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Radiation Flux in Sunspot Umbrae.

Paper II.

By

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With 1 Figure.

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The ratio of umbral intensity to photospheric intensity as a function of wavelength has been studied in the case of four fairly large spots in the wavelength range 4000 Å — 6500 Å. The relative spectrophotometric gradient has been evaluated for each spot.

Introduction.

In a previous paper[1] by A. K. DAS and A. S. RAMANATHAN the radiation flux across a single spot of large size observed under excellent conditions has been studied in some detail in the 4000 Å wavelength region. With a view to extend the flux measurements to the whole visible region, spectra of four sunspots of considerable umbral area were obtained in December-January 1952—53. The Kodaikanal numbers of the spots, the dates of observation, the dates of central meridian passage and the true areas of the spots in Greenwich units are given in Table 1. All the spectrograms were secured under good sky conditions in the morning when the definition was good. Also the spectra were photographed when the spots were at or very near the central meridian. More than a hundred plates were taken in all and each plate contained a set of five spectra of a spot, a spectrum of the limb for determining the correction for scattering and a set of standardisation marks which were obtained in the manner described in paper I.

Experimental Details.

The spectrograms were obtained with a large plane grating spectrograph in Littrow mounting fed by an 18-inch Foucault siderostat and a 12-inch three-component Cooke photo-visual objective giving a constant focal length of about 21 feet over the spectral range from the near ultraviolet to the red. All the spectra were photographed in the 2nd order of the grating where the dispersion was nearly 1.5 Å per mm. Exposures were made in succession in the H and K region, g region,

[1] Hereafter referred to as paper I.

H_β-region, Mg-b region, Na-D region and in the H_α region. In all cases suitable filters were used to suppress the overlapping spectra. The photographic plates used were Ilford Special Rapid Panchromatic for the H_α, Na-D and Mg-b regions, Ilford Selochrome for the H_β region and the Ilford Process for the g and H and K regions. The slit width was kept constant at 0.04 mm. Each plate ($8^1/_2$ in. · $6^1/_2$ in.) contained five spectra of varying densities covering a range of about 250 Å. A spectrum of the sun's limb was also photographed on each plate by focussing the sun's image on the slit plate in such a way that the vertical diameter of the image coincided with the length of the slit. The standardisation spectra were obtained with an auxiliary spectrograph which was the grating spectrograph used for measurements described in paper I. For this investigation one could conveniently have used lesser dispersion so as to cover a larger range of wavelengths on each plate, but in view of the fact that the same plates were intended to be used for the study of the profiles of some metallic lines in the spot spectrum, the above dispersion was necessary. Of all the plates taken, only those (about 60 in number) which had the finest definition and showed clear demarcations between the umbra, the penumbra and the photosphere were selected for microphotometry. On each plate about eight wavelengths were chosen where there was a good continuous spectrum and the microphotometer runs were made in the continuum parallel to the Fraunhofer lines, using the Cambridge Recording Microphotometer of this observatory.

In all cases the central intensity of the umbra was computed as a fraction of that of the adjacent photosphere. A correction for scattering was made following WANDERS' method in the manner described in paper I. It was found that in most of the cases the correction was either nil or very small except for spot No. KKL 9929 which, due to its smaller umbral area, required a scattering correction varying between 2 and 10% for the various spectral regions.

It has been mentioned in paper I that MILNE and UNSÖLD in their theoretical work have assumed that the ratio of umbral intensity to photospheric intensity is about the same for all spots. However, recent observers such as WORMELL, WANDERS, MICHARD actually find that the central flux decreases with increasing area of the spots. The present observations in the case of KKL 9920, KKL 9922 and KKL 9930 indicate a similar trend; only KKL 9929 gives the opposite trend although one perhaps may not rely too much on this spot on account of the considerable scattering corrections required in this case. But as only four spots are observed in the present series this conclusion regarding the variation of umbral flux with area needs further confirmation by observations of sunspots under equally good sky conditions.

Determination of the Gradients $-\Delta \frac{c_2}{T}$.

Since the violet region of the solar spectrum is crowded with strong Fraunhofer lines it is difficult to assign a definite colour temperature to the solar photosphere and therefore to the sunspot for the spectral range comprising the entire visible region. A more satisfactory method of comparison of the energy in the umbra of a spot with that of the photosphere will be to evaluate the spectrophotometric gradient defined by $G_{SP} = -\frac{d\,[\ln I_S(\lambda)/I_P(\lambda)]}{d\,(1/\lambda)} = -2 \cdot 30\,\frac{d \log_{10} I_S(\lambda)/I_P(\lambda)}{d\,(1/\lambda)}$ for the wavelength range considered. Here $I_S(\lambda)$ and $I_P(\lambda)$ represent the intensity of radiation in the spot umbra and the photosphere in the interval between the wavelengths λ and $\lambda + d\,\lambda$ respectively. Since in the visible region $\lambda\,T$ is small $I_{(\lambda,\,T)}$ can very well be represented by WIEN's Law, in which case the expression for the gradient reduces to $G_{SP} = c_2\left(\frac{1}{T_S} - \frac{1}{T_P}\right) = \Delta\,\frac{c_2}{T}$, where T_S and T_P represent the colour temperatures of the spot umbra and of the photosphere respectively.

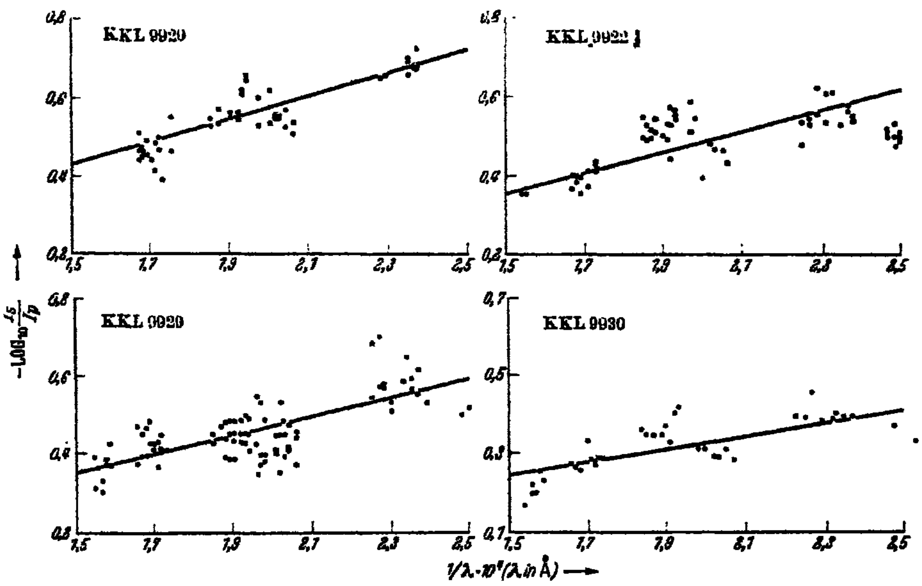

Fig. 1. Determination of Spectrophotometric Gradient for Individual Spots. • • represent single observation. ⊙ ⊙ represent two observations.

Accordingly $\log_{10}\frac{I_S(\lambda)}{I_P(\lambda)}$ was plotted against $\frac{1}{\lambda}$ (λ being expressed in Å) for each spot separately (see fig. 1) and the line of best fit was determined by the method of least squares. The slopes of these lines when multiplied by -2.30 give the gradients for the various spots which are given in the sixth column of Table 1.

Table 1.

Spot No.	Dates of observations	Date of central meridian passage	Area of the spot in millionths of the visible hemisphere	Area of the umbra in millionths of the visible hemisphere	$\Delta \frac{c_2}{T} \cdot 10^{-3}$ Å (Ångström Units)	
					a) From Gradients	b) From Intensities at λ 5000 Å
KKL 9920	Dec. 18, 19, 20, 1952	Dec. 18, 1952	470	85	6.63	6.44
KKL 9922	Dec. 20, 22, 23, 1952	Dec. 20, 1952	285	50	5.55	5.35
KKL 9929	Jan. 10, 11, 12, 1953	Jan. 12, 1953	175	29	5.41	4.99
KKL 9930	Jan. 14, 15, 1953	Jan. 15, 1953	177	40	3.75	3.45

It is now worthwhile to compare these gradients with those calculated from the radiation temperatures for the spot and the photosphere for a mean wavelength, say, 5000 Å. For this purpose the radiation temperatures, T_S and T_P for the spot and the photosphere respectively were calculated by PLANCK's Law making use of MULDERS value for the absolute intensity for λ 5000 at the centre of the disc and the ratio $\frac{I_{S,5000}}{I_{P,5000}}$ (average of 3 wavelengths at 4950 Å, 5000 Å and 5050 Å) from the present measurements. The values of $c_2\left[\frac{1}{T_S} - \frac{1}{T_P}\right]$ thus obtained are incorporated in column 7 of table 1. The agreement between the two values of the gradients appears to be very satisfactory.

In conclusion it is my pleasant duty to thank Dr. A. K. DAS, Director of this observatory for his encouragement and guidance during the course of this work. My thanks are also due to Prof. Dr. A. UNSÖLD who kindly read through the paper and offered valuable criticism.

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