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COMMUNICATIONS FROM THE ASTRONOMICAL INSTITUTE AT AMSTERDAM

Two new instruments for the reduction of stellar spectra, by *A. Pannekoek.*

At the Astronomical Institute of the University of Amsterdam two instruments have been built during the last years, in order to facilitate the reductions necessary in the photometry of stellar spectra. As they have been in use during some time with full success, and the photometry of these spectra takes an ever more important place in astrophysics, it seems worth while to give here a description of these apparatus.

The intensigraph.

The first one, the intensigraph, draws the true intensity curve of a spectrum, proceeding from the ordinary registrogram. In registering photographs of stellar spectra by means of a microphotometer a curve is obtained in which the vertical coordinate gives the intensity of the light falling through each point of the spectrum. It measures the blackness, the density of the silver deposit, or rather the transmission s (taken 0% for total opacity, 100% for the clear plate, where no light has acted). This s is a function of the light intensity of the source I that has produced the silver deposit. In order to find this intensity, intensitymarks of known ratio are put on the same plate. They are used to derive the function $s = f(\log I)$, the characteristic curve for that plate. By means of this curve for each s the corresponding value of I may be derived.

In the case of a spectrum where we want to know the intensity in every part of a line as a function of the intensity of the continuous background of the spectrum, we have to take s_0, the transmission at a point of the background of the spectrum, then find the corresponding I_0 and compute I/I_0 for every other point. We may then better make use of a transformed characteristic curve, expressing not $F(s, \log I)$ but $F(s, I/I_0)$; by deriving I_0 corresponding to s_0, and then reading in the characteristic curve the s belonging to $\log 0{\cdot}9\, I_0$, $\log 0{\cdot}8\, I_0 \ldots\ldots \log 0{\cdot}1\, I_0$ ($I = 0$ corresponds to $s = 100\%$) we may easily construct, as a table or a graph, the transformed characteristic curve.

Because of the enormous amount of computing labour connected with this derivation for the whole extent of a stellar spectrum, it is necessary to look for contrivances to facilitate this work. Different methods and apparatus for this purpose have been described, among which the "transformation pantograph" described by HEMMENDINGER [1]) may be especially mentioned as a solution of the problem. Compared with it our apparatus shows several changes in the underlying principles of construction. It has been devised by D. KOELBLOED, computer of our Institute, and constructed by himself together with TH. WALRAVEN, assistant at the Institute.

It might seem that such an apparatus now is superfluous since MINNAERT and HOUTGAST [2]) described and practised a method of directly registering a true intensity curve from the spectral photograph, without the intermediary of a registered s curve. We could not make use of it, however, because for the application of the contracting method spectra with a large horizontal scale were needed, which would demand a great waste of bromide paper. Their method, moreover, though entirely satisfactory in the case of the solar spectrum, where the background is well visible, presents difficulties for stellar spectra of advanced type, where the continuous background is entirely obliterated by the wings of the apparent lineprofiles, and must be deduced afterwards by a special discussion. So here the tracing of an s curve cannot be avoided, and when it is available, only an apparatus to transform it into an intensity curve is needed.

The differences in construction principles between KOELBLOED's and HEMMENDINGER's instruments may

[1]) *R. S. I.* IX, p. 178. [2]) *Z. f. Aph.* XV, p. 354.

be summarized as follows. Instead of bringing the carriers of the registrograms and the characteristic curve very close together, it seemed better, in order to avoid any parallax, to project the image of one upon the other; then, moreover, the characteristic curve can be drawn on a larger scale, thereby making small drawing errors harmless. Instead of moving the observing microscope up and down, which necessitates a fatiguing identical moving of the observer's head, the direction of the s coordinate was made horizontal and it was observed through a fixed reading glass, using both eyes, the point of coincidence shifting horizontally to and fro. Instead of moving the frame carrying the characteristic

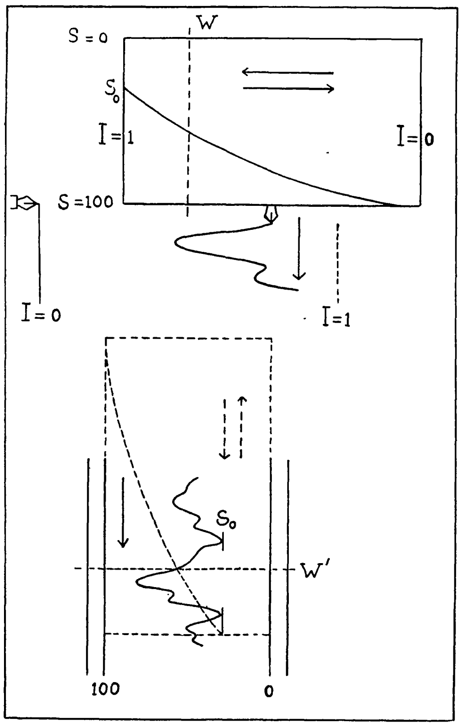

FIGURE 1.

curve from the observer's body away and back, which is an uneasy mode of moving the arms, it was preferred to move this frame to the right and the left, which is a more natural and smooth way and so allows to follow the curve more easily and exactly. These conditions can be fulfilled by turning the image of the characteristic curve 90° in projecting it upon the registrogram, as will be manifest in a schematical figure of the arrangement (Figure 1). The upper part of the figure represents the transformed characteristic curve, $s = s_0$, $I = 1$ corresponding to the unit of intensity, and $s = 100$, $I = 0$ to the clear plate. In the lower part the image of the characteristic curve, also seen from above, turned 90°, is given by dotted lines. The upper figure is moved horizontally, (the wire W remaining fixed) and a pen attached to it draws the intensity curve. The observer, looking at the intersection point of the image W′ with the registered curve, keeps the image of the characteristic curve intersecting them in the same point by moving the upper figure horizontally, which he sees as a vertical movement of the characteristic curve and a horizontal shifting of its intersection with W′.

The lightbeam projecting the characteristic curve upon the registrogram is first going upward, somewhat inclined to the vertical, and is reflected vertically downward by two mirrors at equal height. The conditions to be fulfilled in order that a plane

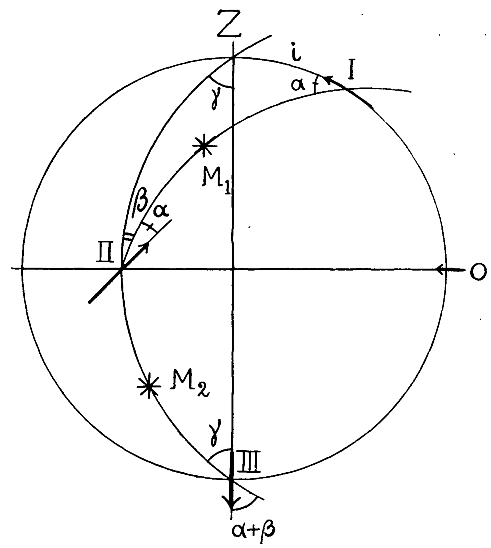

FIGURE 2.

through the first beam should be turned 90° by the double reflection, can be easily deduced from a representation of the directions by spherical coordinates. Let Z and III, in Figure 2 (in stereographic projection) indicate the upward and downward vertical directions, I and III the directions of the incident and the twice reflected beam, and II that of the once reflected horizontal beam. Then the normals to the mirrors are situated in the points M_1 and M_2, halfway between I and II, and between II and III; the second reflection is at 45°. The direction of a plane through the first beam (vertical for an observer looking towards the centre from O) is given by an arrow through point I. The once and twice reflected positions of this plane are given by arrows through II and III. In III this direction should be perpendicular to the arrow in I. From the figure we see that the condition to be fulfilled is $\alpha + \beta = \gamma$, where γ represents the azimuth of the once reflected horizontal beam. If we call i the inclination of the original beam it is readily seen that this condition is expressed by

$$\sin \beta = \sin \alpha \sin i; \ \mathrm{cotg}\ \alpha = \mathrm{tg}\ (\alpha + \beta) \cos i.$$

Were the first beam exactly vertical ($i = 0°$) then the azimuth $\gamma = \alpha$ of the once reflected beam would have been 45°. In practice no computations are necessary, since the exact perpendicularity of the reflected to the true direction of motion can be easily tested and secured by experiment.

The instrument, of which a detailed description follows hereafter, gives a tenfold enlargement of the horizontal (wave length) scale, so that 1 mm on the spectral plate corresponds to 50 cm in the curve; the unit of intensity is taken nearly 20 cm. These dimensions have been chosen, because at our Institute this intensity curve had to be subjected to the further operation of contracting the profiles. If only inspecting and studying the profiles is aimed at, the instrument can easily be fitted to a fivefold enlargement of scale and 10 cm intensity unit; then the profiles are not too steep to be well investigated.

The working with the intensigraph is easy. After some training an observer is able to follow exactly all the sinuosities of the registrogram, when it moves with a velocity of a good cm per minute, thus taking half an hour for a sheet of 40 cm length. It was supposed at first that the observer in this following should be able to eliminate the small irregularities due to silver grain and to follow a smoothed mean curve. It appeared, however, that the observers took the habit of giving their full attention to the exact following of all the details of the curve. In smoothing the resulting curve afterwards due care can be taken that the right middle course of all sinuosities is taken. In deciding as to what irregularities have to be removed and smoothed out the knowledge of the width of the "instrumental curve" of the spectrograph used offers a certain guidance.

The lineprofile contracting apparatus.

In *B.A.N.* No. 301 and *Publ. Amsterdam* VI, p. 15, G. B. VAN ALBADA has described a method of contracting the profiles of absorption lines and thereby facilitating greatly the work of separating composite lines in spectra of advanced type and of determining their equivalent width.

The practical application of this method, however, is very laborious. It takes a great deal of time to measure the ordinates h of a sufficient number of equidistant points of the intensity curve (at distances c corresponding to the width of the instrumental curve, in our case c being 0·03 mm on the spectral plate), then to compute $H_2 = 3\,h_2 - h_1 - h_3$ and to construct a new curve out of these values. On one stellar spectrum of 8 cm length no less than 2700 points had to be treated in this way. A facilitating device was soon put into practice by our computers: not to read the ordinates h, but to connect the points h_1 and h_3, to read their middle point at a vertically movable scale, the zeropoint of which was brought into coincidence with h_2, and then, at a scale with the unit twice as large in the opposite direction mark the point with the same value as had been read. The ordinate of this point $h_2 + 2\,(h_2 - \frac{1}{2}\,(h_1 + h_3)) = H_2$ Then the contracted curve could be drawn through these points.

Still the labour involved in putting separately a large number of points and drawing a curve through them, is rather great. So a means was sought for to draw the contracted curve in such a way that, while the sheet with the intensity curve was moving on slowly, the numerical operations were made mechanically and a pencil moving up and down traced the contracted curve upon the sheet. It was necessary then, that three pins movable parallel up and down at horizontal distances c each should follow exactly the intensity curve. Since it proved impossible to move three pins by eye and hand simultaneously along the curve, this had to be done automatically. After different projects and contrivances had been discussed, Messrs KOELBLOED and WALRAVEN finally succeeded in devising and building the instrument, of which a description is following hereafter. Two essential contrivances form its principle. The first provides, by electrical control, that the three pins (here wheels) are enforced to follow the intensity curve in such a way that with every deviation to one or the other side they are drawn back. The other consists in the mechanical performance, by means of a system of pantographs, of the computation that derives H_2 from the three values h_2, h_1 and h_3.

Whereas in the intensigraph the real work has to be done by the observer, the profile contracting apparatus works entirely automatically and has only to be supervised. Usually a sheet of 4 metres, made from one registrogram and corresponding to 8 mm on the original spectral plate, takes three quarters of an hour to go through the apparatus and depict the contracted curve.