.
4130	1		
4143	5	4553	3
4149	1	4566	2
4153	1	4574	2
4168	3	4591	1
4172	1	4602	1
4177	1	4613	2
4227	1	4620	1
4235	1	4629	2
4241·5	2	4643	2
4253	2	4650	2
		4714	3

Sequence of Spectra in these Stars.

The stars of Table A, Sub-division α, may be arranged in a continuous series. The sequence is shown in Plate 27.

The four typical stars shown are—

ζ Orionis.
γ Orionis.
β Orionis.
α Cygni.

Early observations of these stars seemed to suggest that the lines change their intensities—even to disappearance—from time to time. No such change, however, has appeared at Kensington. In the case of Rigel photographs have been taken October, 1890, and October, 1892, and the spectrum has remained constant. Duplicates of γ, δ, ϵ, and ζ Orionis and β Tauri have also been obtained, without any changes being detected.

It has been a common practice to call the stars of this type "Orion stars," it being supposed that they were confined to the constellation Orion. We now know, however, that they are distributed in nearly all parts of the northern celestial sphere.

(2.) SUB-DIVISION β.

Characteristics of the Spectra.

In the stars of this sub-division the hydrogen lines are not quite so broad as in stars like Sirius, though they are much broader than in those like the Sun. Besides the lines of hydrogen, all the principal lines of the solar spectrum can be made out, but they are much finer than in the stars like the Sun. The metallic lines appear to be stronger when the hydrogen lines are finer and *vice versâ*.

Examples are shown in Plate 28.

α Aquilæ and α Ophiuchi have been included in this list, although they have particularly hazy lines in their spectra. These lines, however, agree in position with those of stars in Sub-division γ. In the case of α Aquilæ Professor PICKERING has also noticed that the lines are hazy, and has suggested that this may be due to the very rapid rotation of the star, the axis of rotation being at right angles, or nearly so, to the plane passing through the star and the Sun.* It is evident that such a rotation would broaden all the lines, and that the fainter lines would most probably disappear.

A special series of photographs of the spectrum of α Aquilæ is being taken at Kensington in order to determine whether the haziness of its spectrum lines is invariable.

Arrangement in Order of Differences.

The stars of this sub-division do not differ essentially from each other, the only difference being in the relative thicknesses of the hydrogen and the metallic lines.

Arranging the stars in the order of differences they may be further sub-divided as follows :—

* 'Annals of Harvard College Observatory,' vol. 26, p. 21.

(1.) The hydrogen lines are very broad, but a great number of fine metallic lines are visible.	(2.) The hydrogen lines are not so broad as in (1), and all the chief solar lines are clearly visible.	(3.) The hydrogen lines are still broader than in the solar spectrum, but not so broad as in (2). All the solar lines are very distinct.
δ Cassiopeiæ β Arietis δ Leonis 13 Comæ Berenicis 16 Comæ Berenicis α Ophiuchi α Aquilæ	β Cassiopeiæ 14 Comæ Berenicis γ Herculis α Cephei ζ Aquarii	α Canis Minoris 12 Comæ Berenicis γ Virginis

A complete list of the lines seen in the spectra of these stars would be superfluous, as it would be practically a list of the lines which appear in the solar spectrum.

(3.) Sub-division γ.

Characteristics of the Spectra.

In the stars of this sub-division, the hydrogen lines are extremely broad, and the additional lines are correspondingly faint. The characteristic lines occupy the same positions as lines in the spectra of stars in Sub-division α, the principal ones being those at $\lambda\lambda$ 4025, 4471, 4481. The stars given in the list bear a close resemblance to each other, but two further sub-divisions may be recognised. In the first of these, of which β Persei may be taken as a type, the lines at 4471 and 4481 are almost of equal intensity; in the second, *e.g.*, α Andromedæ, 4471 is very faint, and other additional faint lines appear.

Further Sub-division.

(1.) The strongest additional lines are at λλ 4024, 4471, and 4481, the latter pair being of equal intensity.	(2.) The intensity of the line at λ 4481 diminishes, whilst the line at λ 4471 is unaffected and other faint lines appear.
ζ Cassiopeiæ β Persei η Leonis α Leonis ι Ophiuchi γ Lyræ Pleiades { Atlas, Alcyone, Merope } δ Capricorni	α Andromedæ 48 Persei β Aurigæ β Canis Minoris β Ursæ Majoris α Pegasi Pleiades { Maia, Taygeta, Electra }

(4.) Sub-division δ.

Characteristics of the Spectra.

In these stars the hydrogen lines are very broad, and the additional lines, as before remarked, are chiefly faint representatives of those which appear in the solar spectrum. There is a complete inversion of the intensities of the hydrogen and metallic lines as compared with the solar spectrum. The most strongly-marked line, next to those of hydrogen, is generally the K line of calcium. A line of magnesium at 4481 is also usually easily distinguished. In the brighter stars, such as α Lyræ, a trace of the line at 4024 appears. In this case, however, it is accompanied by the lines of iron, whereas in Sub-division γ no iron lines have been detected so far.

It will be evident that no sharp line can be drawn between these stars and those of Sub-division β. The difference lies only in the relative intensities of the hydrogen and metallic lines. When all the principal solar lines are easily seen in the photographed spectrum the star has been classed in Sub-division β, but when only a comparatively small number of lines is seen, it has been placed in Sub-division δ.

It has not been found desirable or, indeed, possible to further sub-divide the stars included in Sub-division δ.

VI.—DISCUSSION OF STARS IN TABLE B.

In these stars there is a considerable amount of continuous absorption in the ultra-violet, and the spectra beyond K are very difficult to photograph with the instruments employed, as compared with the stars of Table A. The thickness of the hydrogen lines does not greatly differ from that observed in the solar spectrum.

(1.) Sub-division α.

Characteristics of the Spectra.

The only star of this sub-division which has yet been photographed at Kensington is γ Cygni. The spectrum shows a large number of dark lines, but it presents a very different appearance from that of the Sun. The characteristic grouping of lines about G is entirely absent, and many lines have very different intensities. The lines of calcium, including H and K, are only of moderate thickness.

Among the more prominent lines are the following :—

4383
4372
4351
4340 (G)

4325
4314
4233
4227
4176
4172
4126
4101 (*h*)
4118

The photographed spectrum is reproduced in Plate 26, and it will be seen that in addition to the lines given above there is a great number of less prominent lines.

(2.) Sub-division β.

Characteristics of the Spectra.

All the stars in this sub-division have spectra which very closely resemble the solar spectrum. In the spectrum of Arcturus, for example, over one hundred lines have been photographed in the region between G and *h*, and each line has its counterpart in the solar spectrum, as will be seen on reference to Plate 30. It appears, therefore, that all the substances which are present in the absorbing atmosphere of the Sun, are also present in the absorbing atmospheres of the stars of this sub-division.

The spectra show only small differences when compared with each other. Perhaps the greatest is between Capella and Arcturus. In the former the hydrogen lines are slightly thicker than in Arcturus, while in the latter some of the lines, especially those of calcium, are slightly intensified. The spectrum of Capella more nearly resembles the solar spectrum than does that of Arcturus. In Arcturus, also, the continuous absorption extends a little further towards G than it does in Capella.

We may therefore further sub-divide the stars of this sub-division as follows :—

Further Division into Two Sub-Classes.

(1.) Stars with spectra which cannot be distinguished from that of the Sun.	(2.) Stars with spectra which differ from the Sun in having some of the lines, especially those of calcium, slightly intensified. The lines of hydrogen are somewhat thinner than in (1).
α Cassiopeiæ	β Ceti
α Ursæ Minoris	κ Persei
α Arietis	ζ Hydræ
α Aurigæ (Capella)	α Bootis (Arcturus)
β Geminorum (Pollux)	β Bootis
ε Hydræ	π Herculis
ε Leonis	γ Aquilæ
γ Leonis	
α Ursæ Majoris	
ε Virginis	
η Bootis	
ε Bootis	
ε Ophiuchi	
β Herculis	
ζ Herculis	
η Herculis	
β Ophiuchi	
μ Herculis	
ν Ophiuchi	
70 Ophiuchi	
ζ Cygni	
η Pegasi	
μ Pegasi	

It will be evident that these two sub-divisions must be placed in juxtaposition whatever classification may be finally adopted. The spectra of Capella and Arcturus, which may be taken as types, are reproduced in Plate 29.

Carbon Absorption.

A question of considerable interest, as will appear later, is, whether in these stars there is any evidence of carbon absorption. In a communication to the Royal Society in 1878,* I showed that in the solar spectrum there is a dark fluting of carbon commencing at wave-length 3883. This has since been confirmed by Messrs. TROWBRIDGE and HITCHINS,† who also found that this fluting was the only one which remained visible when a complicated metallic spectrum was added to that of carbon.

It is therefore to be expected that indications of carbon absorption will be found in the spectra of the stars under discussion.

* 'Roy. Soc. Proc.,' vol. 27, p. 308.

† 'Phil. Mag.,' series 5, vol. 24, p. 148.

The photographs already taken do not generally extend beyond K, and hence the fluting in question is not open to investigation. In the spectrum of Arcturus, however, this region has been photographed, and the fluting is apparently present, but its intensity does not differ greatly from its intensity in the solar spectrum.

In a photograph taken by the Brothers HENRY two years ago, there is a decided darkening in the region of another group of carbon flutings commencing at λ 4215, but this does not appear in the Kensington photographs.

VII.—DISCUSSION OF STARS IN TABLE C.

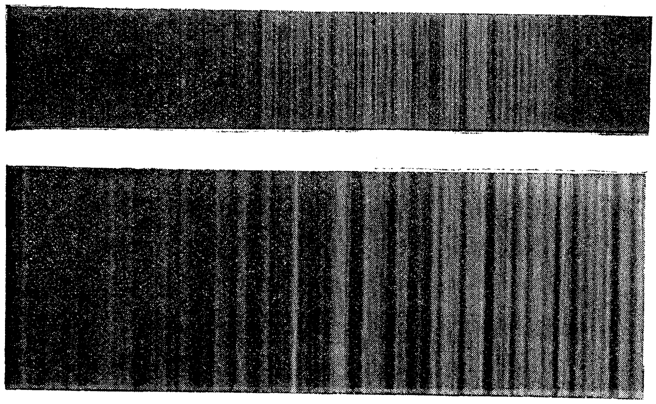
In all the stars included in this Table there is a very considerable amount of continuous absorption in the violet, extending to about G. Long exposures are therefore required, in order that their spectra may be photographed. The brightest star in the Table is α Orionis, and even this requires an exposure of 35 minutes with the instrument A to give a spectrum one-tenth of an inch wide, extending to the K line. With the 30-inch reflector and slit spectroscope, an exposure of one hour is barely sufficient. It is accordingly a matter of considerable difficulty to photograph the spectra of these stars, as most of them are below the third magnitude.

(1.) SUB-DIVISION α.

Characteristics of the Spectra.

Notwithstanding the fact that the visual spectra of these stars are characterised by conspicuous flutings, the region more refrangible than F consists almost entirely of dark lines. Indeed the only indication of flutings in this region in any of the stars named are near wave-lengths 4763 and 4585, and these vary in intensity in the different stars. The flutings are stronger in α Herculis than in any of the other stars in the Table, as will be seen on reference to Plate 26, and they are still stronger in the spectrum of Mira Ceti, as seen in a photograph kindly forwarded to me by Professor PICKERING. So far as the line spectrum is concerned, α Orionis may be taken as a type of the remainder. Lines of hydrogen, iron, manganese, calcium, chromium, cobalt, titanium, and strontium are common to them all. The calcium lines, it will be seen, are considerably intensified as compared with the corresponding lines seen in the solar spectrum. This applies also to the lines of chromium and manganese, so that the spectrum presents a very different appearance from that of the Sun. Many of the lines are at present unidentified. There is a remarkable difference in the lines at G, the grouping of which is so characteristic of the solar spectrum. This will appear from fig. 5.

Fig. 5.



Comparison of the G region of the Spectrum of α Orionis and the Sun.

The Dark Flutings in these Stars.

By the use of EDWARDS' isochromatic plates, photographs of the spectra of some of the stars under discussion have been obtained which extend as far in the green as λ 550. These consequently show some of the flutings which have been mapped by DUNÉR, VOGEL, and others.

The wave-lengths of the flutings have been determined by comparison with the spectrum of Arcturus photographed under the same instrumental conditions. These, compared with the mean values determined from eye observations by DUNÉR* and VOGEL,† are as follows :—

DUNÉR'S number of band.	DUNÉR (eye observations).	VOGEL (eye observations).	LOCKYER (photographs).
10	..	4607	4585
9	4770	4766	4763
8	4958	4959	4958
7	5168	5168	5165
5	5451	5452	5455

The positions given for the bands are for their more refrangible edges, and they are the same in all the stars of this group of which the spectra have been photographed at Kensington. The positions determined by VOGEL and DUNÉR, however, for the same band in different stars vary considerably. For band 5, VOGEL found the wave-length 5444 in α Orionis, and 5458 in α Herculis. These differences are, it is possible, due to the difficulties of observation, and in a small degree to the differing velocities in the line of sight.

* 'Sur les Étoiles,' p. 120.

† 'Bothkamp Beob.,' Heft 1, 1872.

The complete discussion of this region is reserved until better and more numerous photographs have been obtained.

Detailed Discussion of the Spectrum of α Orionis.

As α Orionis is the brightest star given in the Table under discussion, a special investigation has been made of its spectrum. Several photographs have been taken at Kensington, and one at Westgate, with the 3-prism slit spectroscope. The latter was exposed for one hour on November 30, 1891, and, as the slit was very narrow, the spectrum is well-defined. All the lines shown in the Westgate photograph have been reproduced in a later photograph taken at Kensington with the instrument B. The intensity of the violet is somewhat feeble, and the reduction has been limited to the region F to λ 4029. On reference to the photograph (Plate 28), it will be seen that the part of the spectrum extending from the violet to λ 4860 (F) consists almost entirely of lines, over 100 being distinctly visible between F and G. There are distinct groupings of lines, however, which correspond with the flutings seen in α Herculis and other stars of the same type.

For the reduction of the photograph a spectrum of daylight photographed with the same instrumental conditions has been employed.

It is easy to recognise well-marked lines which serve for the construction of the wave-length scale by means of the usual projection curve.

The hydrogen lines at F, G, and *h*, are almost as strong as in the spectrum of the Sun.

The investigation of the origins of the various lines includes also an inquiry into the probable temperature of the absorbing regions in the star. Thus, when we come to investigate the lines due to iron, we find that they do not correspond in relative intensities with those which appear in the arc spectrum. This will be clear on reference to the map, which shows the strongest lines in the arc spectrum, and all the lines of the flame spectrum of iron. Particular attention may be drawn to the four lines in the arc spectrum at wave-lengths 4201·6, 4203·5, 4206·3, and 4209·8. It will be seen that there is a complete inversion in intensities if we take the arc spectrum of iron, and many other cases are equally evident.

When compared with the flame spectrum of iron, which has been specially photographed for this investigation, a smaller number of lines is explained, but there are no inversions of importance. The feeble line at 4132 in the flame spectrum is comparatively strong in the spectrum of the star, but this is in all probability due to the superposition of the line of lithium which has the same wave-length. The only important divergence is in the case of the line 4143, which is much stronger in the star than in the flame spectrum. It is, however, a strong line in the arc spectrum of iron.

These comparisons lead to the conclusion that the temperature of the most important iron-absorbing region in α Orionis is nearer that of the oxy-coal gas flame than that of the electric arc. Still, as many of the arc lines appear to coincide with lines in the spectrum of the star, though they have different relative intensities, it is probable that the average temperature is intermediate between that of the arc and that of the flame, but nearer to the latter.

It is evident then that the flame spectra of other substances should also be compared with the spectrum of the star. Those which show any coincidences are indicated on the map. They include manganese, chromium, calcium, magnesium, strontium, cobalt, and lithium. Here, again, the arc spectra, especially in the case of manganese, show many inversions, and hence the conclusion that the temperature of the absorbing regions is lower than that of the electric arc is strengthened.

The results of the investigations into the origins of the lines are shown in Plate 28.

Elements identified in α Orionis.	
H	Mg
Fe	Co
Mn	Sr
Cr	Li
Ca	C

Many of the lines remain for the present unidentified, although careful comparisons have been made with the flame spectra of all the principal elements.

Amongst the strongest unknown lines are those at wave-lengths 4393, 4406, and 4763. There are also three very strong lines at λ 4038, 4053, and 4164. These are either entirely absent from the solar spectrum or only appear as very faint lines. That at λ 4406 forms a close double with the slightly more refrangible iron line λ 4405. It is strongly marked in the spectrum of α Tauri, as photographed at Kensington, and also appears in the spectra of β Andromedæ, α Herculis, β Pegasi, and other stars of Table C.

Bright Flutings.

In the spectra of α Orionis and α Herculis which have been photographed at Kensington on isochromatic plates there is the bright edge of a fluting at λ 5165 as near as can be determined, and this very closely agrees with the wave-length of the brightest edge of the carbon fluting λ 5164·8, according to measures made from my large scale photographic solar comparisons. If this were the only criterion for bright carbon, the evidence might be considered conclusive. There are, however, two other bright maxima in this compound carbon fluting, at wave-lengths 5128·5 and 5098·3, and we should also expect to find these in the spectrum. In α Herculis, two secondary bright flutings are clearly visible, and the following table will show their positions relatively to the carbon flutings.

Carbon.	α Herculis.
5164·8	5165
5128·5	5136
5098·3	5107

It will be seen that the coincidences are not very exact for the secondary maxima, but the question is complicated by the fact that several dark lines appear in the same region, and the secondary maxima may therefore be masked.

Further photographs will be taken with special reference to this region, special exposures being required, as the photographic plates in use are very slow for this part of the spectrum, and the instrument has to be specially focussed.

Other regions of the spectrum have also been examined for bright flutings, more particularly with reference to the flutings of carbon. From a photograph of the spectrum of Mira Ceti taken by Professor PICKERING, there is strong evidence of the existence of the carbon group, commencing at wave-length 4215·6, but there are no decided indications of it in α Orionis. In the latter spectrum the dark lines are much more numerous than in Mira, and hence the bright fluting, if present, may be masked. It seems more likely, however, that the increased temperature, indicated by the greater number of lines in α Orionis, is the true explanation of the disappearance of the fluting, only the most persistent one—that at λ 5165—remaining. There are no certain indications of the bright fluting of carbon commencing at λ 4736 (see Plate 28).

Sequence of Spectra of these Stars.

Plate 26 shows the spectra of α Herculis, β Pegasi, α Orionis, and β Andromedæ, arranged in the order of differences. This order has been chiefly determined by the flutings near λ 4763 and λ 4585, which gradually thin out in passing from α Herculis to β Andromedæ. It will be seen also that the lines of calcium and some other lines thin out in the same order.

Including the stars of which the spectra have not been reproduced, they have been arranged as follows, those bracketed together being indistinguishable from each other.

{ β Andromedæ.
  α Ceti.
  ν Bootis. }

α Orionis.

{ β Pegasi.
  α Scorpii.
  ρ Persei. }

{ α Herculis.
{ δ Virginis.

{ δ Ophiuchi.
{ μ Geminorum.

(2.) SUB-DIVISION β.

Characteristics of the Spectra.

All the spectra of the stars of Sub-division β of Table C are practically identical, and only that of α Tauri is therefore reproduced.

This is shown in Plate 26, and on comparison with the spectrum of α Orionis the close similarity in the photographic region will be evident.

In all the stars named the intensity of the spectrum beyond G is feeble, and long exposures are required in order to obtain photographs in that region. The falling off of intensity, however, is not so strongly marked as in the stars of Sub-division α.

As in α Orionis, the origins of the chief lines have been traced to hydrogen, iron, calcium, manganese, chromium, magnesium, titanium, cobalt, and strontium. The lines of calcium, especially the low temperature line at λ 4226, are particularly broad. The manganese lines near λ 4029, and the iron line near λ 4045, are remarkably conspicuous. The latter is relatively much stronger than the other iron lines in the same region, as compared with stars like the Sun, and this suggests that it may be strengthened by a line of some unknown substance which has very nearly the same wave-length. On reference to the photograph it will be seen also that the two iron lines λ 4383 and λ 4405 are also considerably intensified in this group of stars. These two pairs of lines, with the strong line of calcium at λ 4226 and the weakness of the spectrum beyond G, serve for the ready identification of all stars resembling α Tauri.

DUNÉR* describes the spectrum of α Hydræ as more resembling that of the Sun than that of α Tauri, but the photographic spectrum is practically identical with α Tauri. The calcium line λ 4226 is very strong, as are also the other characteristic lines to which reference has been made.

Possible Variation in the Spectrum of α Tauri.

An interesting point has followed from the comparison of the Kensington photographs of α Tauri with one taken and kindly forwarded to me by Professor PICKERING. The strong line, about λ 4406, in the Kensington photographs is hardly visible in the photograph taken by Professor PICKERING, and it would, therefore, appear that the spectrum must be variable. This particular line, it may be remarked, probably forms

* 'Sur les Étoiles,' &c., p. 88.

a close double with the iron line λ 4405, being slightly less refrangible. It is a very strong line in a photograph of the spectrum of α Tauri taken at Kensington, on November 20, 1888, and is seen in the spectra of all the stars resembling α Tauri or α Orionis. A photograph taken on September 15, 1892, with the instrument B shows the line strongly marked.

It will be evident from a comparison of the photographs that these stars bear a close relationship to those of Sub-division α. The increased brightness of the violet end of the continuous spectrum, in conjunction with the fading out of the flutings, may be taken as an indication of increased temperature in passing from Sub-division α to Sub-division β.

VIII.—THE GENERAL SEQUENCE OF THE SPECTRA OF THE STARS NOW UNDER DISCUSSION.

(1.) SEQUENCE OF SUB-DIVISIONS.

We have now before us the facts relating to the various spectra which have been photographed at Kensington, and the next thing to do is obviously to attempt to trace the relationships of the various sub-divisions to which reference has been made.

Two Series of Spectra.

One important fact comes out very clearly, namely, that, whether we take the varying thicknesses of the hydrogen or of the lines of other substances as the basis for the arrangement of the spectra, it is not possible to place all the stars in one line of temperature. For example, in the stars of Table A, Sub-division α, the hydrogen lines are of the same average thickness as in the stars of Table A, Sub-division β, but the remaining lines are almost entirely different; and the two sub-divisions cannot be placed in juxtaposition. It is, therefore, necessary to arrange the stars in two series. This has been done, and the general results of the investigation are shown in Plates 26, 27, and 29, where the spectra of eighteen typical stars are arranged in order of differences. The corresponding sub-divisions are as follows :—

Reference to Plates 26 *and* 27.

Typical stars.	Sub-divisions.				
α Andromedæ	Table A,	sub-division		γ	2
β Persei	,,	,,	,,	,,	1
ζ Orionis	,,	,,	,,	α	4
γ Orionis	,,	,,	,,	,,	3
β Orionis	,,	,,	,,	,,	2

Typical stars.	Sub-divisions.	
α Cygni	Table A, sub-division α	1
γ Cygni	,, B ,, α	
α Tauri	,, C ,, β	
β Andromedæ, α Orionis, β Pegasi, α Herculis	,, C ,, α	

Reference to Plate 29.

Typical stars.	Sub-divisions.	
α Andromedæ	Table A, sub-division γ	2
α Canis Majoris, α Geminorum	,, ,, ,, δ	
α Persei	,, ,, ,, β	2
α Canis Minoris	,, ,, ,, ,,	3
α Aurigæ	,, B ,, β	1
α Bootis	,, ,, ,, ,,	2

(2.) Variations Observed.

It will be seen, on reference to Plates 26 and 27, that, starting with α Herculis, we have a mixed spectrum of lines and flutings, the latter gradually disappearing in β Pegasi, α Orionis, and β Andromedæ, until, in α Tauri, nothing but lines remain. At the same time the continuity of the lines is unbroken, so that if we were to arrange the stars according to the thicknesses of, say, the lines of calcium, the same order would be deduced.

Next in the series is γ Cygni, the spectrum of which has much in common with that of α Tauri, but there is less continuous absorption, and many of the lines of α Tauri thin out.

The next step, to α Cygni, is rather a long one, but it seems very probable that, if more photographs were available, intermediate spectra would be found. It will be seen, however, that in α Cygni the hydrogen lines are intensified as compared with γ Cygni, and that all the important lines of α Cygni agree in position with prominent lines in γ Cygni.

At this stage there is a great diminution in the number of lines, as will be seen on referring to the spectrum of Rigel (β Orionis), which is the next star in the series. In passing to Rigel, the more important lines of α Cygni are retained, and a few new lines make their appearance.

The next star in the series is Bellatrix, the line at λ 4471 increasing in intensity, while the line at λ 4481 has almost disappeared.

In the next stage, represented by ζ Orionis, an important new line at λ 4088 makes its appearance, but all the chief lines of Bellatrix are retained.

α Virginis is the next star in the series, and here again it is clear that the continuity is unbroken, the hydrogen lines also being broader than in the stars already dealt with.

β Persei and α Andromedæ are the representatives of the sub-divisions which come next in the sequence, and in these also it will be seen that there is perfect continuity.

From α Herculis to α Andromedæ, we thus have a continuous series of spectra, the dark flutings first disappearing, and afterwards most of the lines of the more common metals such as iron and manganese, lines of unknown origin gradually replacing them. At the same time, the amount of continuous absorption is gradually diminishing, and the lines of hydrogen are increasing in intensity.

We now come to the second series (Plate 29), and here it is quite an easy matter to begin where the first series left off, namely, with such a star as α Andromedæ. In these stars, as already pointed out, there are no certain indications of iron. There are other stars, however, such as Sirius and α Geminorum in which there are all the important lines of α Andromedæ, and, in addition, some of the lines of iron.

In the stars which come next in the sequence, represented by β Arietis, there is an intensification of the metallic lines, and a slight diminution in the breadth of the hydrogen lines. This goes on through the various sub-divisions represented by α Persei, α Canis Minoris, α Aurigæ, and α Bootis, the hydrogen lines thinning out as the metallic lines thicken. Continuous absorption in the ultra-violet commences in the later stars of the series.

Thus, from α Andromedæ to Arcturus there is a perfectly continuous series of spectra.

IX.—DISCUSSION OF RESULTS IN RELATION TO THE METEORITIC HYPOTHESIS.

(1.) Phenomena to be Expected on the Hypothesis.

Reference to Classification based on Eye Observations.

We are now in a position to consider the various divisions of the photographic spectra already arrived at, in relation to the groups which were previously suggested from a discussion of eye observations. This classification was as follows:—*

Group I.—Radiation lines and flutings predominant. Absorption beginning in the last species.

Group II.—Mixed radiation and absorption predominant.

* 'Roy. Soc. Proc.,' vol. 44, p. 26.

GROUP III.—Line absorption predominant with increasing temperature. The various species will be marked by increasing simplicity of spectrum.

GROUP IV.—Simplest line absorption predominant.

GROUP V.—Line absorption predominant, with decreasing temperature. The various species will be marked by decreasing complexity of spectrum.

GROUP VI.—Carbon absorption predominant.

GROUP VII.—Extinction of luminosity.

The fundamental difference between this and other classifications is that it demands the existence of bodies of increasing as well as bodies of decreasing temperatures.

We have, therefore, to inquire how far this condition is satisfied by the mass of new facts at our disposal. This involves the consideration of some points in connection with the meteoritic hypothesis to which brief reference alone has been made in my previous communications.

The Complex Origin of the Spectra of Nebulæ.

On the hypothesis, the bright lines seen in the nebulæ should have three origins.

(1.) The lines of those substances which occupy the greatest volume (or largest area in a section); in other words, the lines of those substances which are driven furthest out from the meteorites and occupy the interspaces, when possibly they may be rendered luminous by electricity. Chief among these, from laboratory experiments, we should expect hydrogen, and next, from the same experiments, we should expect gaseous compounds of carbon.

(2.) We are justified in assuming that the most numerous collisions will be partial ones—grazes—sufficient only to produce comparatively slight rises in temperature. The nebula spectrum, so far as it is produced by this cause, will therefore depend upon the phenomena produced in greatest number, and we may therefore expect to find the low temperature lines of various metallic substances.

(3.) In addition to the large number of partial collisions there will be a relatively small number of end-on collisions, producing very high temperature,* and, so far as this cause is concerned, there will be some lines produced which are associated with very high temperatures.

Combining these conclusions, in the spectra of nebulæ we should expect to find evidence of

Hydrogen.
Compounds of carbon.
Low temperature metallic lines and flutings.
Lines which are only produced at very high temperatures.

* 'Roy. Soc. Proc.,' vol. 43, p. 150.

The Passage to Bright-line Stars.

On the hypothesis, the lines seen in the spectra of bright-line stars should, in the main, resemble those which appear in nebulæ. They will differ, however, for two reasons :—

(1.) Owing to partial condensation of the swarm the hydrogen area will be restricted, and the bright lines of hydrogen will lose their prominence; the volume occupied by the carbon compounds will be relatively increased, and the brightness of the carbon bands will be enhanced.

(2.) On account of the increased number of collisions, more meteorites will be rendered incandescent, and the continuous spectrum will be brighter than in nebulæ.

Stars of Increasing Temperature.

Initially, each pair of meteorites in collision may be regarded as a condensation.

Ultimately, when all the meteorites are volatilized, there will only be one condensation, in the shape of a spherical mass of vapour. Between these points there must be other conditions.

(Stage 1.)—At the stage of condensation immediately following that of the bright-line stars, the bright lines from the interspaces will be masked by corresponding dark ones produced by the absorption of the same vapours surrounding the incandescent meteorites. One part of the swarm will give bright lines, another dark lines at the same wave-lengths, and these lines will therefore vanish from the spectrum. The interspaces will be restricted so that absorption phenomena will be in excess, and the first absorption will be that due to low-temperature vapours, that is, fluting absorptions of various metals. The radiation spectrum of the interspace will now be chiefly that of the compounds of carbon. Under these conditions we know from laboratory experiments* that the amount of continuous absorption at the blue end will be at a maximum.

(Stage 2.)—With further condensation the radiation spectrum of the interspaces will gradually disappear, and the fluting absorptions will be replaced by dark lines, for the reason that the incandescent meteorites will be surrounded by vapours produced at a higher temperature, the number of violent collisions per unit time and volume being now greatly increased. This dark line spectrum need not necessarily resemble that of the Sun.

(Stage 3.)—The line absorption and the continuous absorption at the blue end of the spectrum will diminish as the condensations are reduced in number, for the reason that only those vapours high up in the atmospheres surrounding

* LOCKYER and ROBERTS-AUSTEN, 'Roy. Soc. Proc.,' 1875, p. 344.

the condensations will be competent to show absorption phenomena, in consequence of the bright continuous spectrum of the still disturbed lower levels of those atmospheres.

Among the more important lines which will disappear at this stage will be those of iron, for the reason that there will be bright lines from the interspaces occupying the same positions as the dark lines produced by the absorption of the vapour surrounding the stones.

The number of violent collisions per unit time and volume being further increased, we should expect the absorption of very high temperature vapours.

The Hottest Stars.

Ultimately, then, we should expect that the order of the absorbing layers will follow the original order of the extension of the vapours round the meteorites in the first condition of the swarm, and the lines seen bright in nebulæ, whatever their origins may be, should therefore appear almost alone as dark lines in the hotter stars, and the hydrogen especially should have its lines broadened with each increase of depth in the atmosphere. The continuous absorption at the violet end of the spectrum will be at a minimum. If, when the hydrogen lines are thickest the swarm is not yet completely condensed, that is, if there be nebulous matter surrounding the central mass of vapour, a fine bright line will be seen down the centre of each dark one.

Stars of Decreasing Temperature.

When we consider the cooling condition, that is, what happens when the temperature of the mass of vapour is no longer increased by the fall towards the centre of meteorites composing the initial swarm, we should expect to find the phenomena indicated below.

(Stage 1.)—The hydrogen lines will begin to thin out, on account of the diminishing depth of the absorbing atmosphere, and new lines will appear.

As I have already pointed out,* the new lines will not necessarily be the same as those observed in connection with stars of increasing temperature. In the latter there will be the perpetual explosions of the meteorites affecting the atmosphere, whereas in a cooling mass of vapour we have to deal with the absorption of the highest layers of vapours. Those lines which will first make their appearance, however, will be the longest low temperature lines of the various chemical elements.

(Stage 2).—The hydrogen lines will continue to thin out, and when the absorption of the hotter lower layers makes itself felt the spectra will show the

* 'Roy. Soc. Proc.,' vol. 45, p. 382.

high temperature spectra of the various chemical elements, showing many more lines. The difference between these and the lines seen in stars of increasing temperature should be one due to the different percentage composition of the absorbing layers, so far as the known lines are concerned.

With this increasing line absorption there will be a recurrence of the continuous absorption in the ultra-violet.

(Stage 3).—With the further thinning of the hydrogen lines and reduction of temperature of the atmosphere, the absorption flutings of the compounds of carbon should come in.

So much, then, for what we should expect, assuming the hypothesis to be true.

I now proceed to show how far these requirements are satisfied by the mass of new facts now at our disposal.

(2.) The Actual Phenomena Recorded on the Photographs.

Nebulæ.

A preliminary account of the photographs of the spectrum of the Orion Nebula taken with Instrument E has already been published,* and though the discussion is not yet completed, it may be stated that the lines recorded in the spectrum are at wave-lengths which approximate very closely to the lines of hydrogen, to flutings which appear in the spectra of compounds of carbon, to a fluting of magnesium at 5006, and to the longest flame lines of iron, calcium, and magnesium.

The chromospheric line designated D_3 has been recorded in the visual spectrum of the Orion Nebula by Dr. Copeland,† and the observation has since been confirmed by Mr. Taylor.‡

The line which is always associated with D_3 in the spectrum of the chromosphere, viz., that at λ 4471 (Lorenzoni's *f*), is also shown in the photograph of the spectrum of the Orion Nebula.

The requirements of the hypothesis with regard to nebulæ are therefore met in every point so far considered by the new facts.

Dividing up the lines into the three groups of origins suggested, we have in the case of the Orion Nebula :—

(*a*.) Spectrum of large interspace (= that of non-condensable gases driven out of the meteorites) } = Lines of hydrogen ; flutings of carbon.

* 'Roy. Soc. Proc.,' vol. 48, p. 199.

† 'Monthly Notices,' vol. 48, p. 360.

‡ *Ibid.*, vol. 49, p. 124.

(b.) Spectrum of vapours produced by the large number of partial collisions	=	Fluting of magnesium at λ 5006;* low temperature, lines of iron, calcium, and magnesium.†
(c.) Spectrum of the vapours produced at a very high temperature by the relatively small number of end-on collisions. The solar chromosphere may be taken as indicating the spectrum associated with this very high temperature	=	Chromospheric lines, $D_3 + \lambda$ 4471.

A detailed reference to those nebulæ showing the spectra of carbon bands alone is reserved for a future communication.

Bright-Line Stars.

Professor PICKERING has shown that the Draper Memorial Photographs (copies of which he has very kindly forwarded me) prove that bright-line stars are intimately connected with the planetary nebulæ, the lines in the spectra being almost identical, as the following table will show :—‡

* My suggestion of the coincidence of the brightest line of the nebular spectrum with the fluting of magnesium at λ 5006·5, has given rise to discussion, and some observations have been made by Professor KEELER, with the three-foot Lick refractor and the third order spectrum of a diffraction grating, on this subject. When I first suggested magnesium as the origin of the chief line in the nebular spectrum, the measurements then available were quite sufficient to justify it as regards position, and there were other and stronger grounds for the suggestion, depending upon laboratory experiments and upon the frequently observed fluted character of the line. There are so many pitfalls attending the delicate measurements involved in such an inquiry, that I am not yet convinced that the absolute wave-length of the nebular line has been determined. The Astronomer-Royal has recently pointed out ('Monthly Notices,' vol. 52, p. 245) that the varying flexure of the telescope, when presented to different parts of the sky, has an effect on the measurements, and in the spectroscopic determinations of the motions of the stars in the line of sight at Greenwich, the displacement of the lines in the spectrum of a star was found to give clear indications of the existence of the systematic error referred to. Further, I have convinced myself of the fluted nature of the line by new observations made with instruments best fitted to show it, while the Lick telescope is perhaps the ideal telescope *not* to employ in such an inquiry. Hence, although the visibility of magnesium in nebulæ is not fundamental for my argument, I still hold that it is more probably the origin of the nebular line than an unknown form of nitrogen.

† I have previously given evidence deduced from eye observations, indicating the presence of other low temperature flutings of manganese and magnesium.

‡ 'Ast. Nach.,' No. 3025, p. 1.

PROFESSOR PICKERING's Table of Bright Lines.

Planetary nebulæ.	Bright-line stars. Type I.	Bright-line stars. Type II.	Bright-line stars. Type III.
501			
486	486	486	
470	469	469	
..	462	464	464
..	454	455	455
..	..	451	451
447	..	447	
..	..	..	443
434	434	434	434
..	420	420	421
410	410	410	412
..	406	406	407
..	402	402	
397	398	397	
..	395	..	395
388	389	389	

The main point of difference is that the chief nebular line near λ 5006 is not seen in the spectrum of bright-line stars, and this no doubt is due to the relative absence of feeble collisions as condensation goes on. The brightening of this line in the spectra of Nova Cygni and Nova Aurigæ, as the stars faded away, is sufficient evidence that it is associated with low temperature, and hence it is not surprising to find that it is absent from the spectra of the bright-line stars, which on this hypothesis are hotter than the nebulæ, since they are more condensed.

I have stated that we should expect—

(*a.*) The carbon flutings, and
(*b.*) The continuous spectrum to be brighter than in nebulæ, while
(*c.*) The hydrogen lines are fainter.

(*a.*) I may add, by way of reminder, that in my previous discussion of these bodies* I showed that there was evidence of a very considerable amount of carbon radiation in the visible region of the spectrum. Subsequent work at Kensington and Westgate, and an examination of Professor PICKERING's photographs have strengthened this view. The photographs show a band which agrees very closely in position with the band of carbon commencing at λ 4736, but which under certain conditions has its brightest part at λ 468.† A full discussion of this question will form the subject of a future communication.

* 'Roy. Soc. Proc.,' vol. 44, pp. 33–43.
† *Ibid.*, p. 38.

(*b.*) There can be no question as to the continuous spectrum being brighter in bright-line stars than in nebulæ.

(*c.*) The hydrogen lines also are decidedly less prominent. Indeed they were not recorded at all in the eye observations of γ Argûs (Arg.-Oeltz., 17681), or WOLF and RAYET'S 2nd and 3rd stars in Cygnus,* but they are shown in Professor PICKERING'S photographs.

Stars of Increasing Temperature.

Stage 1.—We should expect the spectra to show :—

(*a.*) Absence of bright lines.
(*b.*) The presence of dark metallic flutings.
(*c.*) The presence of bright carbon flutings.
(*d.*) Continuous absorption in the violet.

We know that there are spectra—those of stars in Table C, Sub-division α—which answer these requirements.

(*a.*) They show no bright lines under normal conditions, but if the stars are variable, the disturbances which bring about the change of luminosity at maximum, produce bright lines in the spectrum as in the case of the spectrum of Mira Ceti photographed by Professor PICKERING.

(*b.*) In my discussion of DUNÉR'S observations† I showed that most of the dark flutings observed in the part of the spectrum visible to the eye approximated very closely to the flutings seen in the flame spectra of manganese, lead, and iron. As already stated (p. 702) some of these dark flutings have been photographed at Kensington, but they have not yet been completely investigated.

(*c.*) In my discussion of DUNÉR'S‡ eye observations, I also showed that in addition to dark metallic flutings we had to deal with radiation flutings of carbon.§ The evidence afforded by the photographs has already been referred to (p. 704) and although there is now no reason to doubt the actual presence of carbon radiation, further photographs are being obtained to carry on the inquiry.

The stars of this class which have already been photographed at Kensington are well advanced in condensation, as indicated by the numerous dark lines, and all the flutings, both bright and dark, are confined to the region less refrangible than G. We should therefore not expect to get the more refrangible carbon flutings, as I have

* 'Roy. Soc. Proc.' vol. 44, pp. 33–43.

† *Ibid.*, p. 49.

‡ *Ibid.*, p. 52.

§ Subsequent observations by myself and Mr. FOWLER seemed to leave no doubt as to the pointed out in a previous communication.* It is among the least condensed stars that we should expect the bright carbon to be more manifest, and, indeed, in the spectrum of Mira Ceti photographed by Professor PICKERING, there is strong evidence of the presence of one of the more refrangible carbon bands commencing at λ 4215.

(*d.*) That there is a very considerable amount of continuous absorption in the ultra-violet or violet has already been stated, and the photographs reproduced in Plate 26 fully demonstrate this.

It is evident that the sequence of the spectra photographed should resemble that deduced from eye observations. In the case of the stars already photographed (see Table C, Sub-division *α*) this order was as follows, the group of stars being divided into fifteen species :—

α Orionis *ν* Bootis	Species 15.
α Ceti δ Virginis *α* Herculis	,, 10.
α Scorpii *β* Pegasi δ Ophiuchi	,, 9.
μ Geminorum *ρ* Persei	,, 8.

There is evidence that *β* Andromedæ, which was not included by DUNÉR in his Tables, should also be included in Species 15. GOTHARD observed the spectrum of this star in 1882,† and stated its spectrum as VOGEL'S Class III.—*α*. (Group II.); DUNÉR, however, re-examined the spectrum‡ and recorded that it was like that of *α* Tauri, in the red there was "almost a band," but the remainder of the spectrum consisted entirely of lines. My own observations at Westgate, and Mr. FOWLER'S observations at Kensington, in the latter part of 1888, showed that the spectrum

presence of these bright carbon flutings.[1] Dr. COPELAND had previously made important observations of "Nova" Orionis with reference to this point,[2] and he identified one of the bright bands as "the great hydrocarbon band seen in the spectrum of every comet that has been examined under favourable circumstances." Referring to his observations of *α* Orionis, Mr. MAUNDER[3] states that "the carbon band at 5164 was coincident (within the limits of observation with this dispersion) with the bright space towards the blue of DUNÉR'S band 7."

* 'Roy. Soc. Proc.,' vol. 44, p. 59.

† 'Public. des Astr. Obs. zu Herény,' Heft 1, p. 50.

‡ 'Sur les Etoiles,' p. 86.

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[1] 'Roy. Soc. Proc.,' vol. 47, p. 40.

[2] 'Monthly Notices,' vol. 46, p. 112.

[3] 'Greenwich Spect. Observations,' 1889, p. 22.

was then intermediate between α Orionis and α Tauri, and that it should, therefore, be placed in Species 15. It is, perhaps, possible that the spectrum is slightly variable.

Other eye observations at Kensington,* showed that α Ceti should be transferred to Species 15. Including β Andromedæ and this star we should, therefore, have the following relation :—

Order from eye observations.	Order from photographs.
{ β Andromedæ.	{ β Andromedæ.
{ α Ceti.	{ α Ceti.
	{ ν Bootis.
{ α Orionis.	
{ ν Bootis.	α Orionis.
{ α Herculis.	{ α Scorpii.
{ δ Virginis.	{ β Pegasi.
	{ ρ Persei.
{ α Scorpii.	
{ β Pegasi.	α Herculis.
{ δ Ophiuchi.	
	δ Virginis.
{ μ Geminorum.	
{ ρ Persei.	{ δ Ophiuchi.
	{ μ Geminorum.

It will be seen that very nearly the same order as that derived from eye observations is arrived at from the photographs, and the wonderful thing is that the observations of DUNÉR will bear the severe test which has thus been applied to them.

(Stage 2.)—At this stage we should expect—

(*a.*) Diminution in the amount of continuous absorption.

(*b.*) Spectrum consisting of dark metallic lines, but possibly differing from the solar spectrum.

These conditions are fulfilled by the stars of Table C, Sub-division β, and Table B, Sub-division α, of which α Tauri and γ Cygni may be taken as types. The continuous absorption is least in latter. These spectra show numerous metallic lines, but they do not exactly resemble the solar spectrum. The hydrogen lines are comparatively thin, while other lines have very different intensities as compared with lines in the solar spectrum.

In these stars we have to deal with the varying volatilities of the meteoritic constituents of the swarm, while in the case of stars which are cooling we have to

* 'Roy. Soc. Proc.,' vol. 45, p. 385.

deal with successive combinations rendered possible by the fall of temperature in a gaseous mass. Hence differences in the spectra are to be expected.

(Stage 3.)—The phenomena which would be expected on the hypothesis, at this stage, are fully satisfied by the stars of Table A, Sub-division α. In these stars there is no continuous absorption in the violet or ultra-violet, and the spectrum is one with simple line absorptions, the iron lines quite disappearing after such a star as α Cygni is passed. The new lines which now make their appearance include the chromospheric line at λ 4471, and possibly a few others. It is important to note that the photographic region of the spectrum of the chromosphere has not yet been fully investigated, and hence a fair comparison with the spectra of these stars in the region F to K is not yet possible. M. DESLANDRES and Professor HALE have photographed the chromospheric spectrum in the region more refrangible than H, but have not as yet published any account of the spectrum in the region now under discussion.

The Hottest Stars.

The conditions required by the hypothesis with regard to the stars at this stage are satisfied by the stars of Table A, Sub-division γ.

In these stars we have—

(*a*.) Broad lines of hydrogen, and

(*b*.) Other absorption lines agreeing in position with some of the bright lines which appear in nebulæ. This will be seen from the following Table, showing the coincidences of the lines which appear in α Andromedæ with the lines of the Orion Nebula:—

α Andromedæ.	Orion Nebula.
3933 (K)	3933
3968 (H)	3968
4025	4025
4066	4068
4101 (*h*)	4101
4130	4130
4143	4142
4152	4155
4168	4167
4187	4188
4202	4200
4268	4268
4340 (G)	4340
4471	4471

Professor PICKERING's photographs have shown that in the spectrum of Pleione there are bright lines down the middle of the broad dark lines of hydrogen, and we know from the photographs taken by Mr. ROBERTS and others that this star is involved in uncondensed nebulous matter. Hence, another possible condition in the hottest stars is satisfied by the photographic facts at our disposal.

It will be seen then, that these considerations of the conditions of increasing temperature demanded by the hypothesis, have enabled us to determine that the series of spectra represented in Plates 26 and 27 is in all probability a series in *ascending* order of temperature. All the phenomena we should expect, on the hypothesis, are met with among the spectra of celestial bodies.

We have next to consider the phenomena connected with stars of decreasing temperature.

Stars of Decreasing Temperature.

(Stage 1.)—We have seen that with the failure of the supply of meteorites falling into the centre of the now vaporized mass, cooling will commence, and the longest lines in the spectra of the various chemical elements should make their appearance. This condition is met with in the stars of Table A, Sub-division δ. The following Table will show that this is true in the case of the iron lines, if we take the spectrum of Sirius as a type.

Some of the Iron Lines in the Spectrum of Sirius.

4045
4063
4071
4215
4298
4307
4383
4404
4414

(Stage 2.)—The conditions at this stage of cooling are satisfied by the stars of Table A, Sub-division β. In these stars, as already pointed out (p. 696), we get, in addition to fairly broad lines of hydrogen, nearly all the lines which appear in the solar spectrum, and these it is well known agree in the main with the arc spectra of the various chemical elements.

(Stage 3.)—The stars of Table B, Sub-division β, represent the conditions which are required by the hypothesis at this stage of cooling. The metallic line absorption is again at a maximum, and we find the lines of the various chemical elements similar to those seen at Stage 2 of the ascending series, but with different intensities and with different amounts of continuous absorption at the violet end of the spectrum. This difference, so far as the known lines are concerned, I have already pointed out will be due to a different percentage composition of the absorbing mass of vapour (p. 713).

Continuous absorption in the violet begins at this stage, as will be seen on reference to the spectrum of Arcturus. The question of carbon absorption at this stage has already been referred to (p. 700). There is undoubted evidence of its presence in the solar spectrum, and in the spectrum of Arcturus—the only star which has yet been investigated with special reference to this point.

Hence, it seems probable, as I stated in a former paper,* that "the indications of carbon will go on increasing in intensity slowly, until a stage is reached, when, owing to the reduction of temperature of the most effective absorbing layer, the chief absorption will be that of carbon."

It is evident that all such stars will be dim, and hence their spectra have not been met with in this preliminary survey of the photographic spectra of the brighter stars.

The phenomena we should expect on the hypothesis, in stars of decreasing temperature, therefore actually appear in the series of spectra represented in Plate 29.

The general result of the above discussion then, as far as it goes, is as follows:—Among the 171 stars already considered there are really two series of spectra, one representing the changes accompanying the increase of temperature, while the other represents the effects of decreasing temperature. The fundamental requirement of the meteoritic hypothesis is, therefore, fully justified by the discussion of the photographs.

A very important point in connection with the two series of successive spectra is that one spectrum, such as that of α Andromedæ, possesses characteristics common to both, and we might, therefore, connect the two series together by this spectrum. In that case we should find, if we commence with the first spectrum in Series 1, say that of α Herculis, that the continuous absorption diminishes and that the breadth of the hydrogen lines regularly increases, until such a spectrum as that of α Andromedæ is reached (Plates 26 and 27). Then the condition would be reversed, the breadth of the hydrogen lines diminishing and the continuous absorption in the ultra-violet increasing in extent until such a star as Arcturus is reached (Plate 29).

I have previously discussed the question of what spectrum is associated with the hottest stars,† and, generally speaking, it appears to be that in which the continuous radiation at the violet end of the spectrum is greatest, and the hydrogen absorption lines are broadest.‡

* 'Roy. Soc. Proc.,' vol. 43, p. 155.

† Bakerian Lecture, 'Roy. Soc. Proc.,' vol. 44, p. 26.

‡ An erroneous idea with regard to the indications of the temperature of the stars has been held by those who have not considered the matter specially. It has been imagined that the presence of the series of hydrogen lines in the ultra-violet was of itself sufficient evidence of a very high temperature. The experiments of CORNU[1] however, have shown that the complete series of lines can be seen with an ordinary spark without jar. Hence, the high temperature of such a star as Sirius is not indicated by the fact that its spectrum shows the whole series of hydrogen lines, but by the fact that there is bright continuous radiation far in the ultra-violet.

[1] 'Journal de Physique,' vol. 10, 1886.

The stars with flutings in their spectra are probably among the coolest, as we know from laboratory experiments that flutings are always associated with low temperatures. Assuming these distinctions to be true, it is seen that when the two series of ascending and descending spectra are united in this way, the hottest stars, as we should expect, fall in the middle of the combined series.

(3.) Relation of the Groups to the Tabular Divisions.

We may next proceed to inquire into the relationships of the groups in the classification first suggested by the eye observations to the various sub-divisions in the tables of photographs which have already been given.

The Ascending Series.

It has already been shown (p. 707) that the most probable sequence of spectra in what we have now demonstrated to be the ascending series is as follows, the stars of highest temperatures being placed at the head of the list.

Table	A,	Sub-division	γ, 1.
,,		,,	α, 5.
,,		,,	α, 4.
,,		,,	α, 3.
,,		,,	α, 2.
,,		,,	α, 1.
,,	B,	,,	α.
,,	C,	,,	β.
,,		,,	α.

If, as in the original classification, we take Group II. to include all the stars with dark flutings, Group III. to include all the stars of increasing temperature which have line spectra, and Group IV. to include the hottest stars, we shall evidently have the following relation :—

Table A,	Sub-division	γ, 2	Group IV.
,,	,,	γ, 1	
,,	,,	α, 5	Group III.
,,	,,	α, 4	
,,	,,	α, 3	
,,	,,	α, 2	
,,	,,	α, 1	
,, B,	,,	α	
,, C,	,,	β	
,,	,,	α	Group II.

It will be seen that the sequence now determined from the photographs follows exactly the same order as the groups originally suggested by the hypothesis, from a discussion of the eye observations. That is, it is not necessary to interchange any of the groups in order to obtain agreement with the photographic results.

The Hottest Stars. (Group IV.)

At this point it becomes necessary to consider what spectra shall be included in Group IV. In the Bakerian Lecture I wrote as follows with regard to it :—

"The next group, the fourth, brings us to the stage of highest temperature, to stars like α Lyræ ; and the division between this group and the prior one must be more or less arbitrary, and cannot at present be defined. One thing, however, is quite clear, that no celestial body without all the ultra-violet lines discovered by Dr. HUGGINS can claim to belong to it."

We are met by a similar difficulty when we attempt to draw the dividing line between this group and the next (Group V.).

The photographic spectra, however, enable us to more clearly define the group, and it will be convenient to include the stars of Table A, Sub-division γ, 1 ; Table A, Sub-division γ, 2 ; and Table A, Sub-division δ. The stars in the first of these sub-divisions are still increasing their temperatures, though having almost reached their maximum, and they are distinguished from stars of Group III. by the reappearance of the line at λ 448, and in having broader hydrogen lines than those stars.

The stars of Table A, Sub-division γ, 2, represent, so far as we can judge at present, the stars of highest temperature. They are distinguished from those of the previous sub-division by the disappearance of the line at λ.

Stars of Table A, Sub-division δ, which include α Lyræ and Sirius, are marked by the appearance of iron lines in the spectrum. They probably represent the earliest stage of cooling.

The dividing line between Group IV. and Group V. may very conveniently be taken by the absence or presence of the blue line of calcium at λ 4226·6, this line making its first appearance in the stars of Table A, Sub-division β.

We have then the following relation to the tables :—

Table A, Sub-division	γ, 1		Group IV.
,, ,,	γ, 2		
,, ,,	δ		

The Descending Series.

If we treat the descending series in the same way, accepting the original definition of Group V., we have the following relation :—

Table A, Sub-division	γ, 2	Group IV.
,, ,,	δ	
Table A, Sub-division	β, 1	Group V.
,, ,,	β, 2	
,, ,,	β, 3	
,, B, ,,	β, 1	
,, ,,	β, 2	

Here again, the photographs, so far as they go, fully justify the grouping suggested by the meteoritic hypothesis.

Combining the two series, we thus get exactly the same order from the photographic spectra, as that originally deduced, on the hypothesis, from eye observations.

(4.) Extension of the Original Classification.

Formation of Sub-groups.

These considerations enable us to provisionally extend the classification originally suggested by the eye observations, as there are now many more details at our command. Further sub-division into species was attempted in the case of Group II., and Group I. was divided into the two well-defined sub-groups of nebulæ and bright-line stars. In the case of the other groups, a finer division was not possible from the available facts.

Group II. was originally divided into fifteen species from a consideration of the eye observations. Since the photographs open up the blue for our investigation, the sub-division may be based on extent of the fluting-absorptions in the way which will be indicated.

Taking the groups in order, perhaps the most useful sub-division will be as indicated below.

GROUP I.—Radiation lines and flutings predominant.

Sub-group α.*—Nebulæ.

Sub-group β.—Bright-line stars.

GROUP II.—Mixed fluting radiation and absorption predominant. Much continuous absorption in the violet.

Sub-group α.—Dark flutings probably extending from the red end to the region more refrangible than G† (λ 434).

Sub-group β.—Dark flutings extending as far as G. *E.g.*, Mira Ceti.

Sub-group γ.—Stars in which the most refrangible dark fluting is at λ 4585. *E.g.*, α Herculis.

Sub-group δ.—Stars in which the most refrangible dark fluting is at λ 4763. In addition to the flutings there is a large number of dark lines. *E.g.*, α Orionis.

GROUP III.—Line absorption predominant, with increasing temperature. Less continuous absorption at the violet end.

Sub-group α.—Stars with line spectra resembling those of Group II., Sub-group δ, but with only a single fluting in the red remaining. *E.g.*, α Tauri.

Sub-group β.—Continuous absorption in violet less than in Sub-group α. The calcium lines are less intense, while lines at λλ 4172, 4233, and 4177, have their intensity increased. *E.g.*, γ Cygni.

Sub-group γ.—Stars with spectra consisting of a relatively small number of dark lines. The hydrogen lines are of only moderate breadth, and among the additional lines are some which are seen bright in the solar chromosphere. In this sub-group the continuous absorption in the violet is almost a minimum. *E.g.*, β Orionis.

GROUP IV.—Simplest line absorption predominant, the hydrogen lines being very broad.

Sub-group α.—The spectra are marked by the presence of fine lines at wave-lengths 4024, 4471, 4481, the two latter being of almost equal intensity. *E.g.*, β Persei.

Sub-group β.—Highest temperature. The spectra show additional faint lines, and 4471 almost disappears. *E.g.*, α Andromedæ.

Sub-group γ.—The lines of iron make their appearance, but the line of calcium at λ 4226 is not yet distinct. *E.g.*, Sirius.

* The Greek letters have been adopted to avoid confusion with the symbols employed in VOGEL'S classification.

† None of the stars of this sub-group have yet been photographed at Kensington, but their existence is indicated by the discussion of DUNÉR'S observations, and on the hypothesis, there must be an intermediate stage between the bright-line stars and stars like Mira Ceti.

GROUP V.—Line absorption predominant, with decreasing temperature.

Sub-group α.—The lines of hydrogen are still broad, and the line of calcium at λ 4226 is clearly visible. The grouping of lines about G, which is so characteristic of the solar spectrum, is not visible. *E.g.*, β Arietis.

Sub-group β.—All the solar lines are now clearly visible, but the hydrogen lines are broader than in the solar spectrum. The grouping at G is only partially developed. *E.g.*, Procyon.

Sub-group γ.—The spectra very closely resemble the solar spectrum, the characteristic grouping of lines about G being fully developed. Carbon absorption commencing in the ultra-violet. *E.g.*, Capella.

GROUP VI.*—Carbon absorption predominant.

Sub-division into Species.

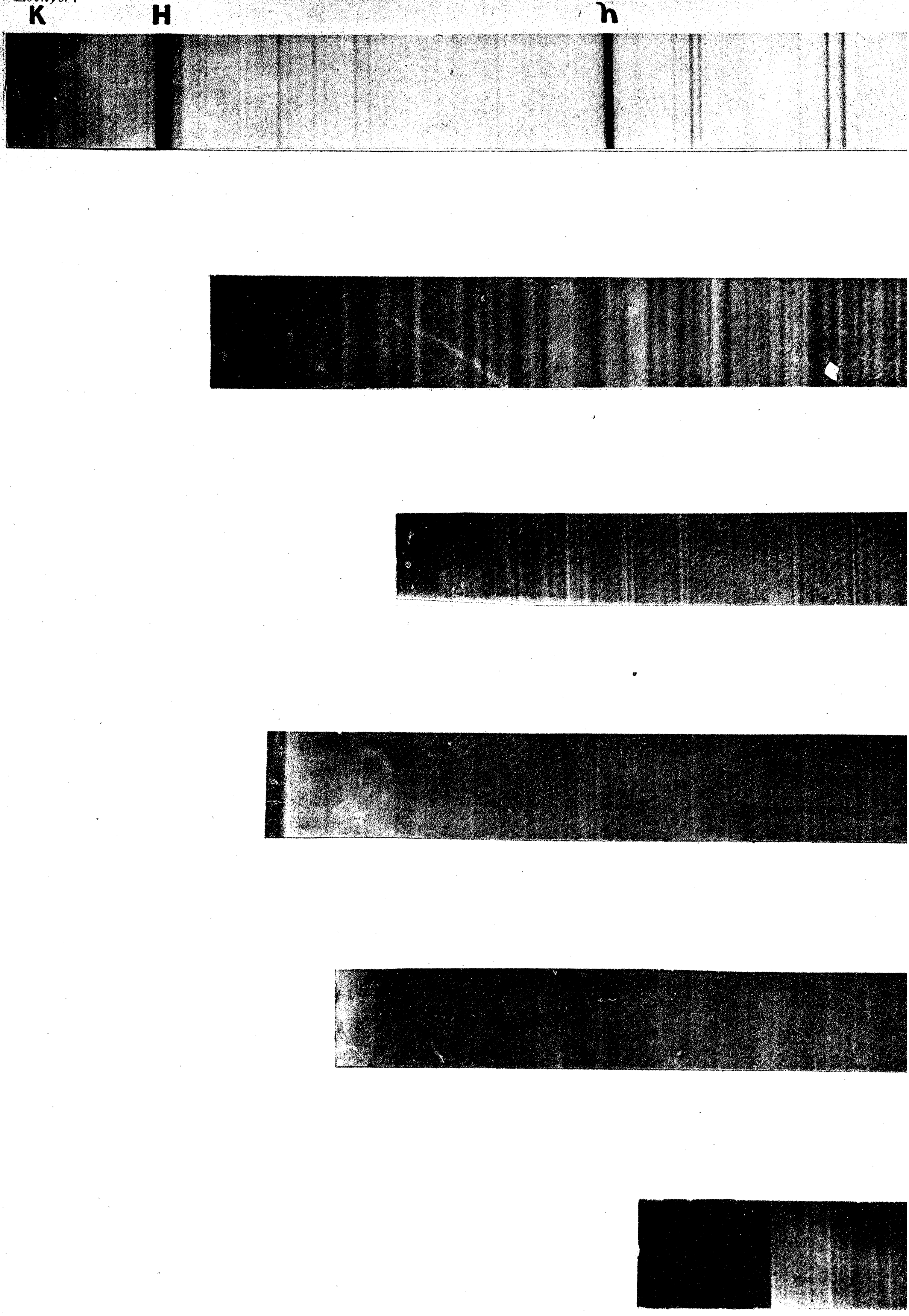
As more photographs become available for detailed examination, it will be possible to sub-divide the various sub-groups into species. Thus, in the case of the bright-line stars, Professor PICKERING, agreeing with me in classifying the bright-line stars with the nebulæ, has already divided the former into three types. In consequence, however, of there being less than 200 stars included in the present discussion, I have not thought it desirable to attempt the further sub-division in the present communication. It is clear already that the species of Group II. given in my former communication will hold good.

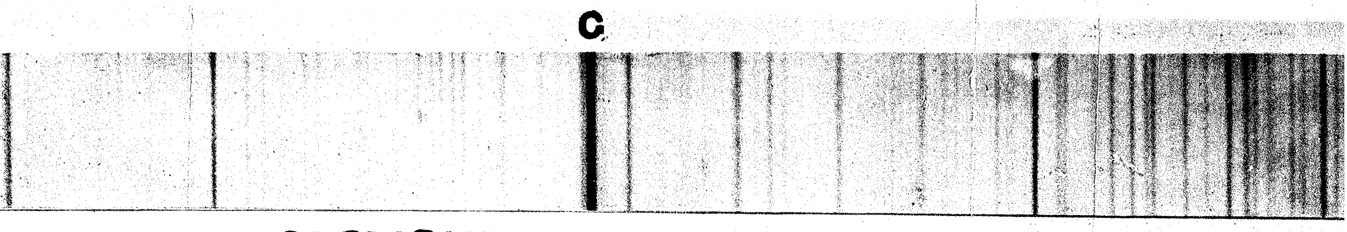
In concluding this communication, I am anxious to express my obligations to those who have assisted me in the different branches of this inquiry.

The chief labour entailed in taking the photographs has been borne by Messrs. FOWLER, BAXANDALL, and SHACKLETON. It is impossible to overrate the zeal and the patience they have shown in the almost hopeless observing conditions of the last two years. Repeated visits to the observatory on the same night have often been made. Some of the photographs obtained at Westgate-on-Sea were taken by Mr. W. J. S. LOCKYER. Mr. FOWLER and Mr. BAXANDALL are chiefly responsible for the determination of wave-lengths, Mr. FOWLER having also largely aided in the final discussion of the photographs. Messrs. GREGORY and FOURNIER have assisted from time to time, and the photographic enlargements have been made by Sergeant KEARNEY and Corporal HASLAM.

* No photographs of the spectra of stars of this group have yet been photographed at Kensington. So far as they are yet known, they are all below the fifth magnitude, and the investigation of their spectra is therefore almost impossible with the present means. With the instrument D the spectrum of 152 Schj. could not be photographed with an hour's exposure.

Lockyer.





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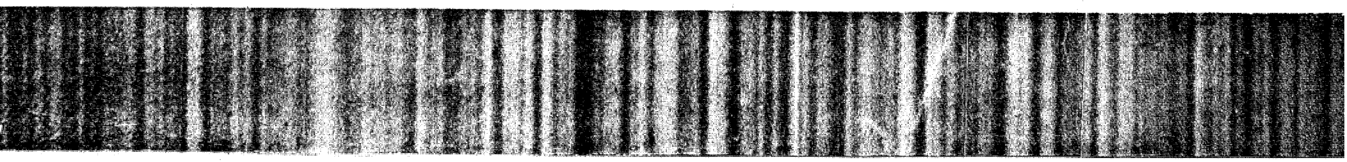

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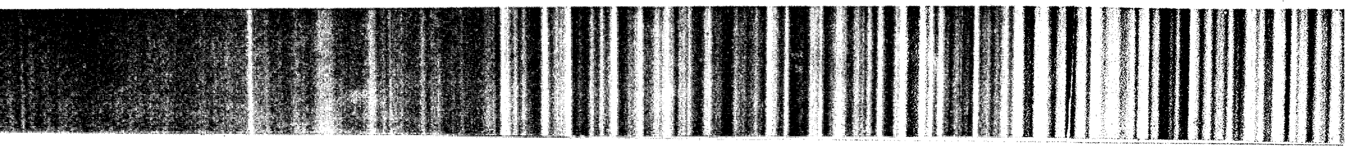

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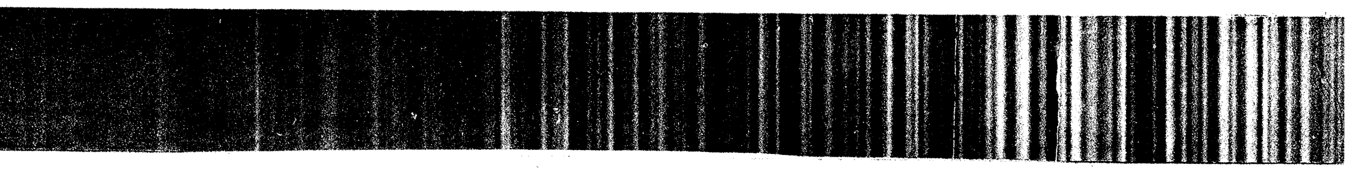

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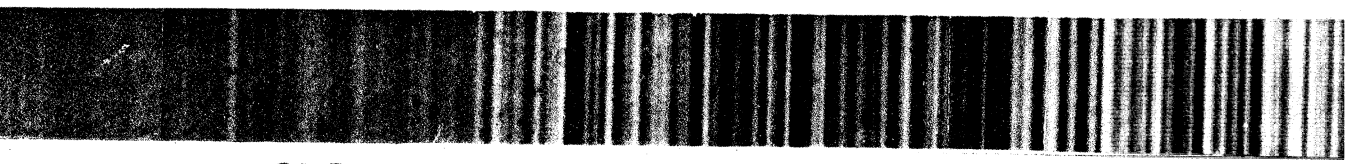
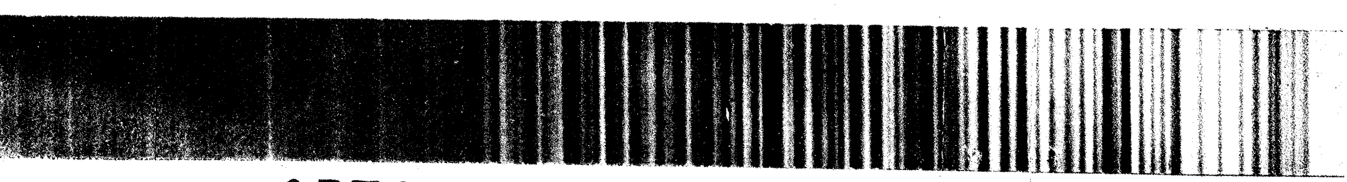
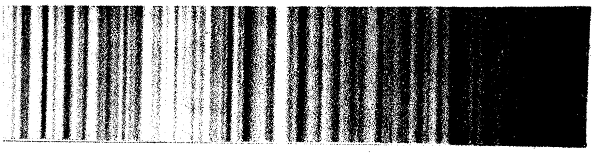
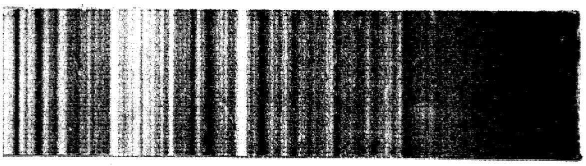


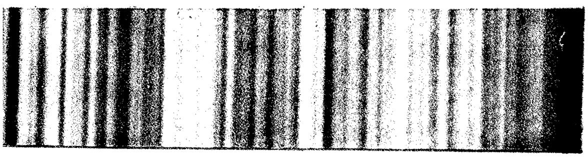
α ORIONIS

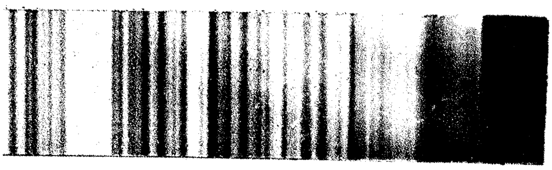


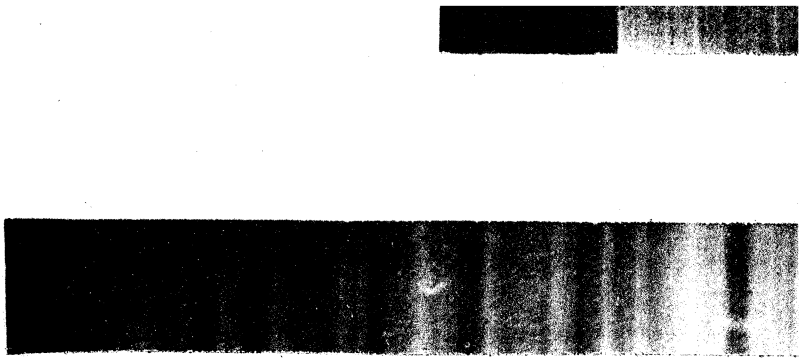
β PEGASI











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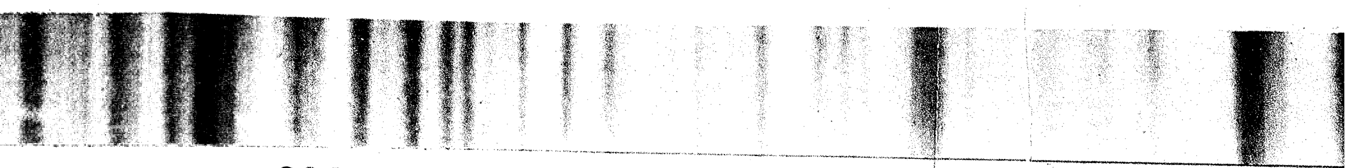
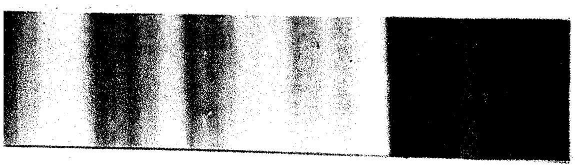
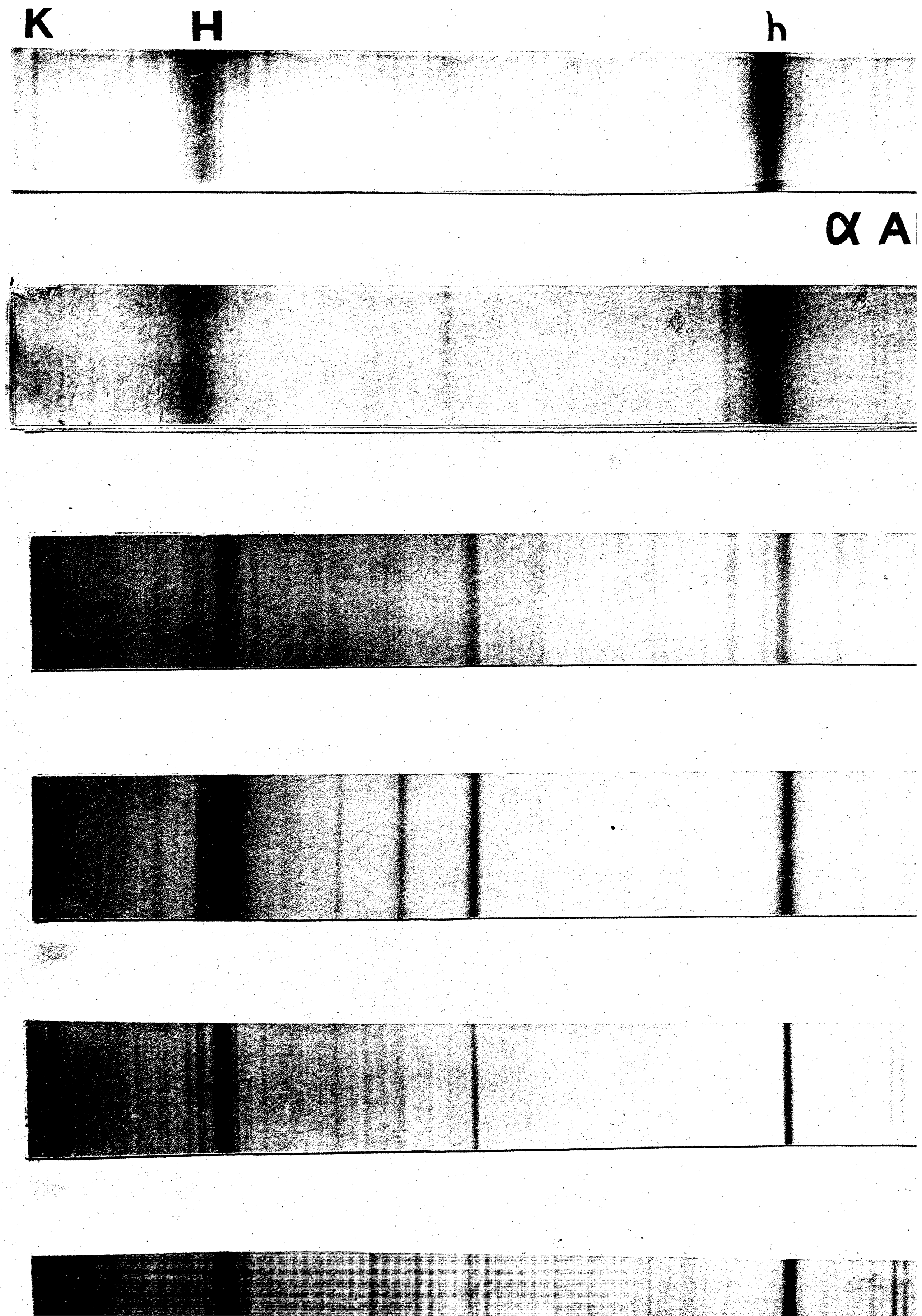
β PECASI



α HERCULIS

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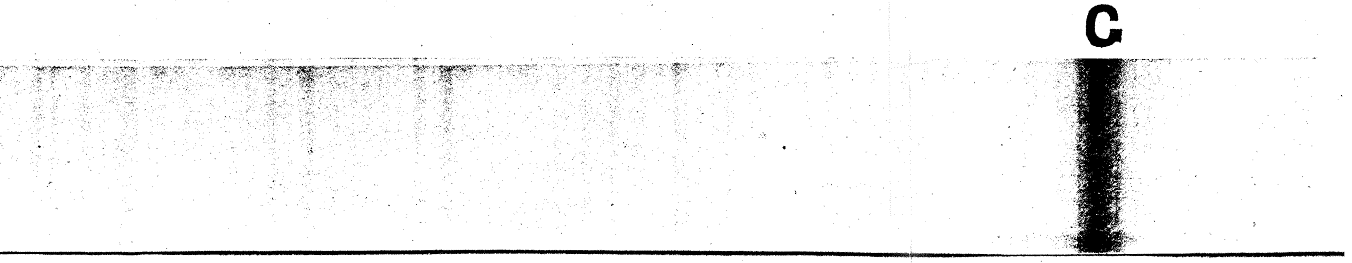
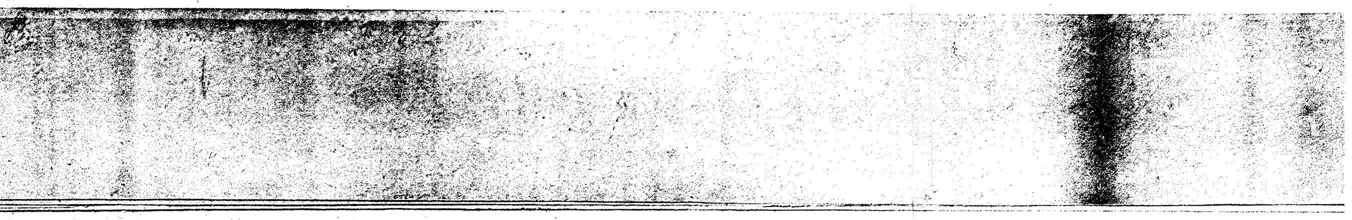


ANDROMEDÆ



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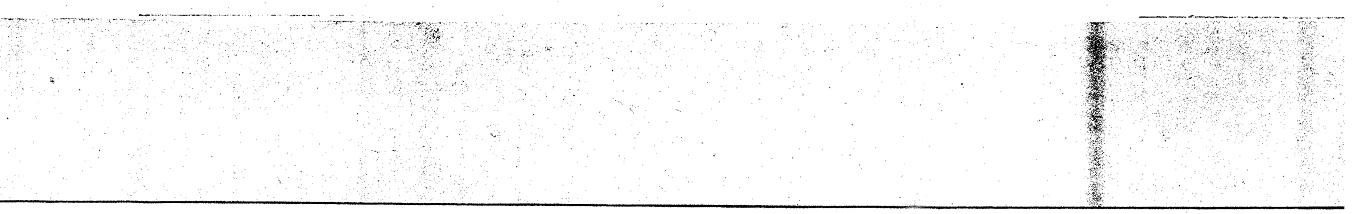
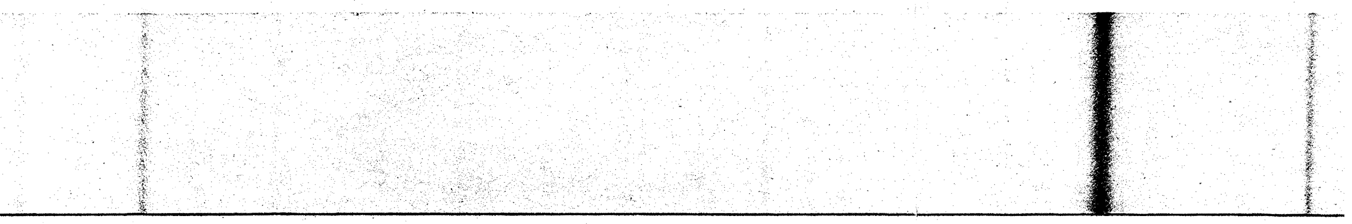


ζ ORIONIS



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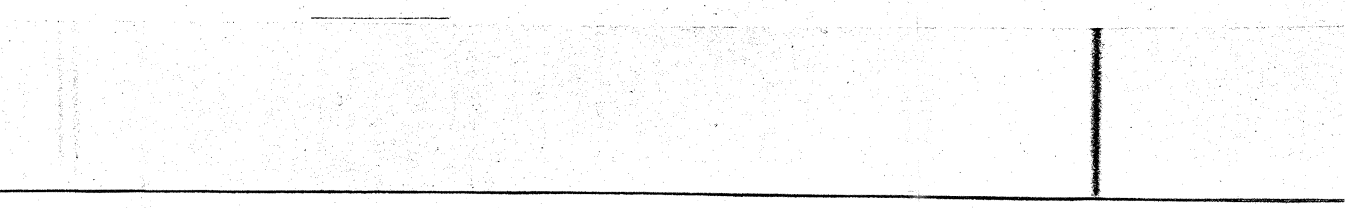

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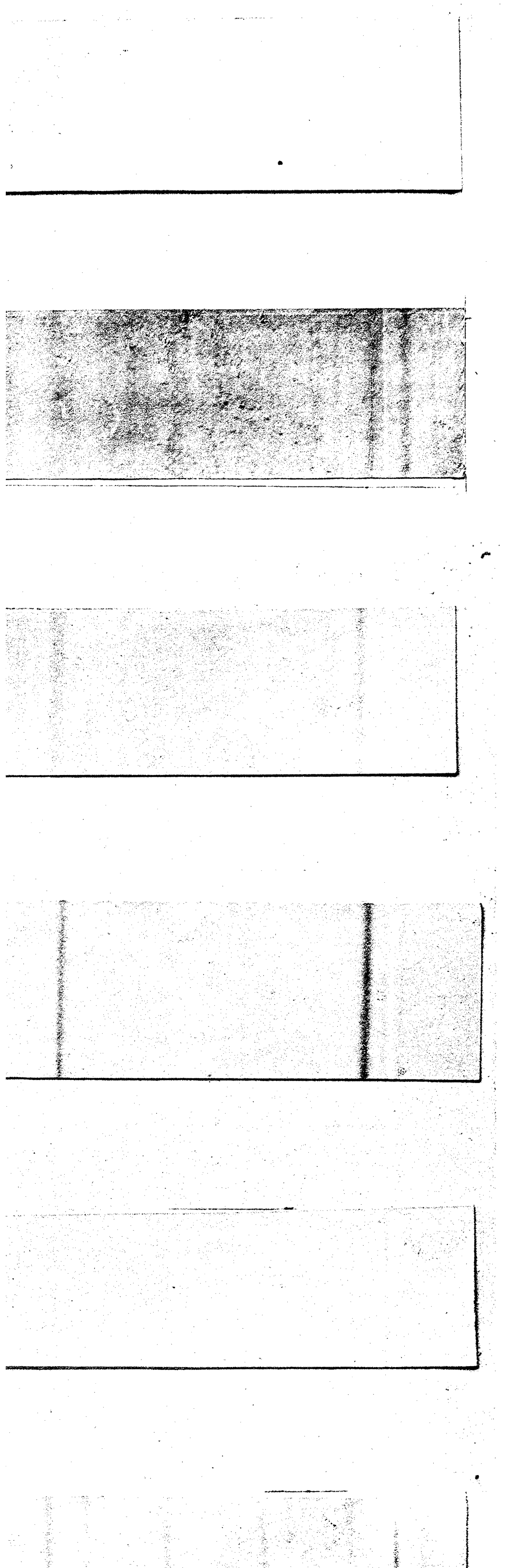

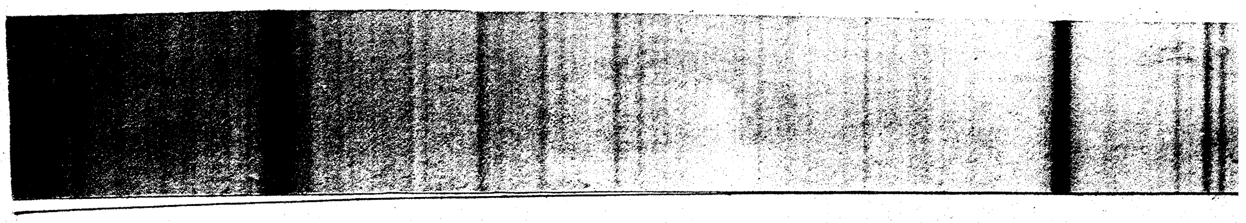

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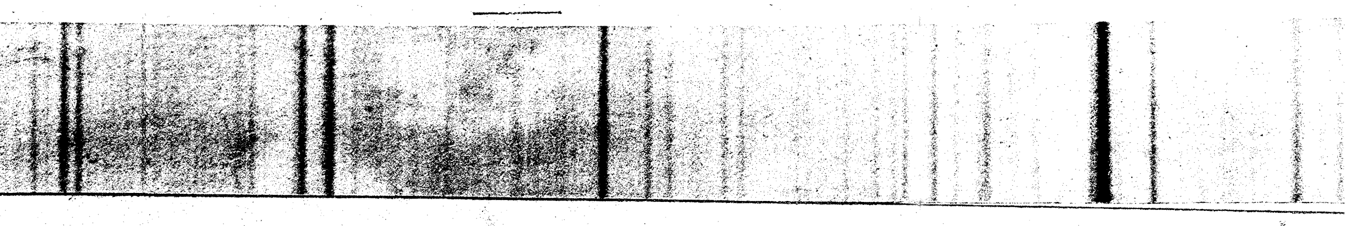

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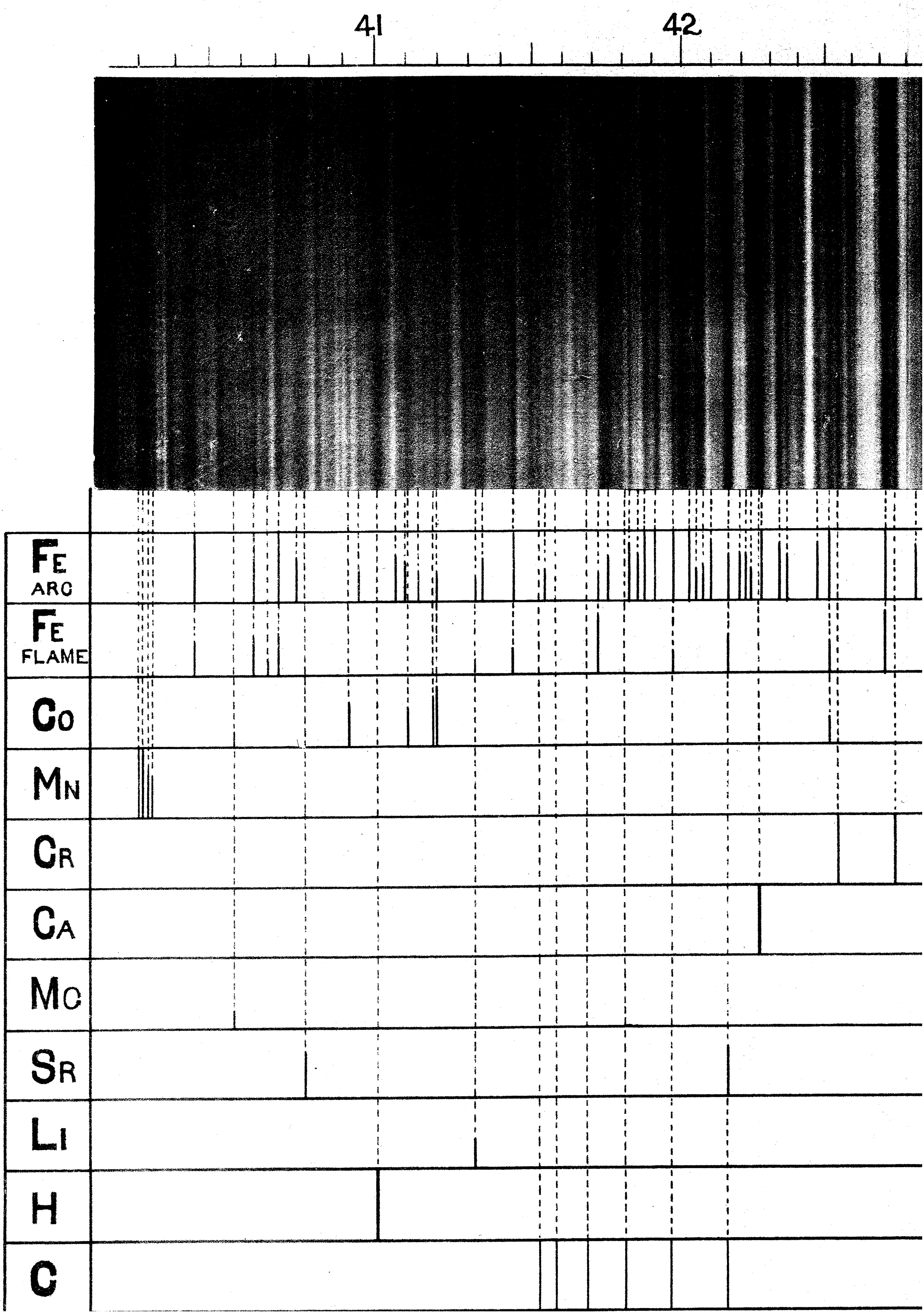
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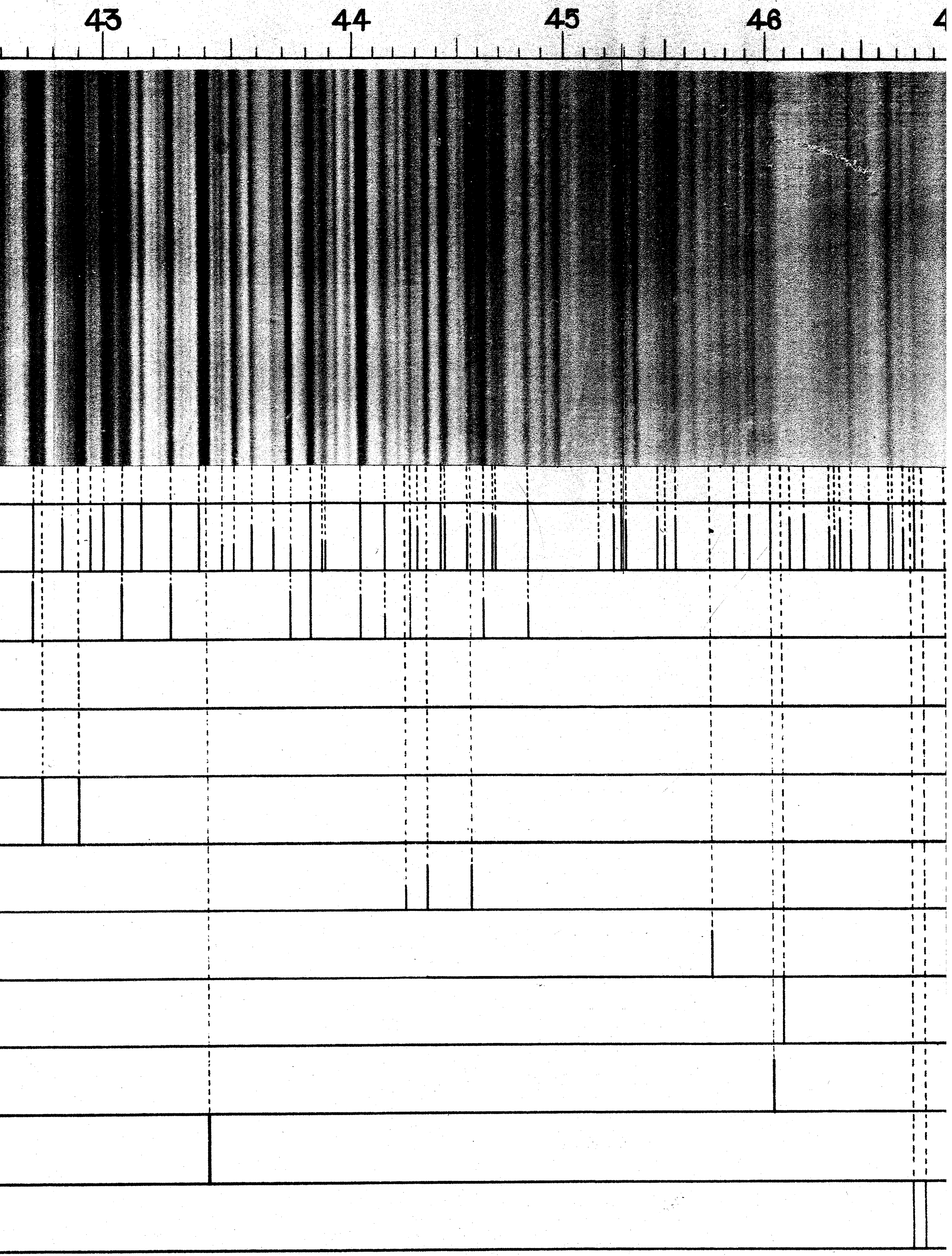
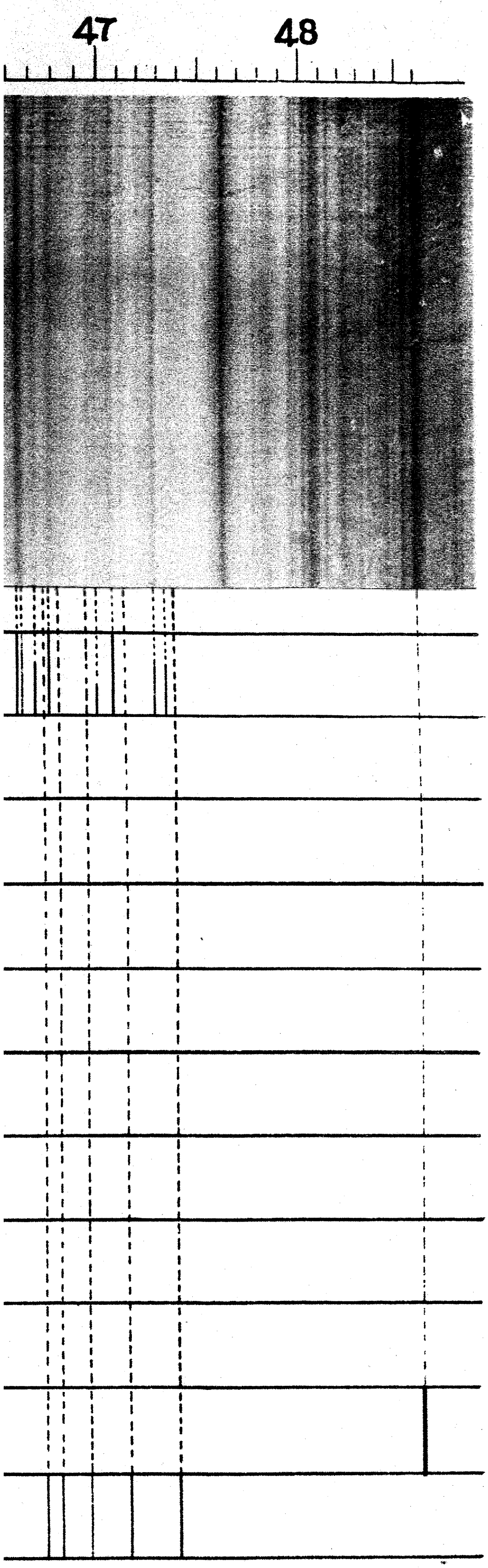
α ORIONIS





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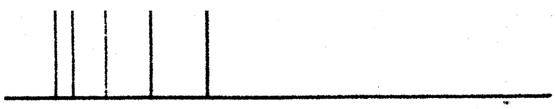

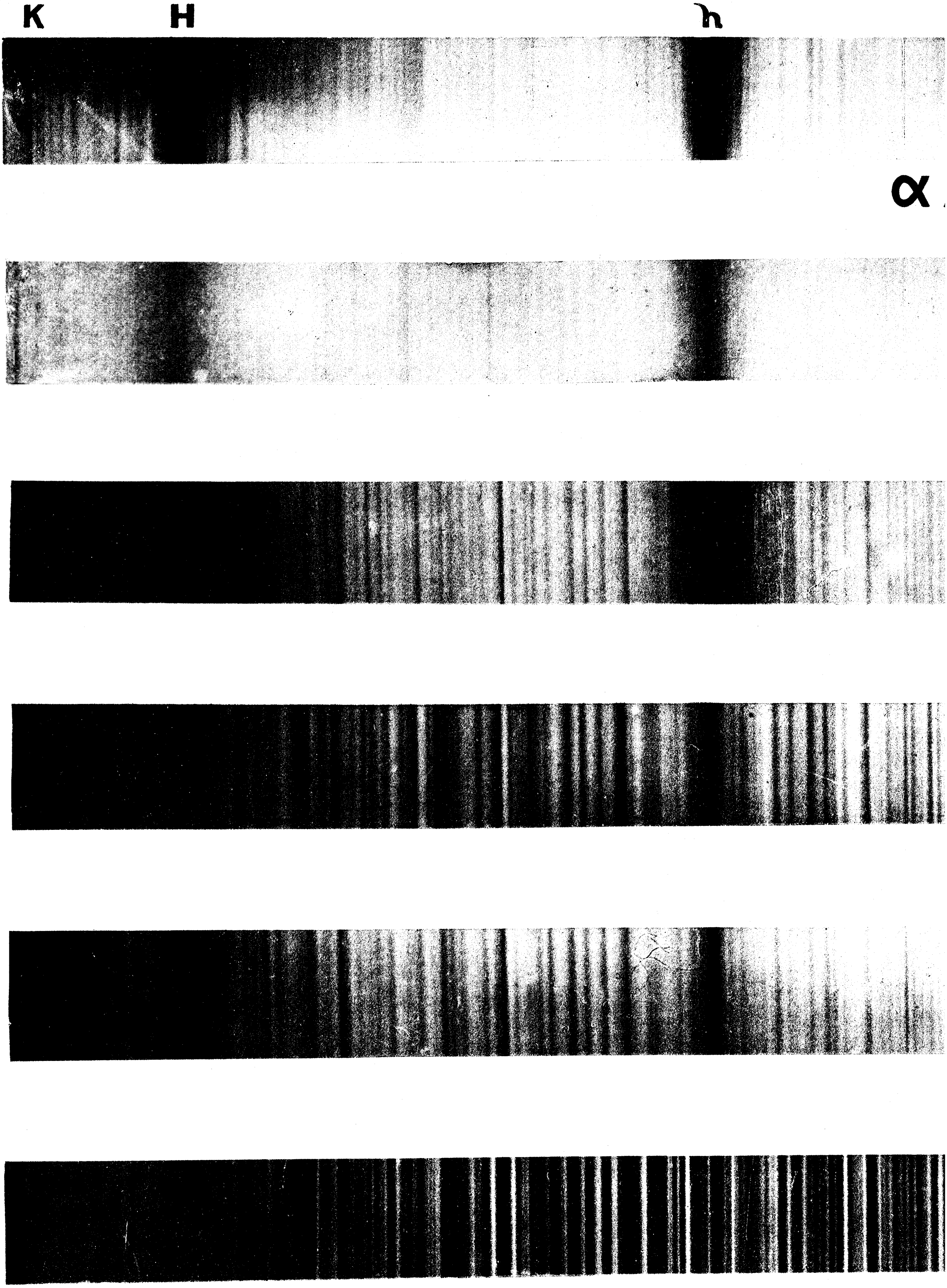
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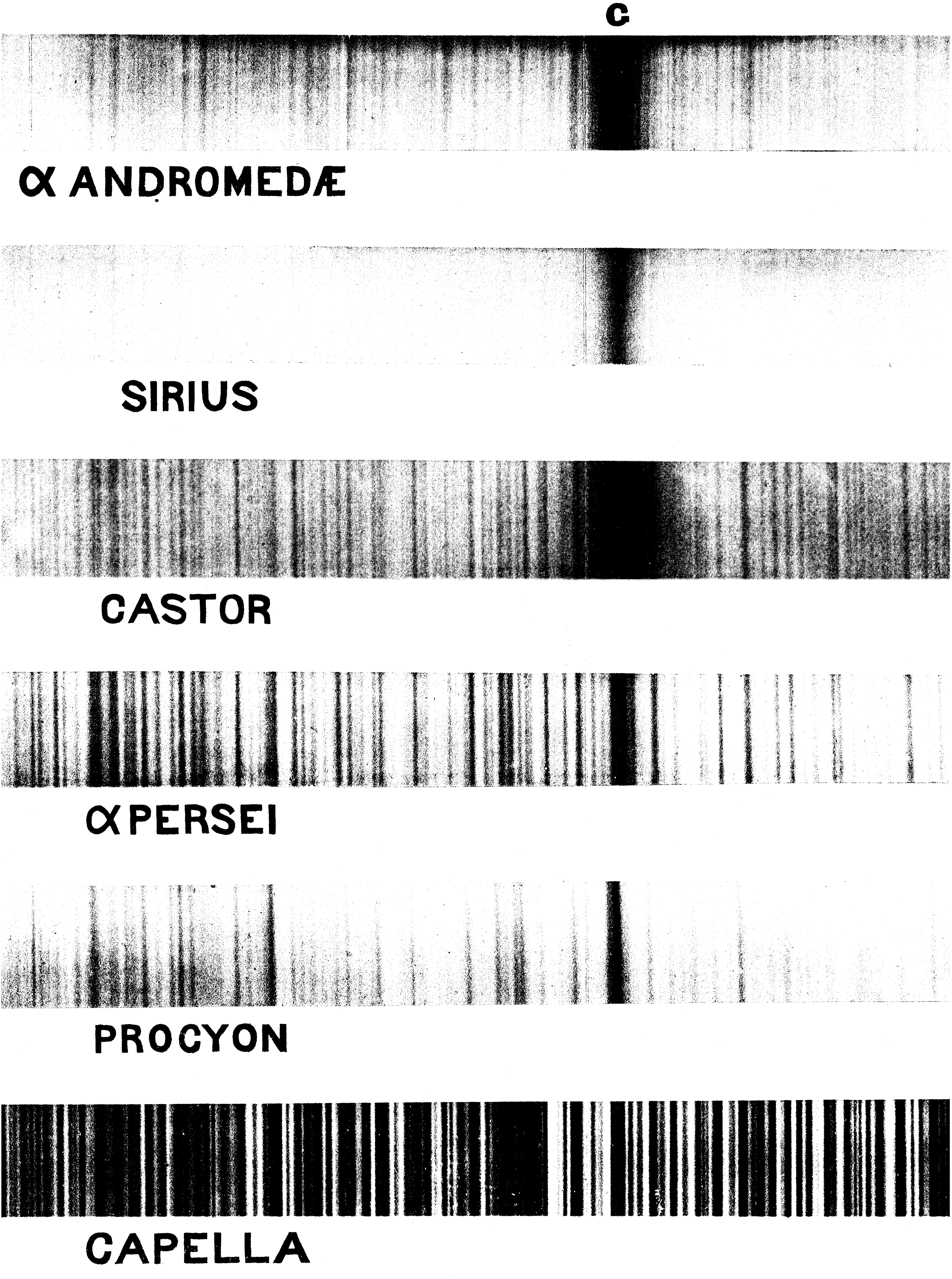
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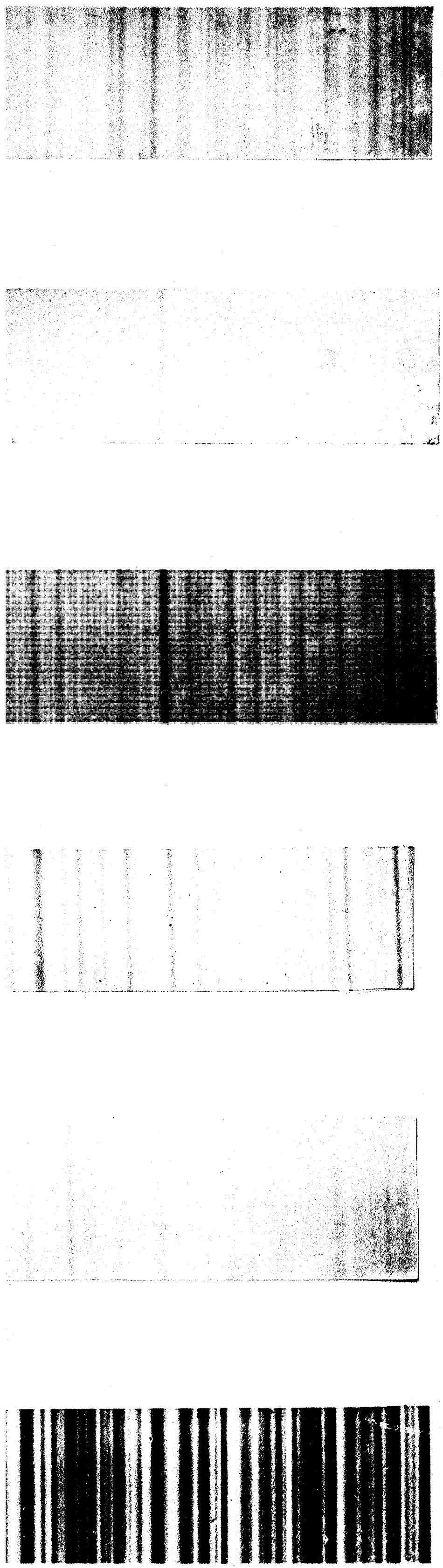

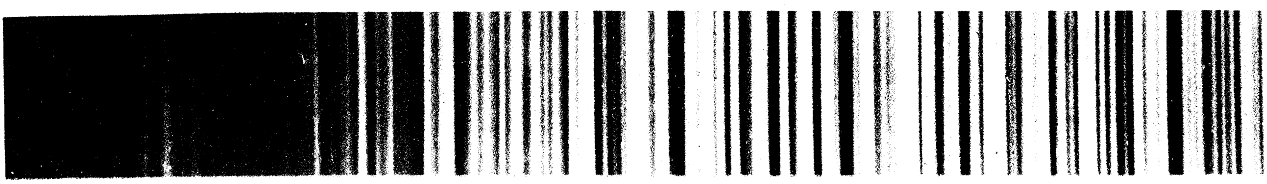

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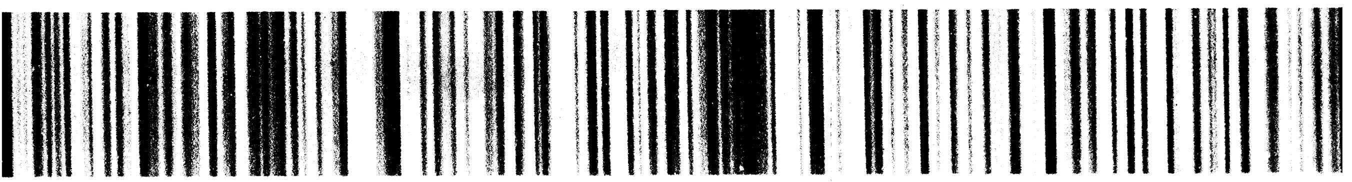
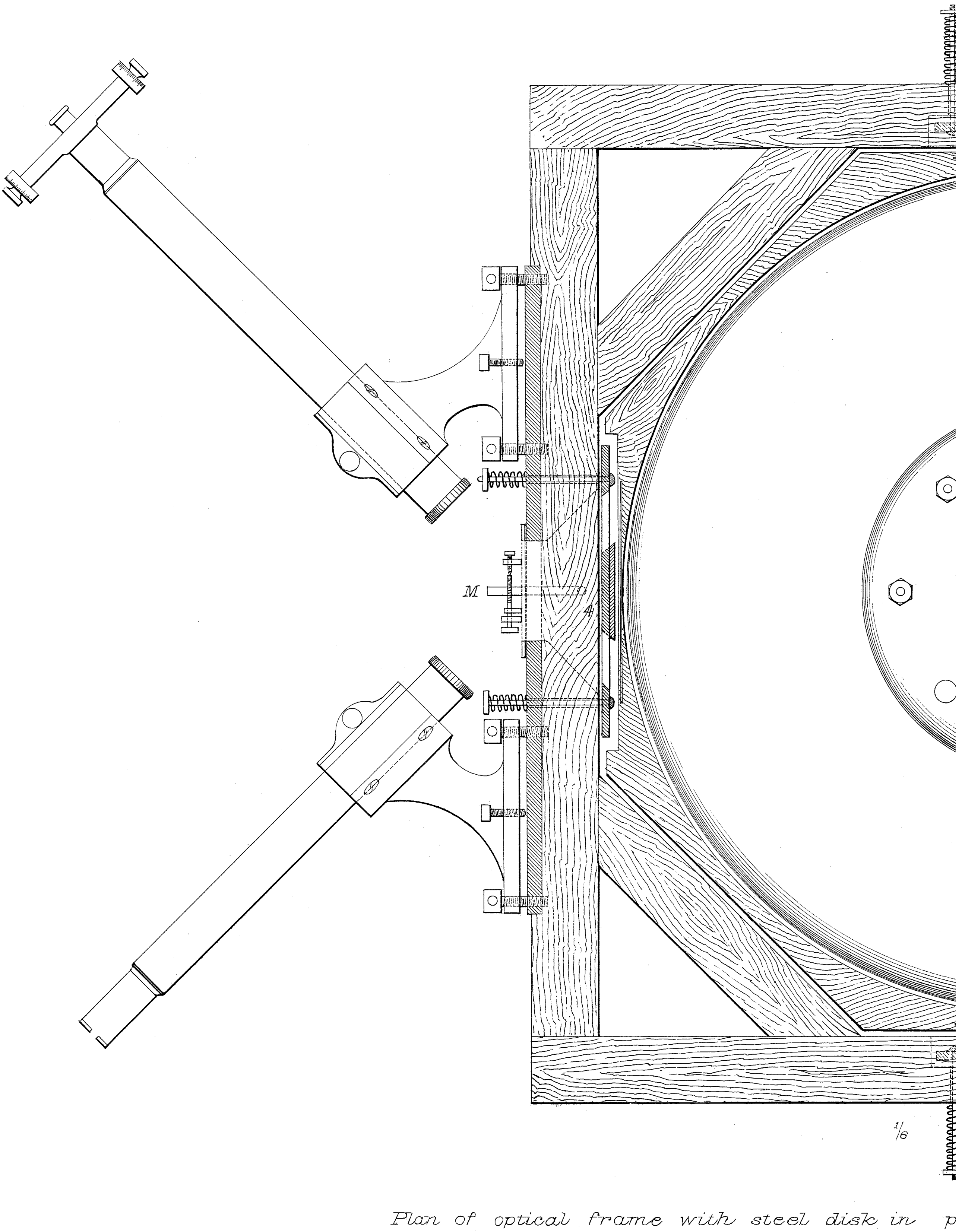
CAPELLA



ARCTURUS



Plan of optical frame with steel disk in p
frame. G represents one of the panes of
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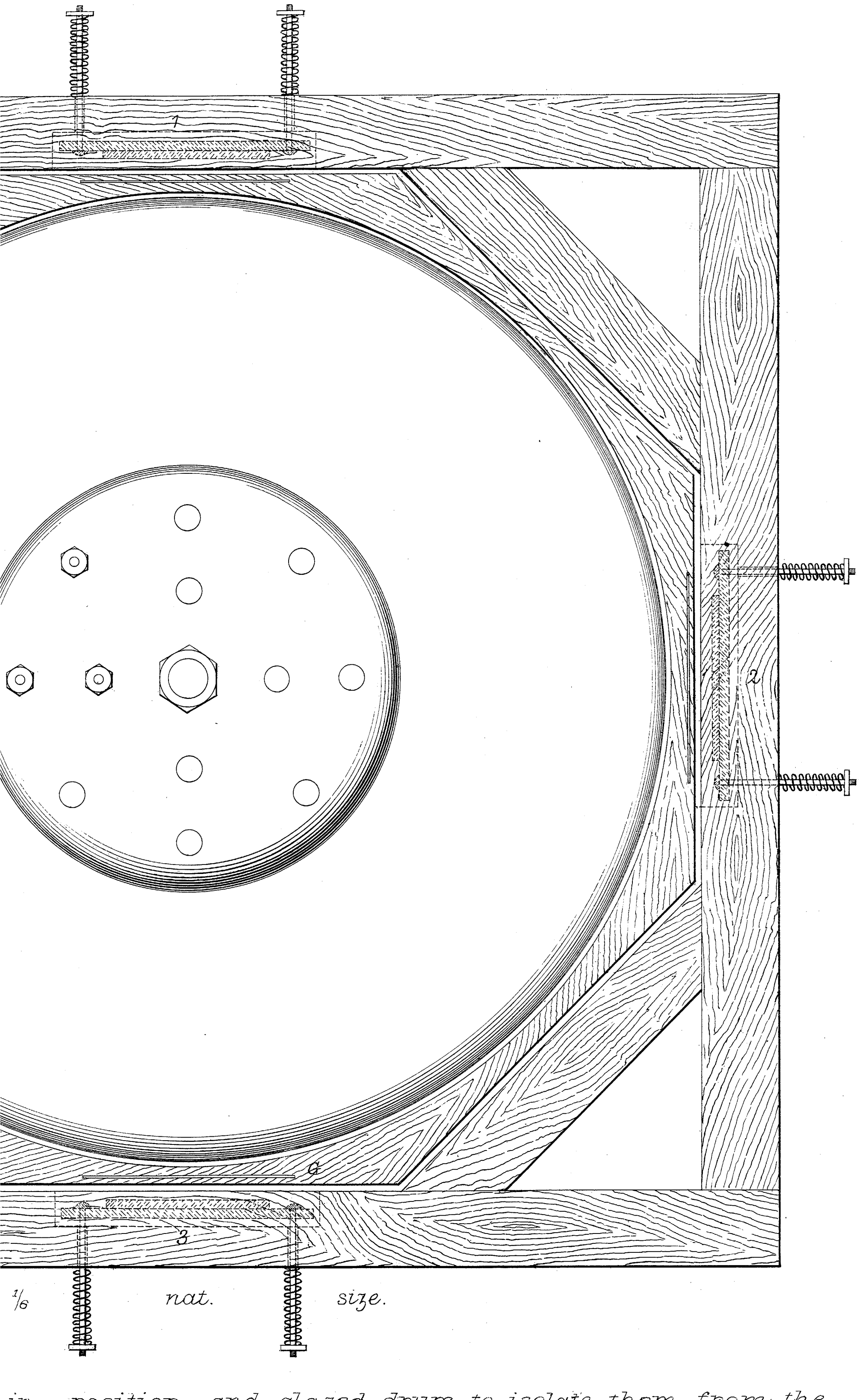

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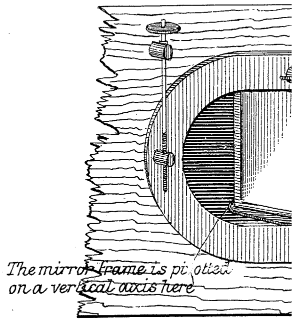

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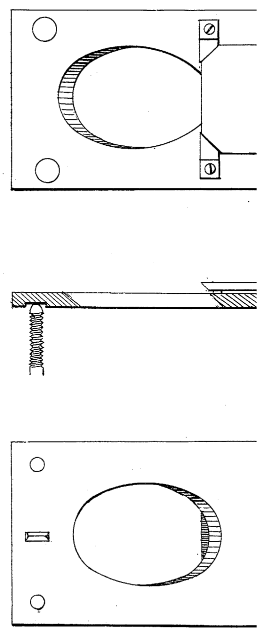
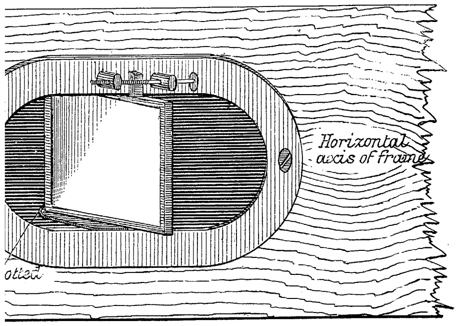


1/4

Details of brass plate
front, side, and back
Back view shows th
the ends of the suppor
fine adjustment; the
three rigid pushes

in position, and glazed drum to isolate them from the
nes of optical glass. Supports of telescope and collimator also
four mirrors 1.2.3.4., three of them let into recesses in the wooden



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mounting the semitransparent
I so as to give altitude and
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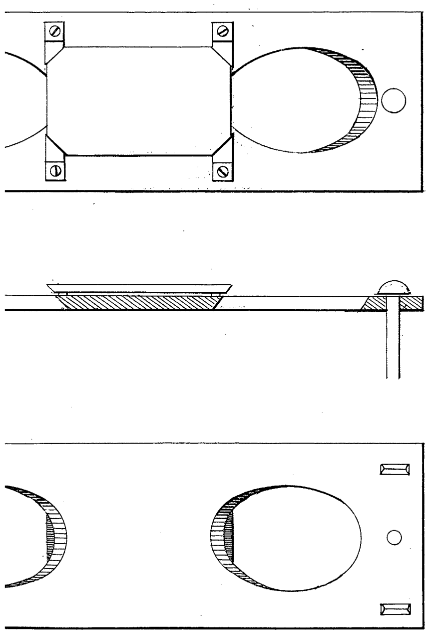


1/4 nat. size

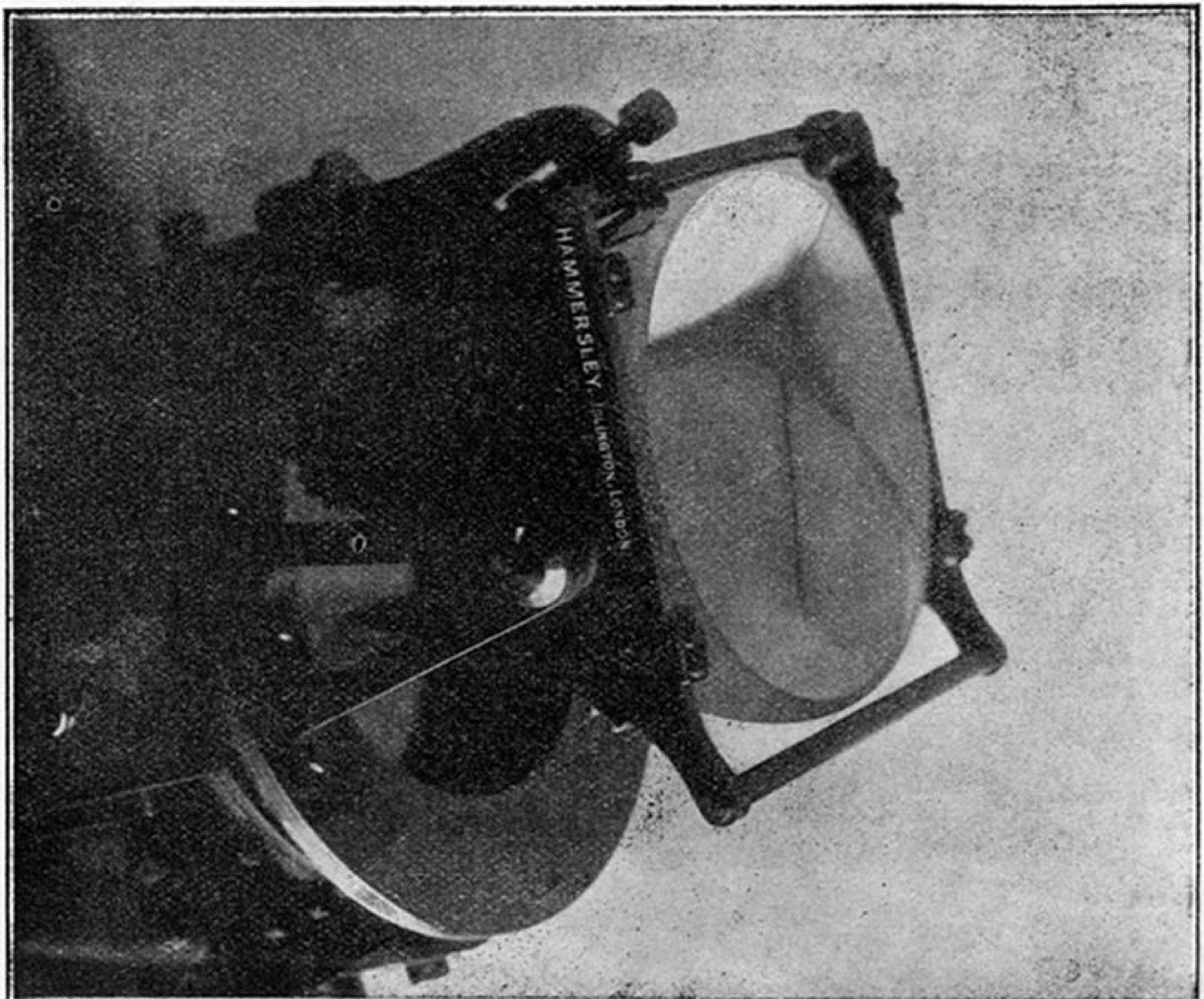
ss plate supporting fourth mirror
nd back views.
iows the three slots in which
supporting screws rest, giving a
ent; the plate being supported by
ushes and three elastic pulls.

Plan of optical frame with steel disk in p
frame. G represents one of the panes of
shewn, and part of the fixing of the four m
frame, each mirror held by a brass plat
it is pressed by the spring-bolts sh

in position, and glazed drum to isolate them from the
nes of optical glass. Supports of telescope and collimator also
four mirrors 1.2.3.4., three of them let into recesses in the wooden
s plate supported by three finely cut screws against which
lts shewn. M is the semi-transparent mirror.

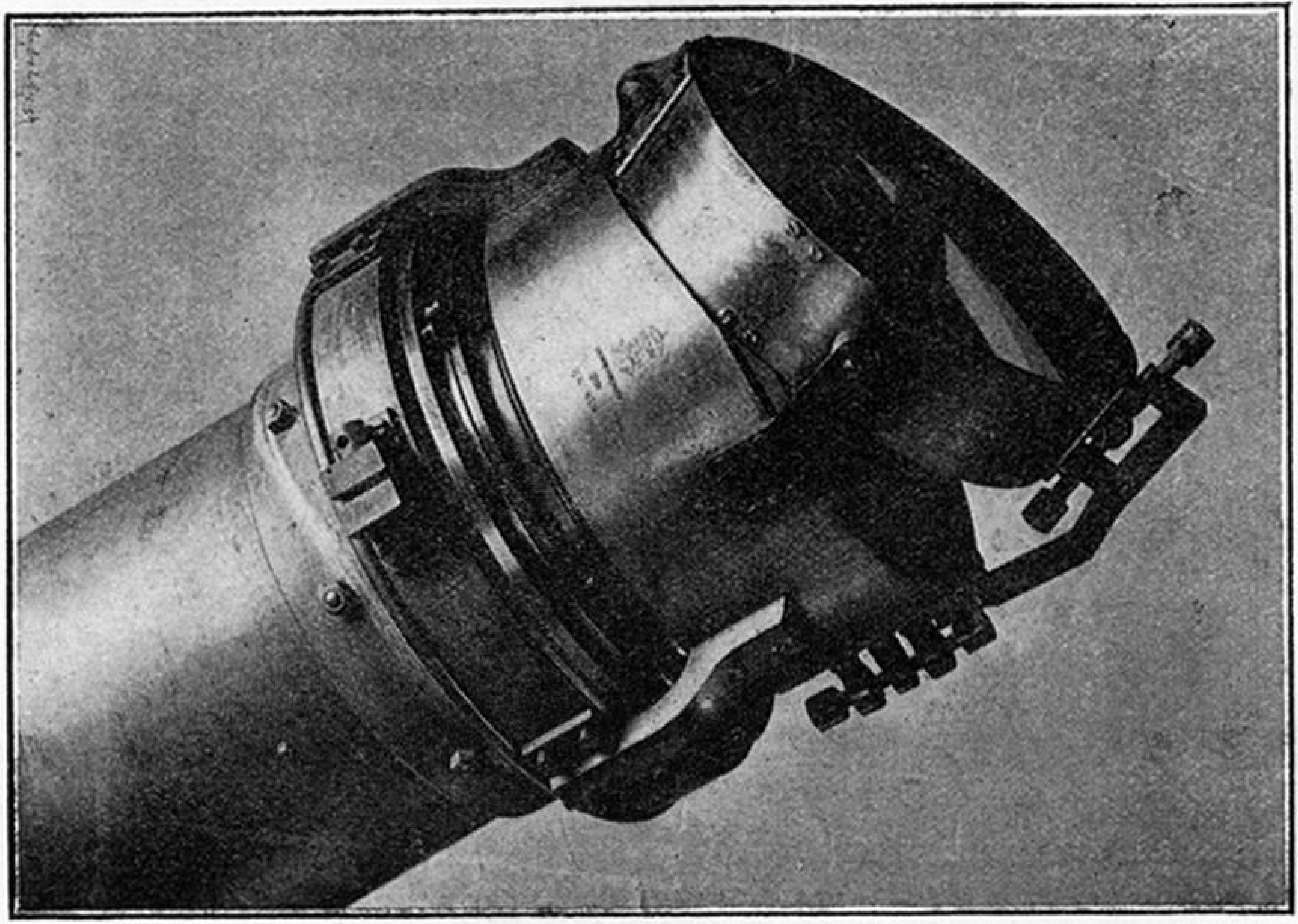
West, Newman lith.

Fig. 1.



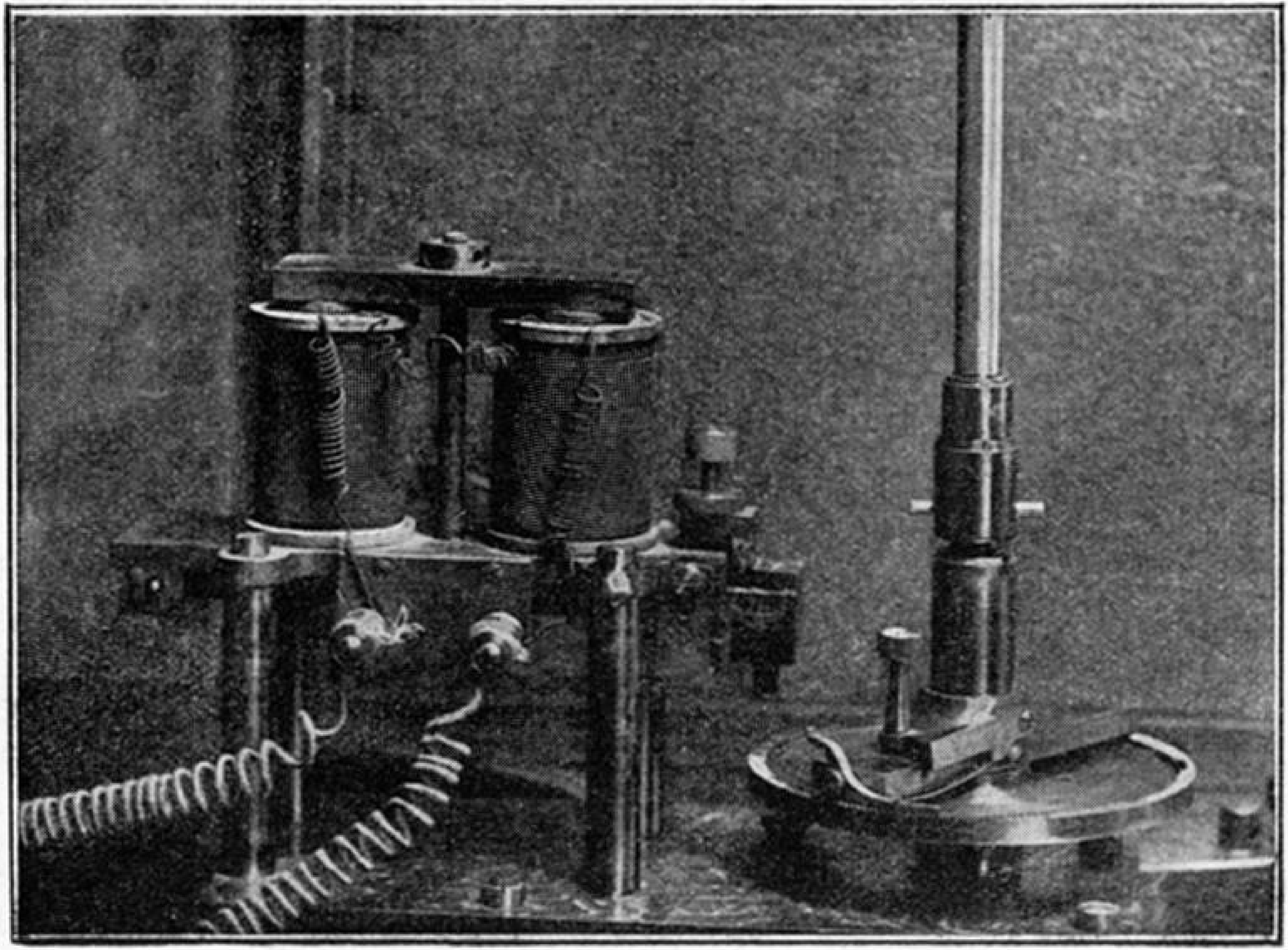
Objective prism of 45° fitted to 6-inch object-glass.

Fig. 2.



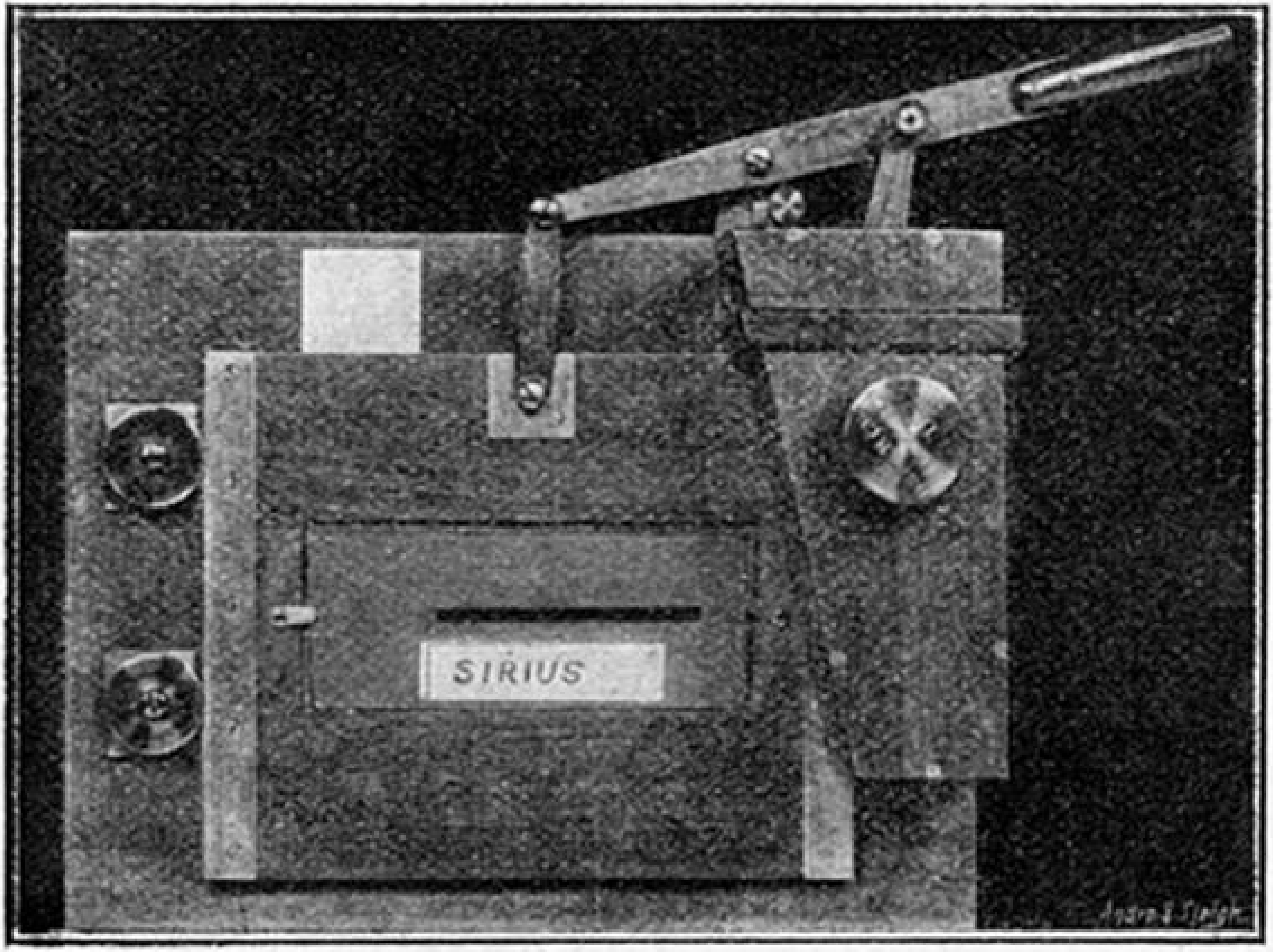
Objective prisms of $7\frac{1}{2}°$ each attached to 10-inch object-glass.

Fig. 3.



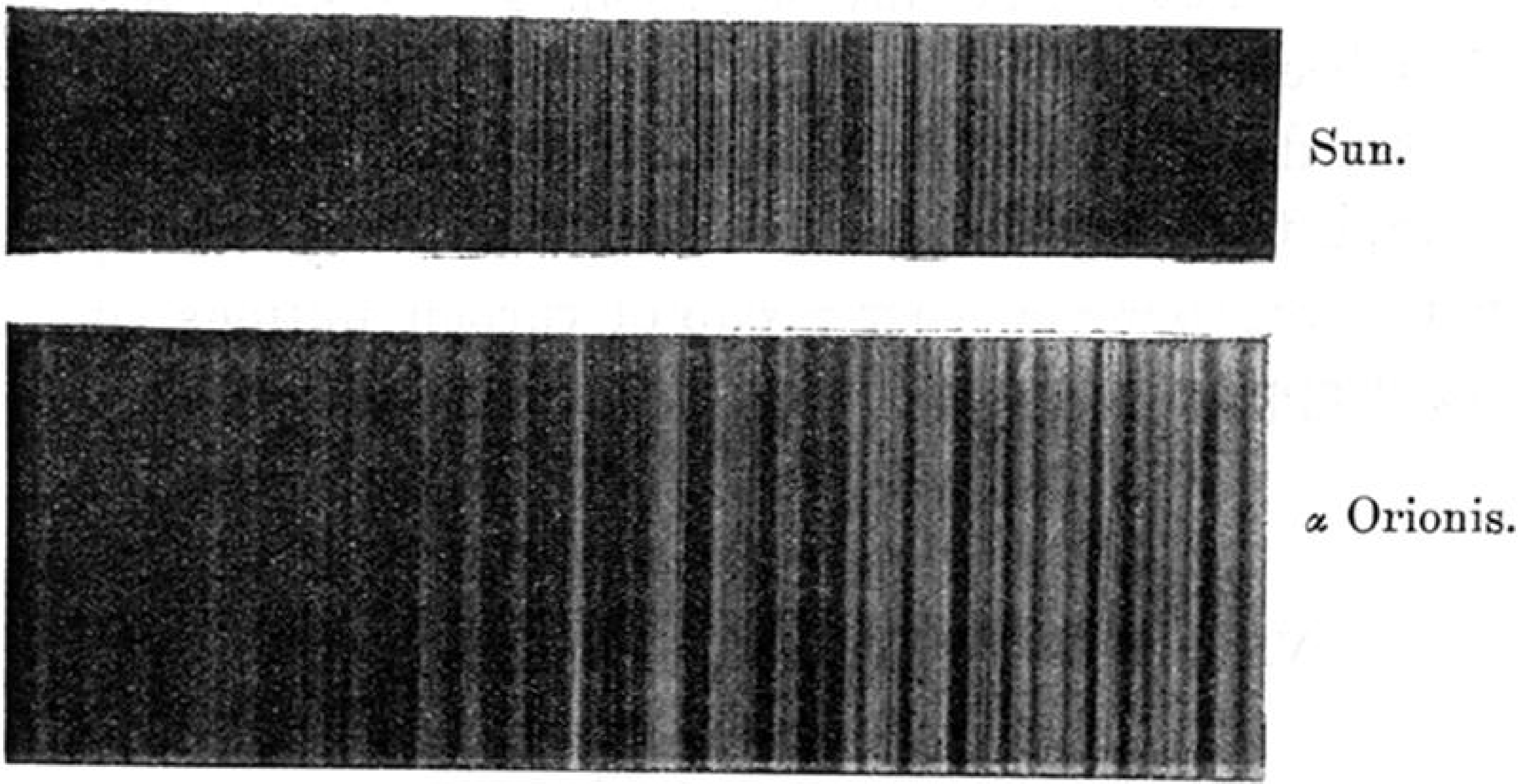
Electrical control for 10-inch equatorial.

Fig. 4.



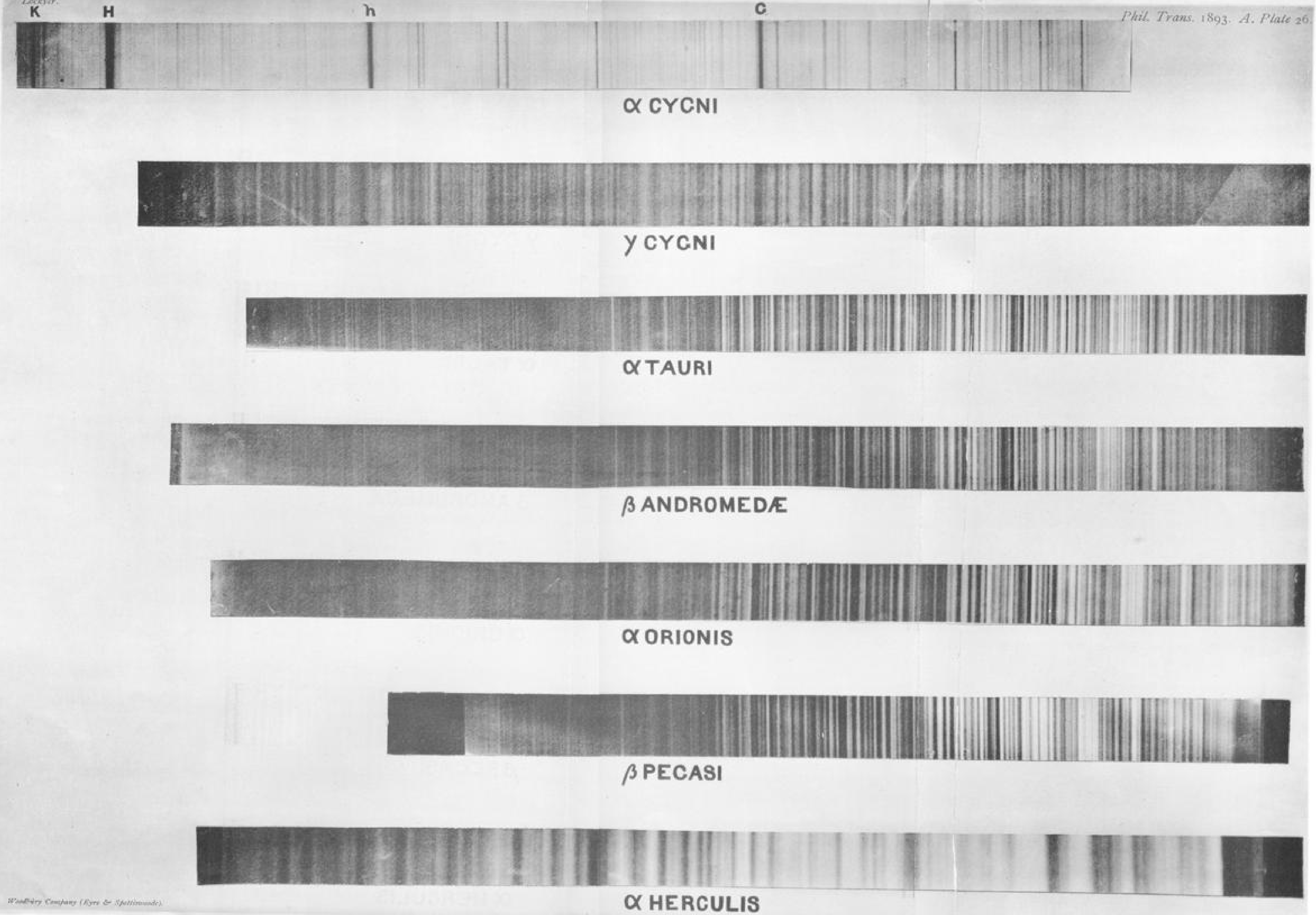
Negative holder used in enlarging.

Fig. 5.



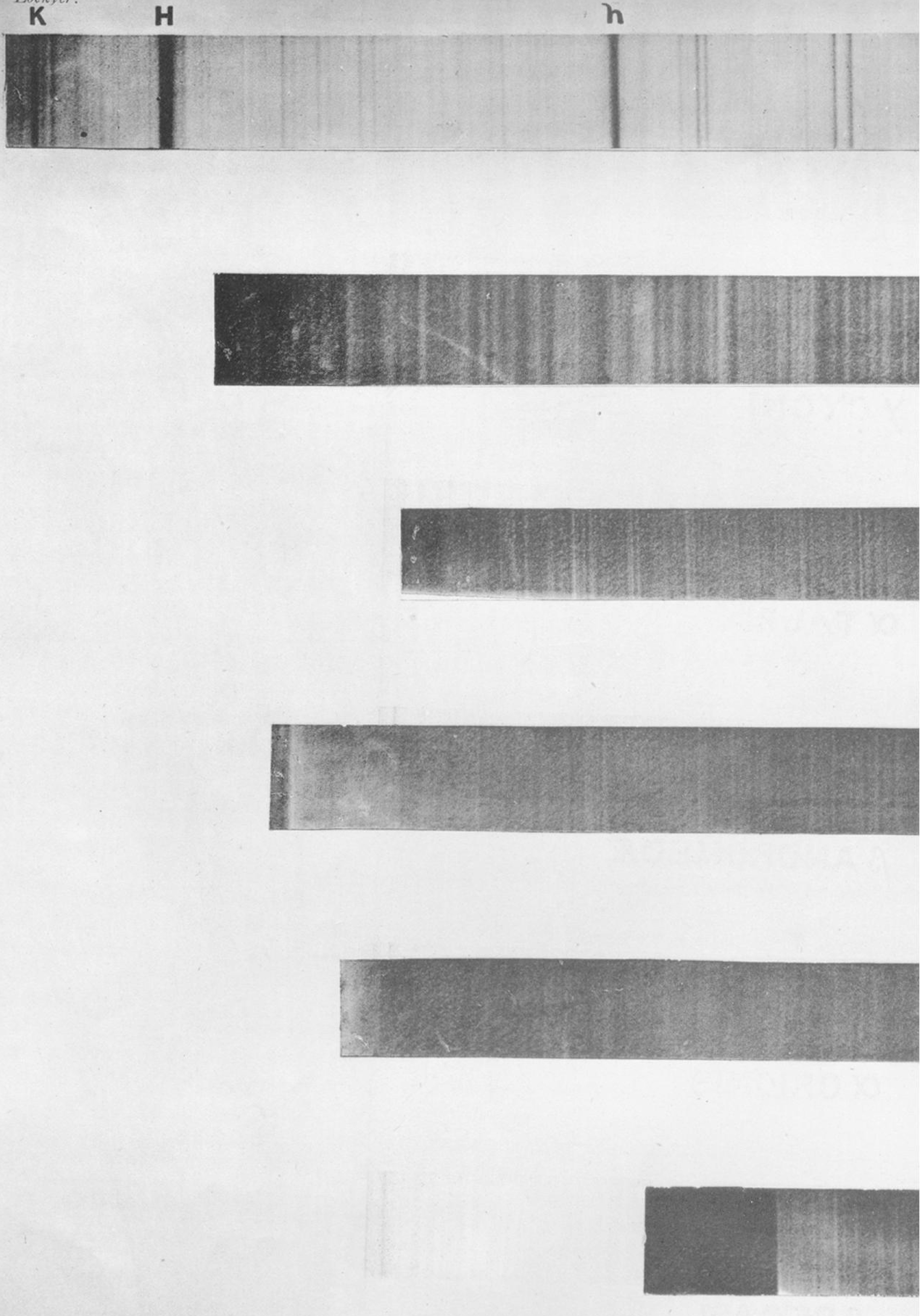
Comparison of the G region of the Spectrum of α Orionis and the Sun.

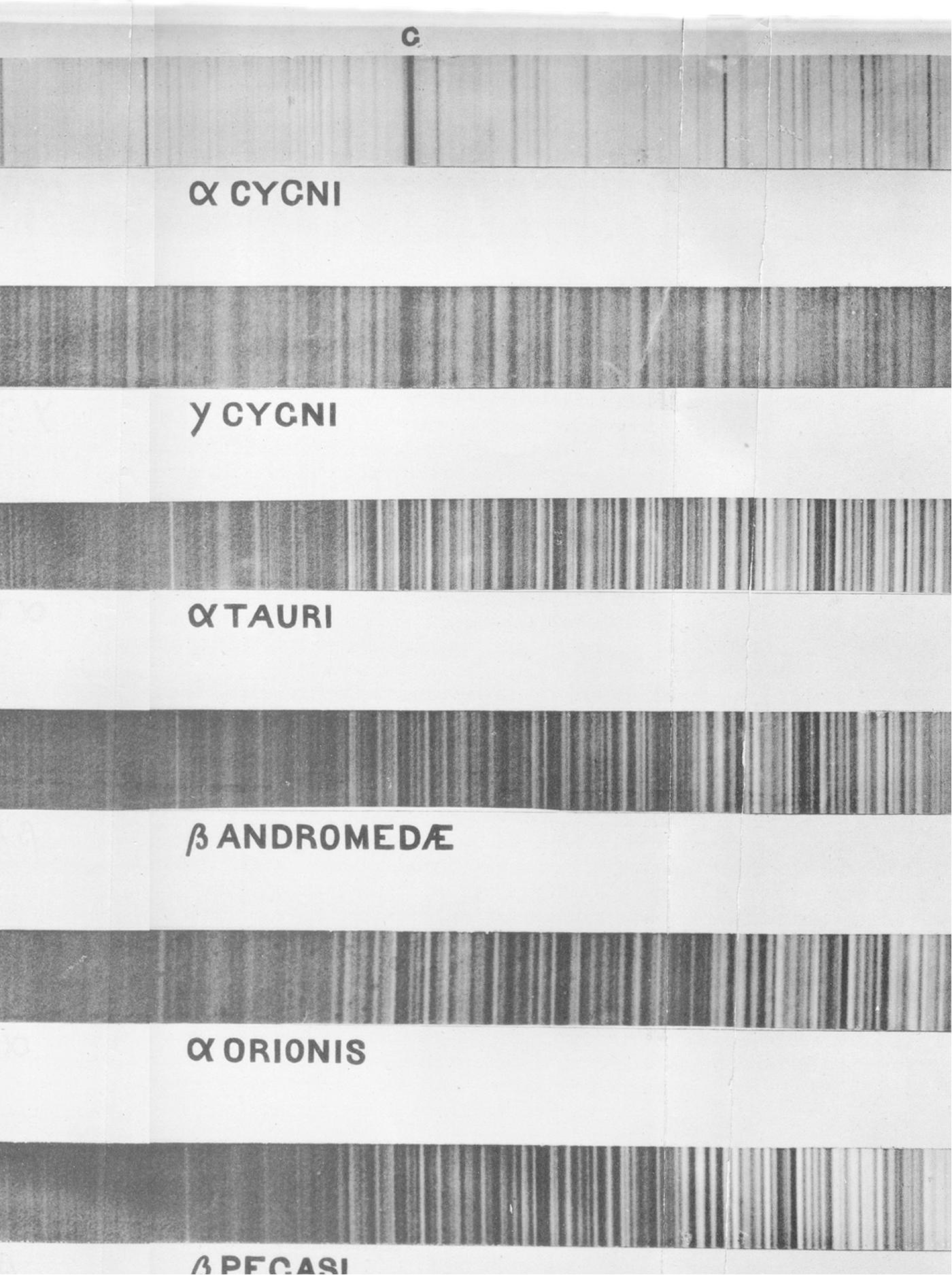
Phil. Trans. 1893. A. Plate 26.

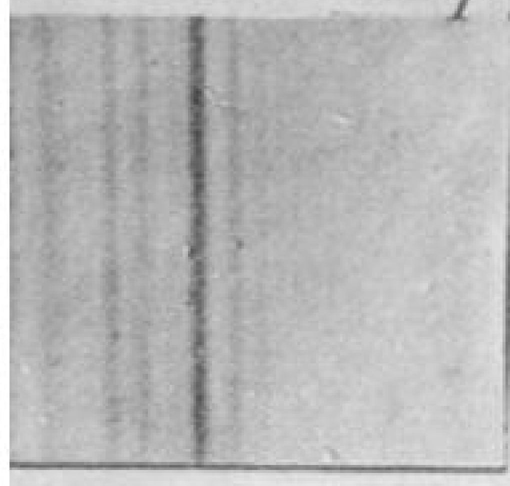


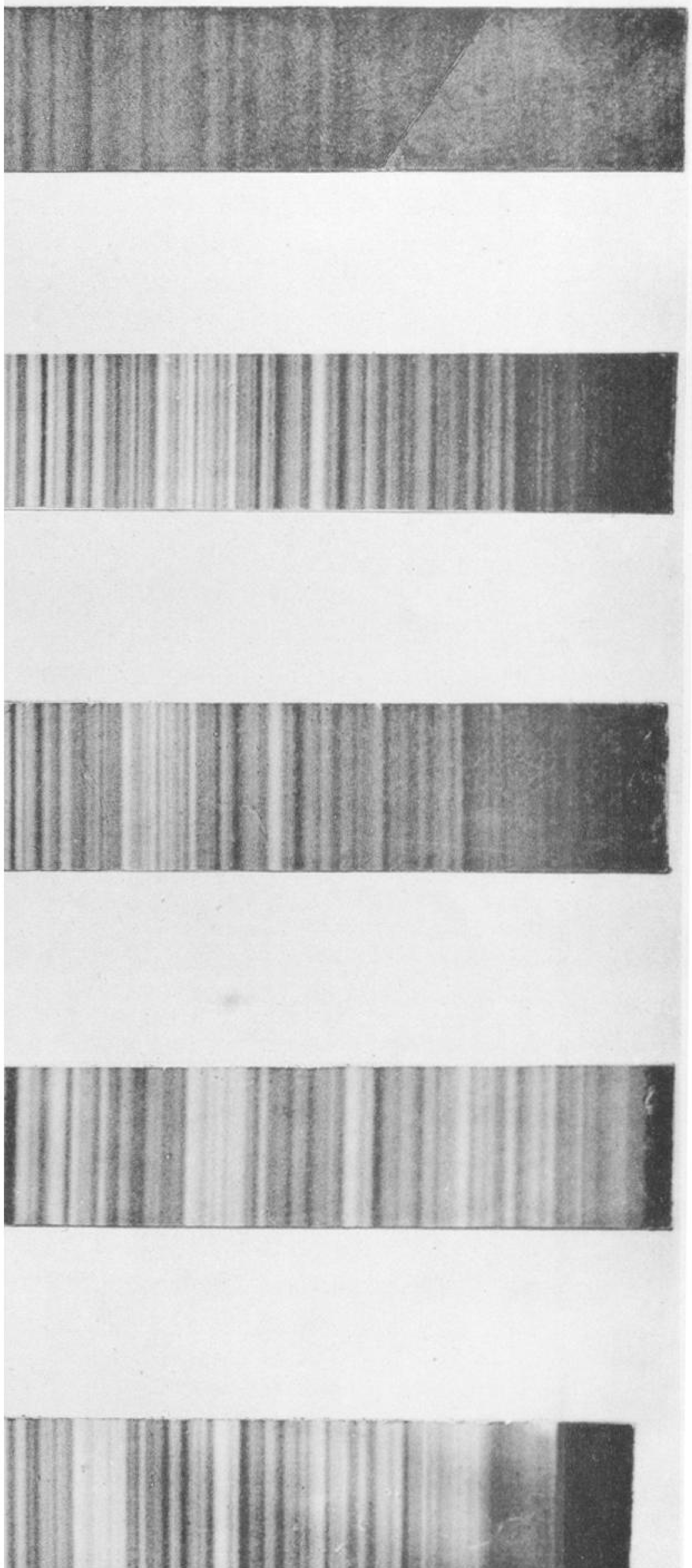
Woodbury Company (Eyre & Spottiswoode).

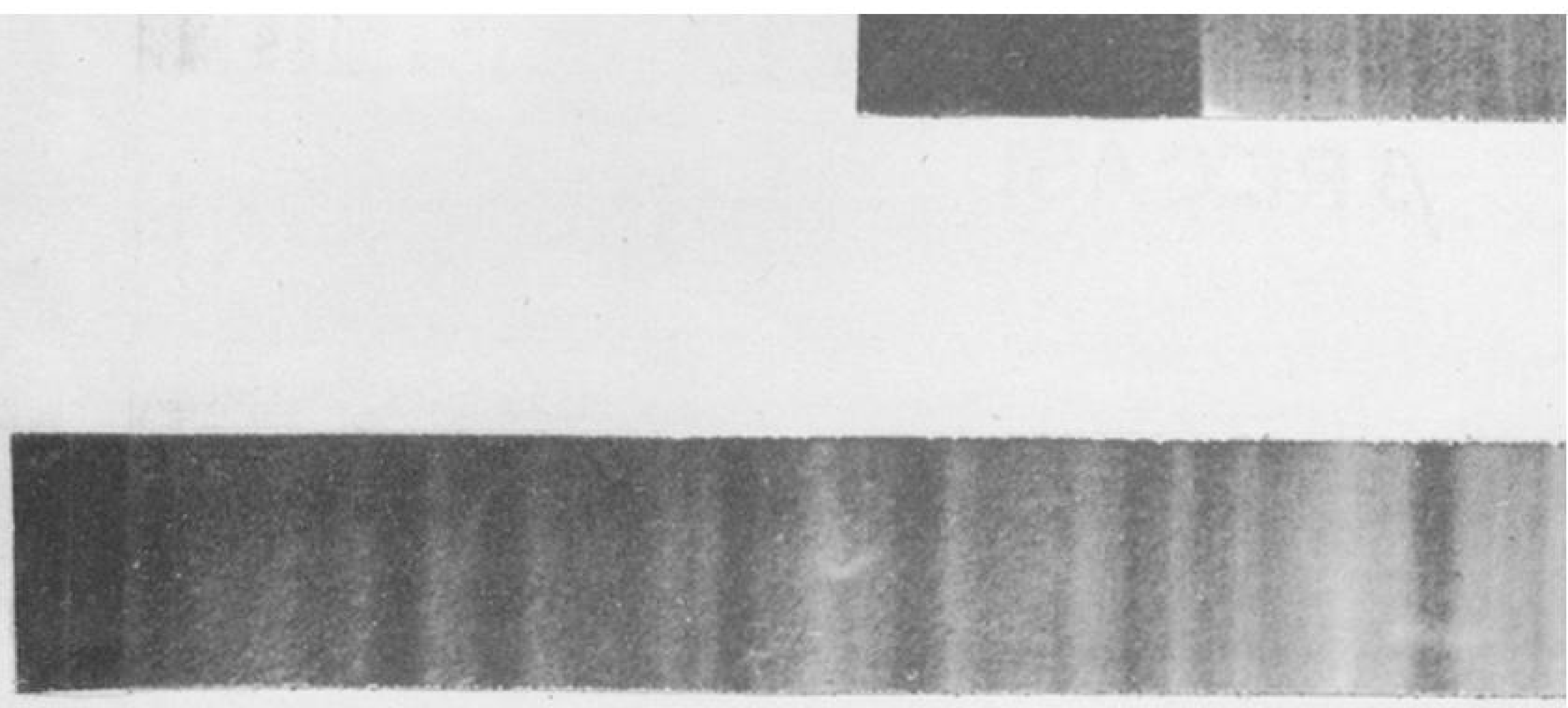
Lockyer.



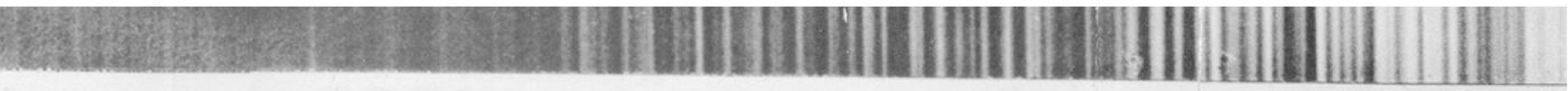

G
α CYGNI
γ CYGNI
α TAURI
β ANDROMEDÆ
α ORIONIS
β PEGASI



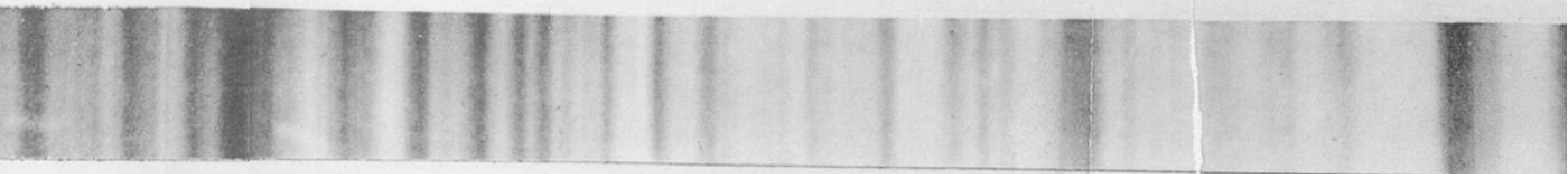




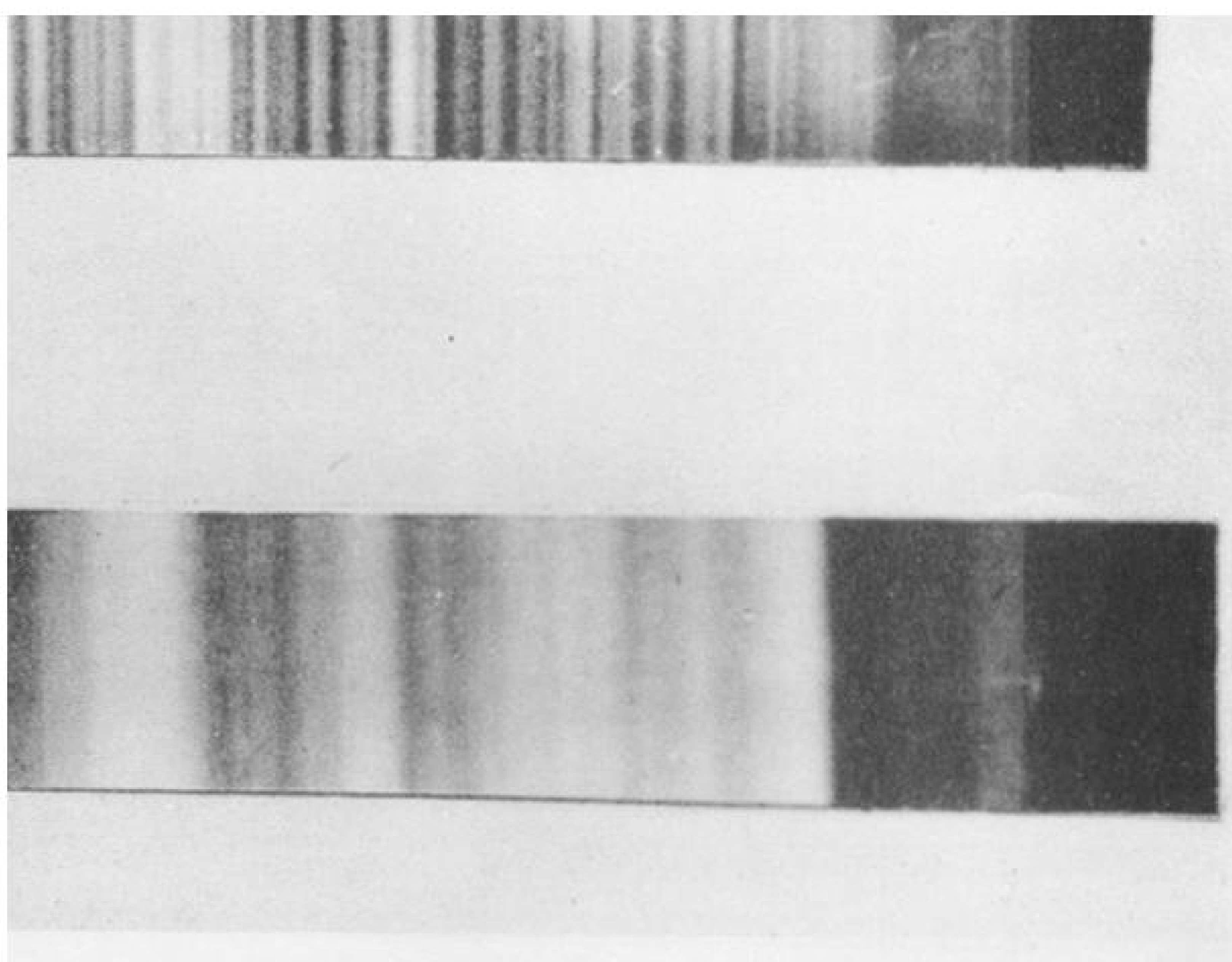
Woodbury Company (Eyre & Spottiswoode).

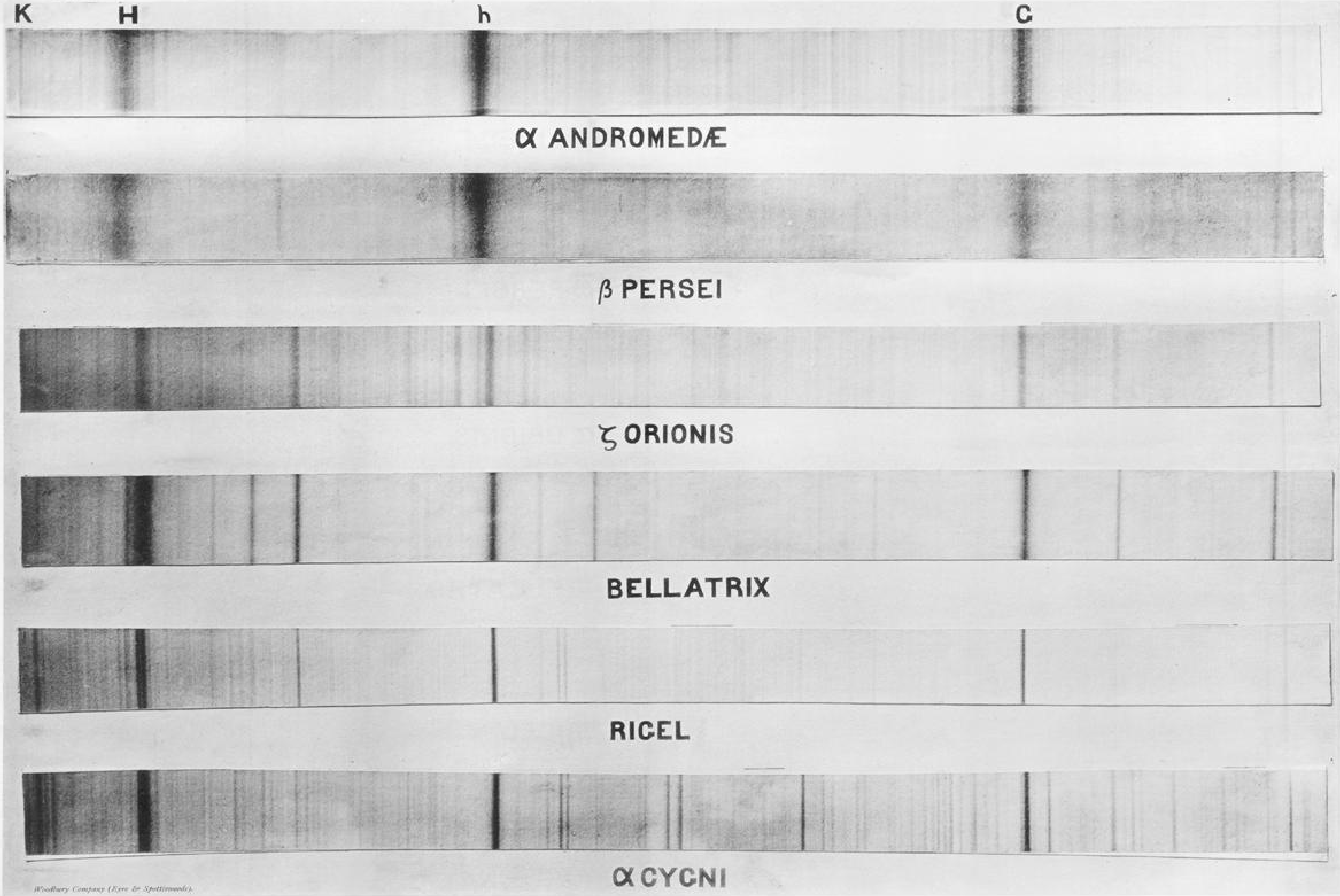


β PEGASI



α HERCULIS

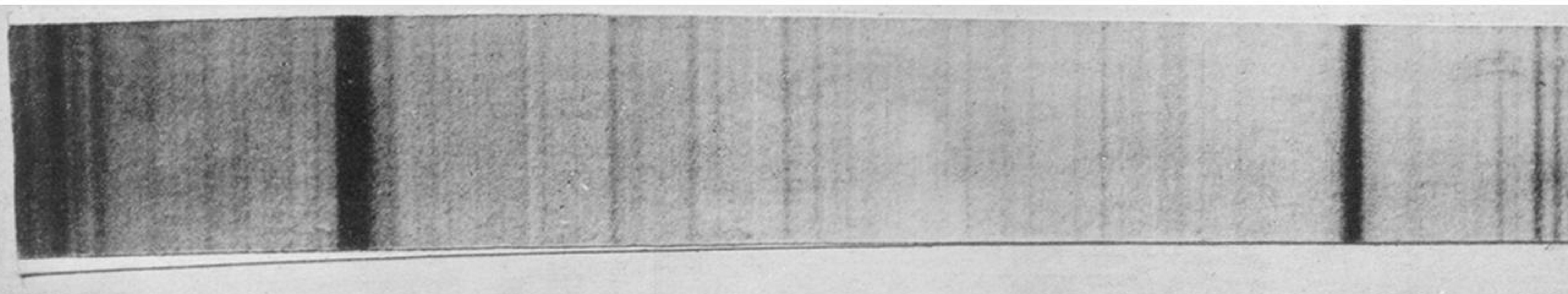




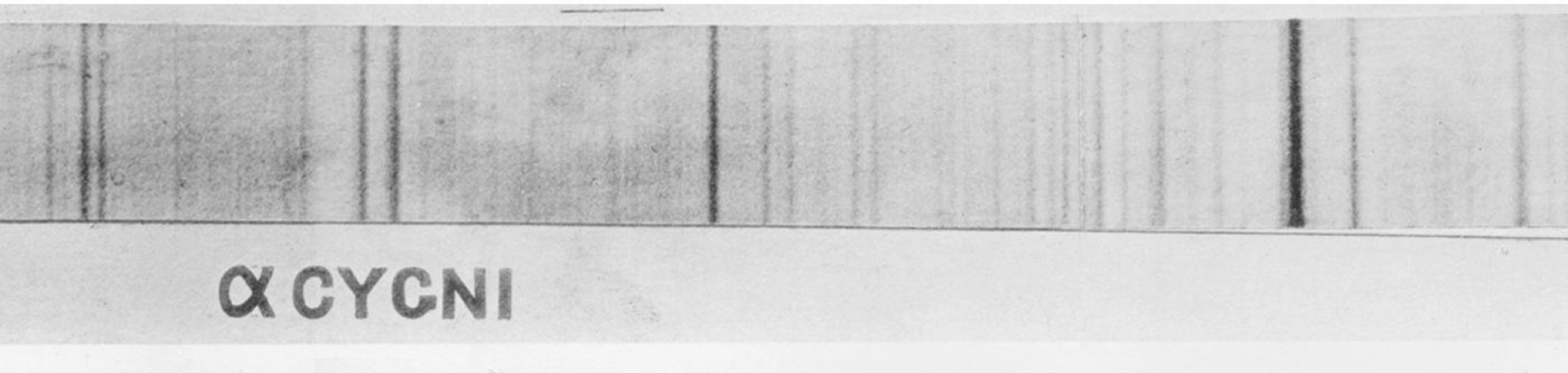
Woodbury Company (Eyre & Spottiswoode).


K
H
h
α A


G
ANDROMEDÆ
β PERSEI
ζ ORIONIS
BELLATRIX
RIGEL

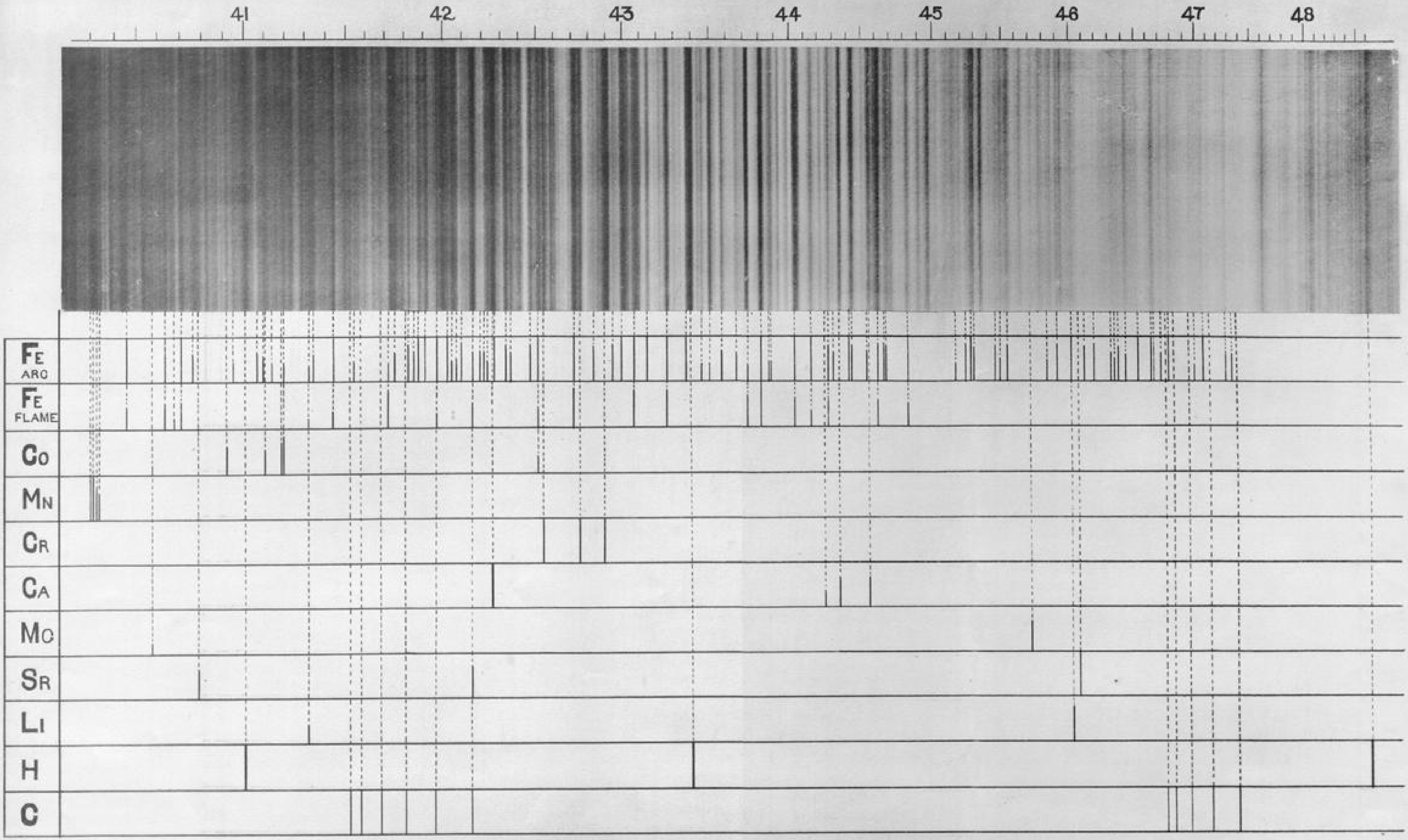


Woodbury Company (Eyre & Spottiswoode).

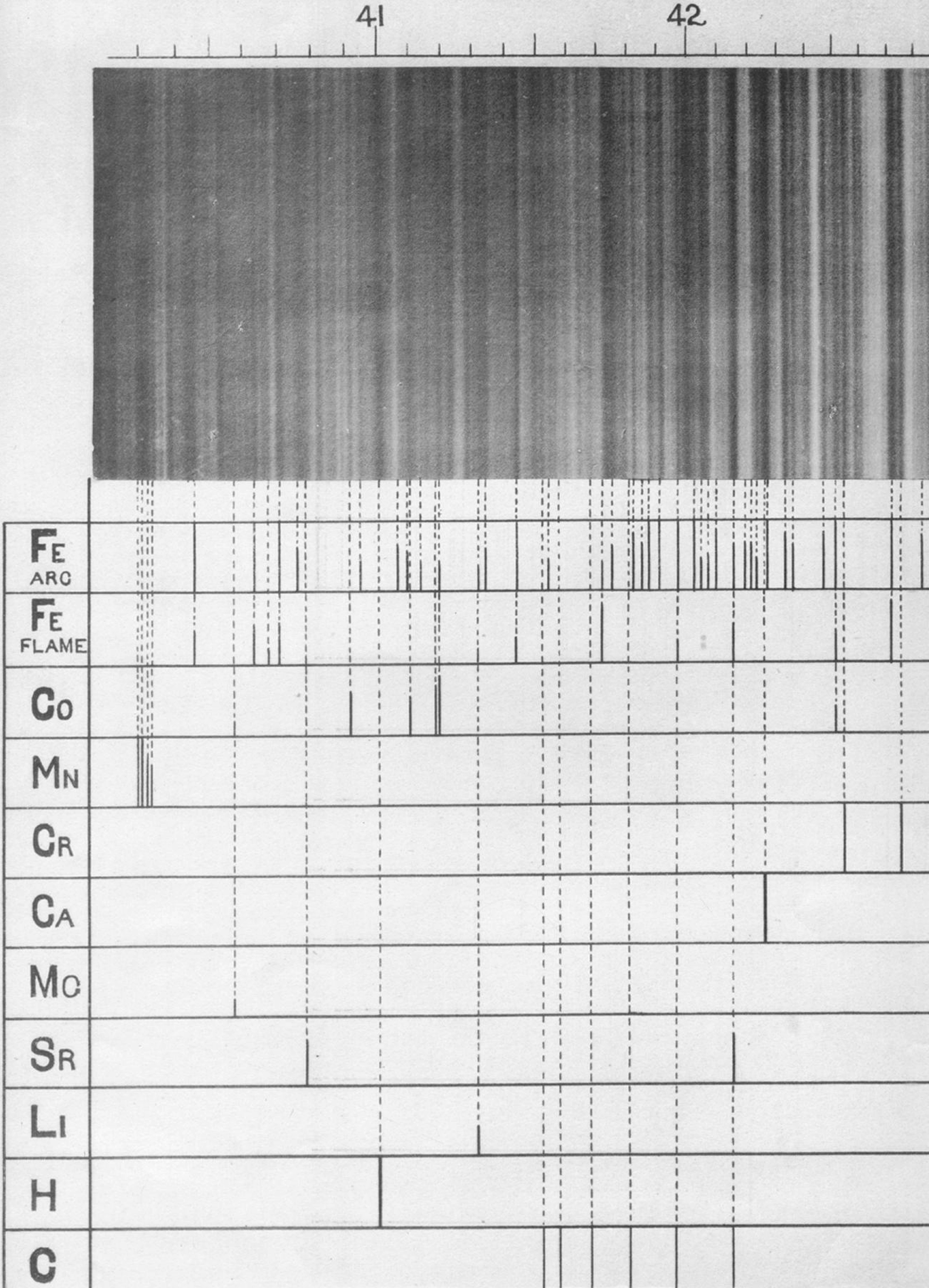


α CYGNI

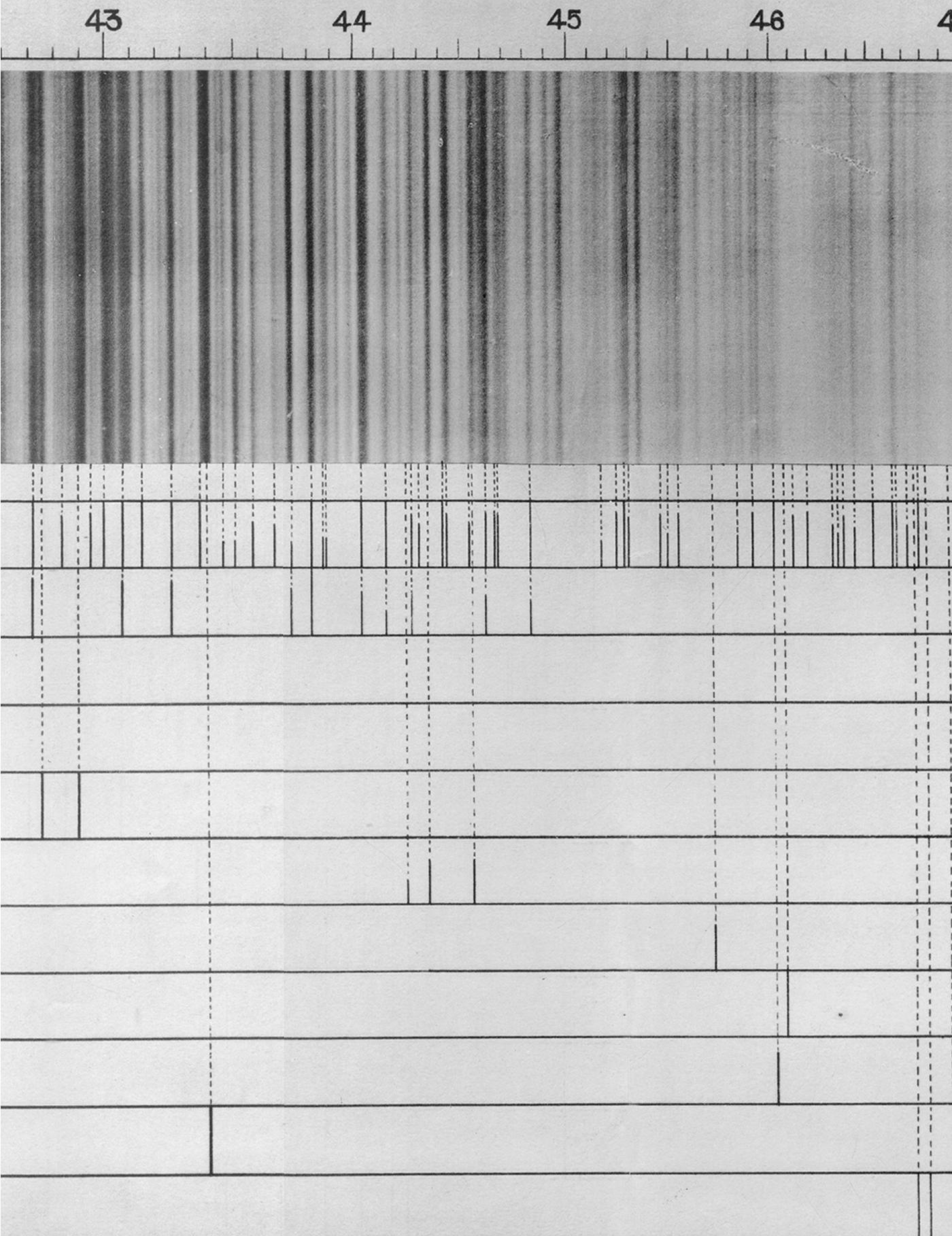
α ORIONIS

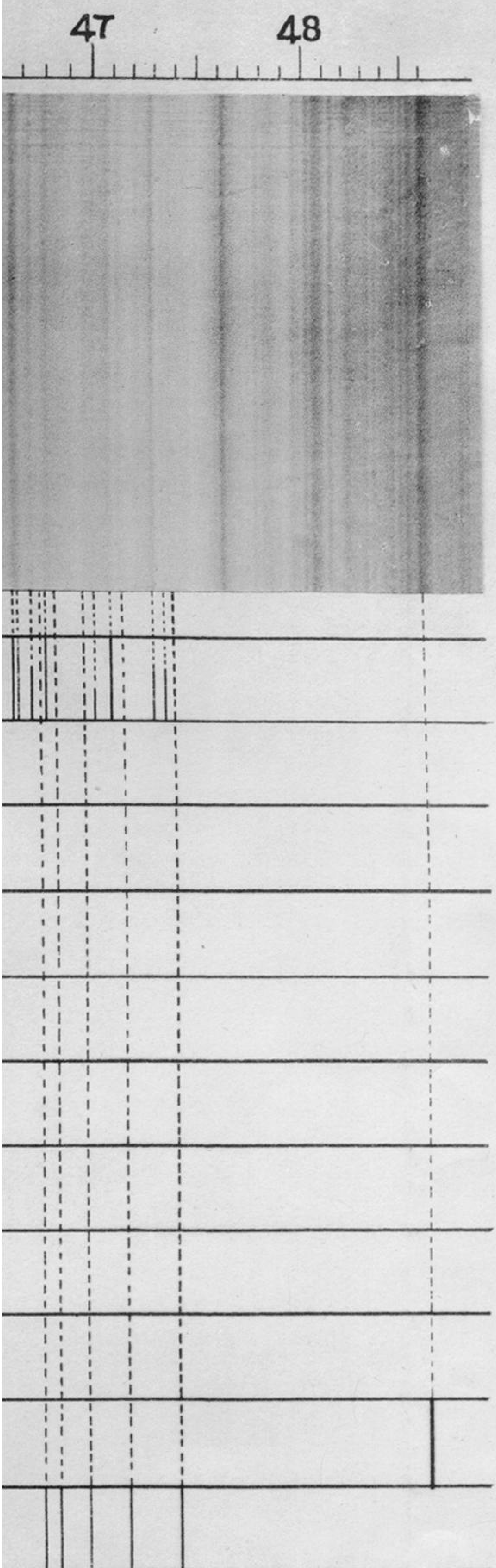


Woodbury Company (Eyre & Spottiswoode).


41
42
FE ARC
FE FLAME
CO
MN
CR
CA
MG
SR
LI
H
C

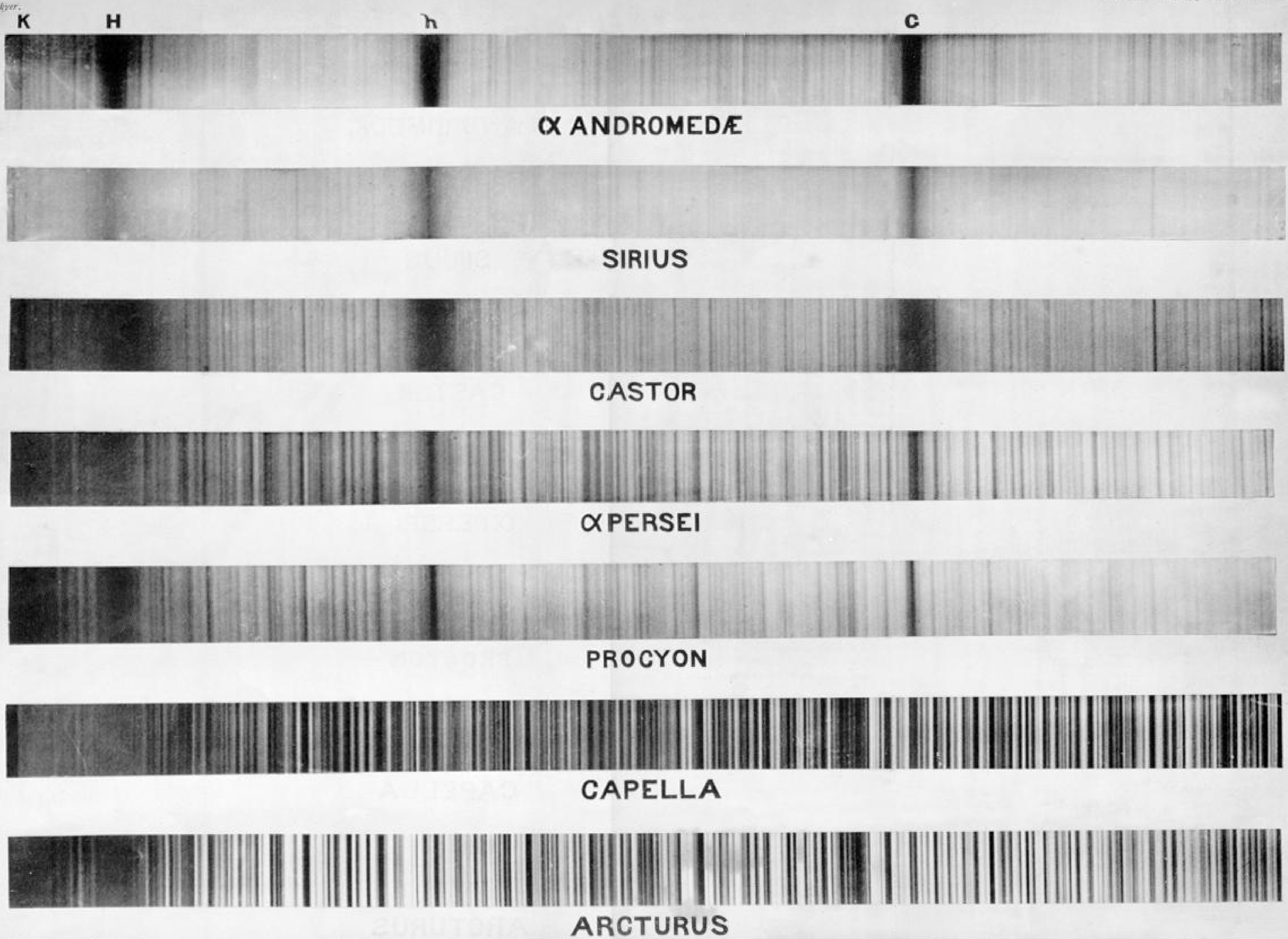
α ORIONIS




47
48

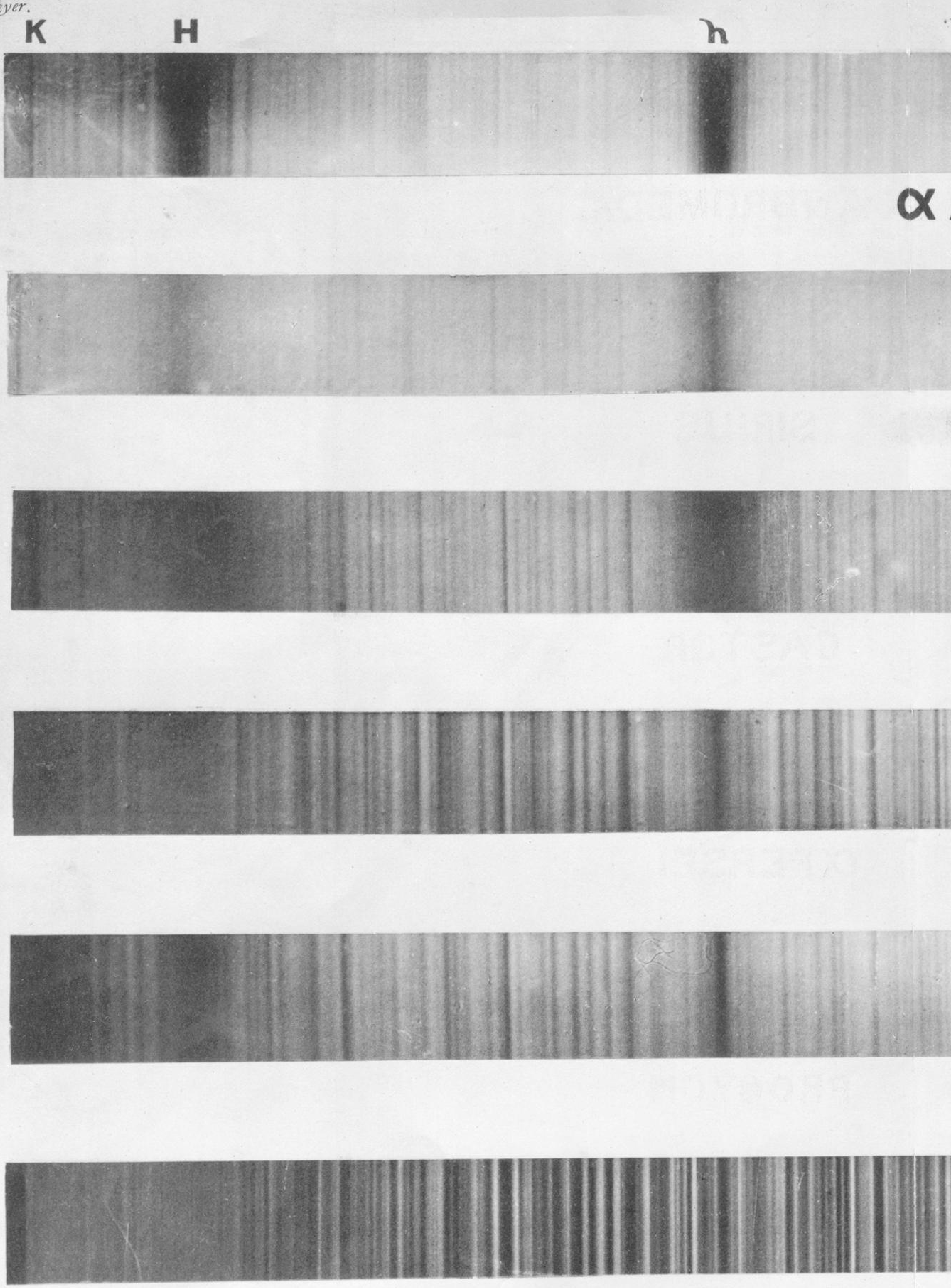
C	

Woodbury Company (Eyre & Spottiswoode).

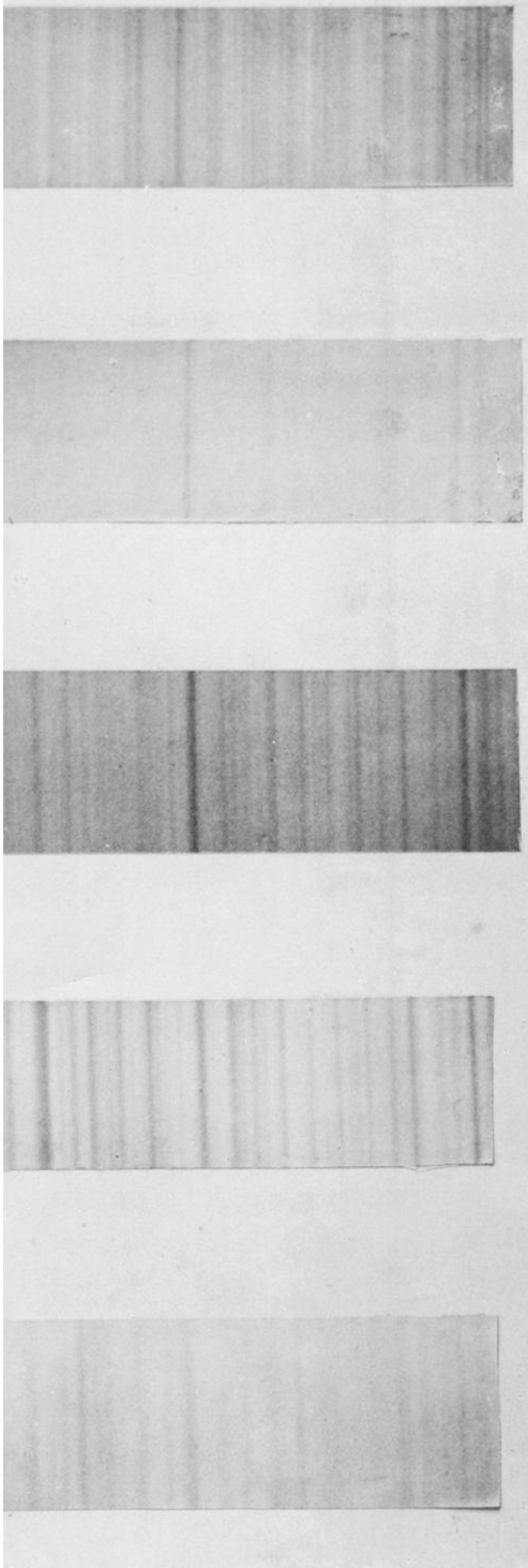


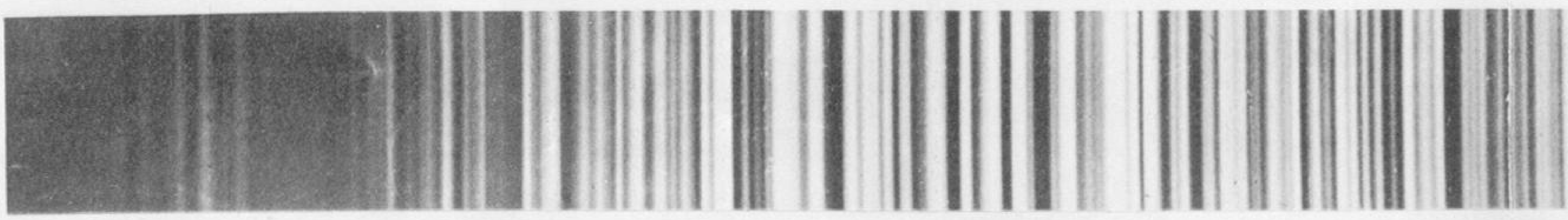
Woodbury Company (Eyre & Spottiswoode).

Lockyer.




C
α ANDROMEDÆ
SIRIUS
CASTOR
α PERSEI
PROCYON
CAPELLA

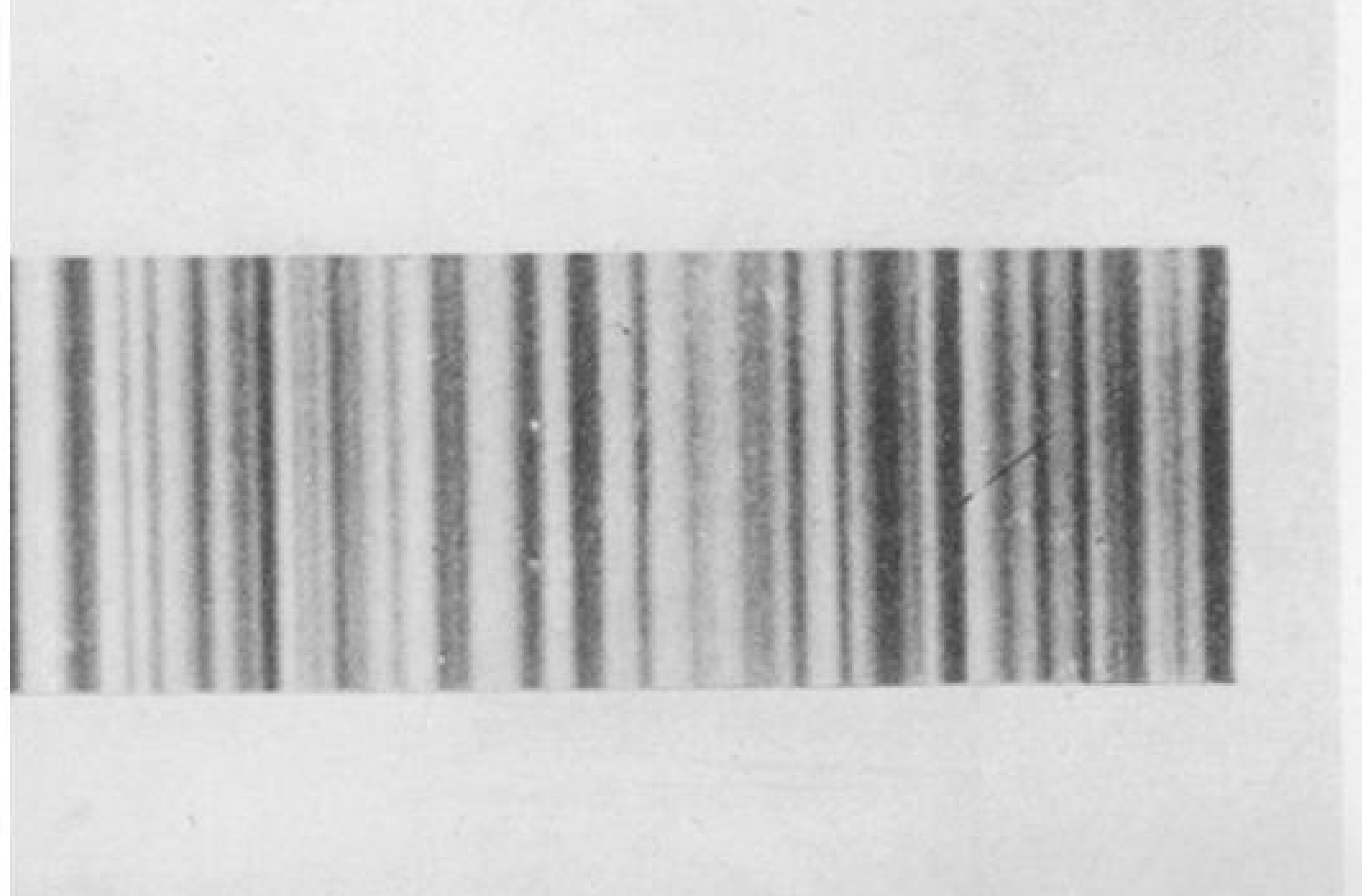


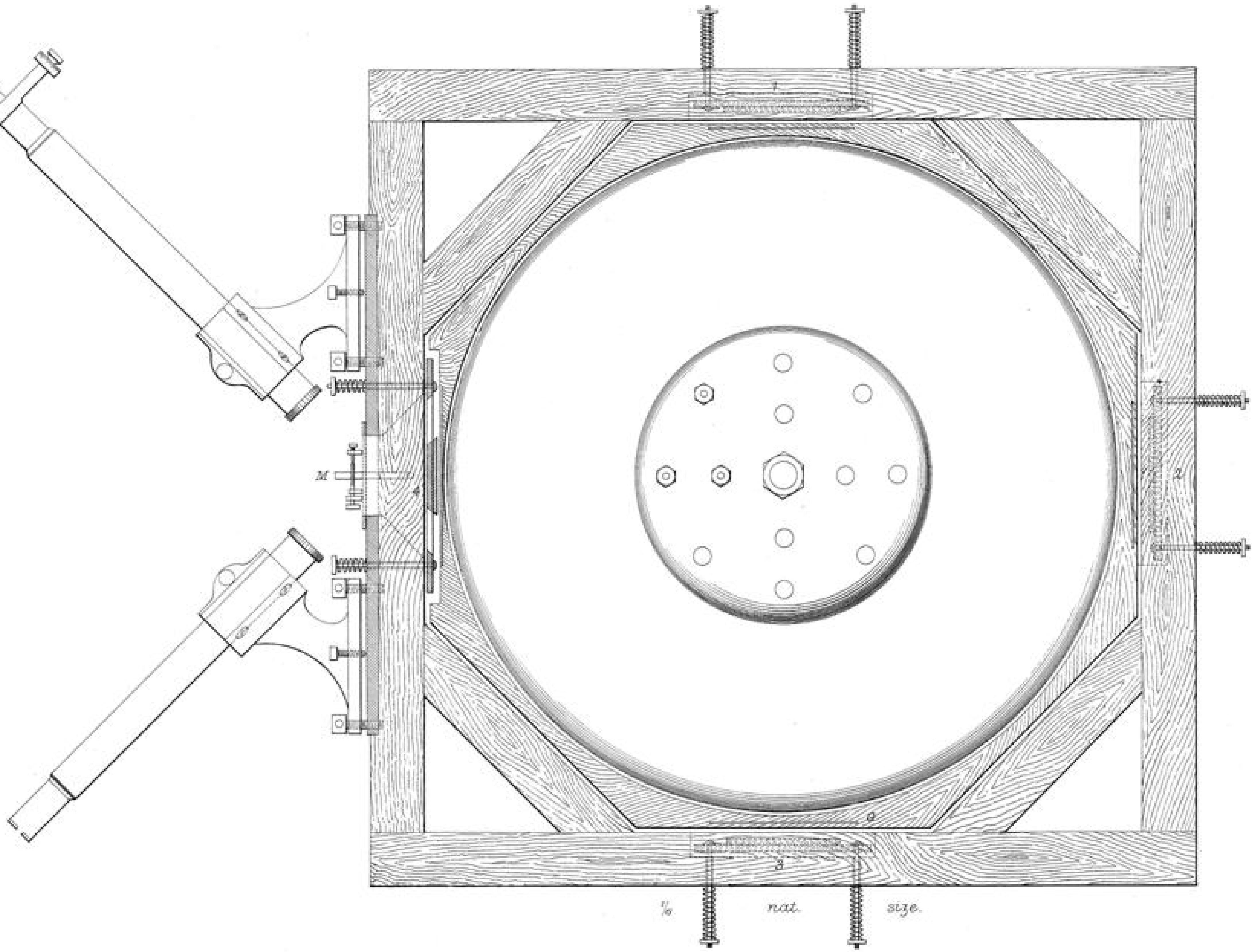


Woodbury Company (Eyre & Spottiswoode).

CAPELLA

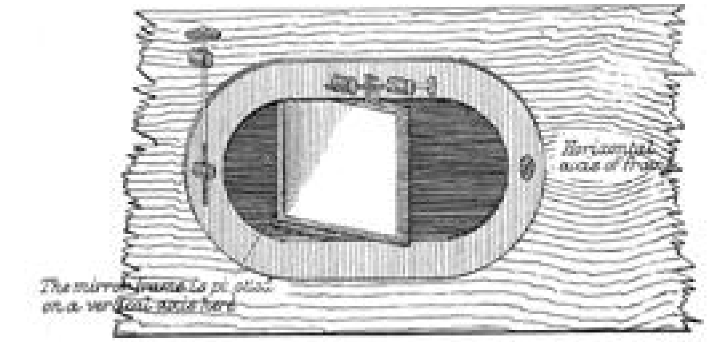
ARCTURUS





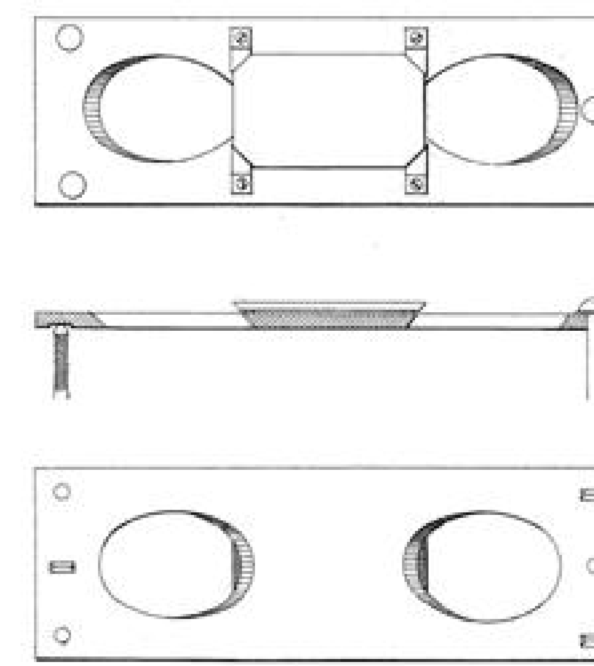
⅛ nat. size.

Plan of optical frame with steel disk in position, and glazed drum to isolate them from the frame. G represents one of the panes of optical glass. Supports of telescope and collimator also shewn, and part of the fixing of the four mirrors 1.2.3.4., three of them let into recesses in the wooden frame, each mirror held by a brass plate supported by three finely cut screws against which it is pressed by the spring-bolts shewn. M is the semi-transparent mirror.



¼ nat. size

Mode of mounting the semitransparent mirror M so as to give altitude and azimuth movement to the reflected beam.



¼ nat. size

Details of brass plate supporting fourth mirror, front, side, and back views.
Back view shows the three slots in which the ends of the supporting screws rest, giving a fine adjustment; the plate being supported by three rigid pushes and three elastic pulls.

West, Newman lith.