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Diurnal Variation of Sodium Dayglow at Poona

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The detection of sodium dayglow is an extremely difficult instrumental problem as the emission has to be detected in the presence of an overwhelming background which is larger by a factor of 10,000 or more. A Zeeman photometer incorporating the principles of resonance scattering and magnetic scanning was developed for surmounting these difficulties of detection. A total of 68 days of observations was secured using this instrument during the year 1976. A suitable sample of these data is analyzed to indicate the capability of the instrument. Our statistical analysis indicates that the dayglow can be detected by this instrument even under the above-mentioned adverse conditions of signal-to-noise ratio. The diurnal variation of the intensity of sodium dayglow was thereby deduced, which shows a symmetrical pattern around the noon as obtained by earlier investigators. The possible lines of improvements and analysis are indicated and discussed in the light of recent criticism on the method of Zeeman photometry.

1. Introduction

Sodium is one of the important minor constituents for understanding the D-region photochemistry. Its optical emission, viz. D-lines (5890 Å and 5896 Å) can be conveniently observed from the ground during nighttime, under favourable sky conditions using narrow band interference filters (10 to 100 Å) and photoelectric photometry. The results based upon such observations at this station have been reported earlier from time to time.[1-3] However, as "determination of the diurnal variation of sodium preferably throughout the full 24 hr is a key to the construction of a satisfactory model of the behaviour of atomic sodium in the upper atmosphere",[4] we strongly felt a need of obtaining observations of sodium dayglow.

The detection of the dayglow is an extremely difficult instrumental problem as the emission has to be detected in the presence of an overwhelming background. We present in Table 1, a comparison of typical signal-to-noise ratios involved in night and dayglow photometry. For a good quality narrow band interference filter at 10 Å bandwidth a signal-to-noise ratio of convenient magnitude such as 10 : 1 is available in night airglow, whereas this ratio is as adverse as 1 : 50,000 even for an improbably narrow filter of 1 Å bandwidth in day airglow due to overwhelming Rayleigh scattered sunlight background. For the same reasons high resolution monochromators and interferometers are also of little help.

This difficult problem has been circumvented by Blamont[5,6] by introducing a novel technique of detection which employs principles of resonance scattering. This technique was first employed for twilightglow[7] and later for dayglow by several workers.[4,8-12] This allows us to have a considerable improvement in resolution, since it now equals the width of the line itself (0·02 Å). Table 1 clearly shows that, there thus exists an improvement by a factor of 50 for sodium D-lines. A further improvement is provided by the fact that once the line-width detection is achieved, Fraunhofer absorption takes care of this ratio by a further factor of 20 as only about 5% residual D-lines emission is present in the scattered sunlight.[8]

2. Experimental Set-up

As stated above this experiment incorporates the principle of resonance scattering. Our complete optical set-up is shown in Fig. 1. This set-up consists of three main components besides the light collecting optics. An interference filter F of about 80 Å half bandwidth separates out a narrow region of skylight spectrum alongwith the dayglow emission signal. An interference filter is not of any direct relevance in separating the background as can be inferred from Table 1. But it substantially reduces

Table 1—Signal-to-Noise Ratios in Night and Day Airglow Photometry (λ = 5893 Å)

Airglow	Emission sign l kR	Background noise kR	Detector bandwidth Å	Signal-to-noise ratio
Night	10^{-1}	10^{-2}	10	10 : 1
Day	1	5×10^{4}	1	1 : 50000
For linewidth detection	1	1000	0·02	1 : 1000
For Fraunhofer residual (5%)	1	50	0·02	1 : 50

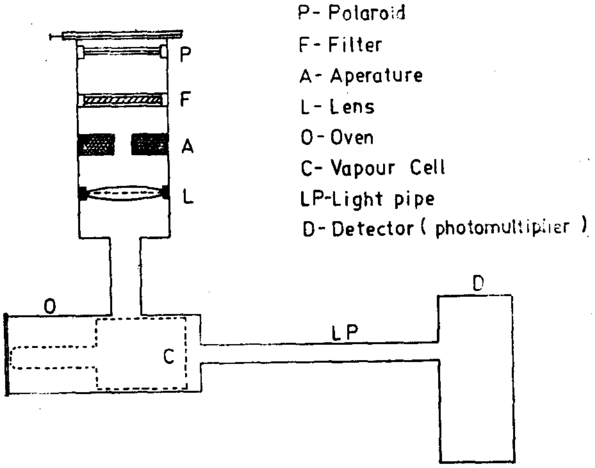

Fig. 1—Complete optical set-up of the Zeeman Photometer (side view)

the level of instrumentally scattered light, which is usually termed as "parasitic" light. The polaroid P at the entrance ensures a definite direction of polarization of the incoming signal, even though polarization of skylight may change depending upon the position of the sun.[4]

The third and the most important component is the resonance vapour cell. The details of fabricating this cell are described elsewhere.[13] It consists of a pyrex cell of dimensions 5 cm × 2·5 cm with a tail of about 5-6 cm at one end. Sodium is filled in this cell at a pressure of 10^{-6} mm before sealing off the cell and it vaporizes when the cell is heated to a temperature of 165°C by enclosing it in an oven. We maintain the temperature manually by adjusting the currents and voltages for heating the oven as our automatic thermal control is yet under development.

Fig. 2 illustrates the physical principles of resonance scattering with reference to the energy level diagram of sodium. The incident emission is absorbed and re-emitted by the sdoium atoms in the vapour state. The re-emitted radiation could be observed from a direction at right angles to the incident direction. As the sodium vapour will not respond to any other radiation besides its own resonance frequency in the above manner, all the other neighbouring radiations are discriminated out, except for the one in the line-width itself. To separate the dayglow emission from the residual Fraunhofer D-line radiation, one sets in Zeeman effect by enclosing the cell alongwith its oven in a magnetic field. We show in Fig. 3 our arrangement for producing a magnetic field of the order of 4 kgauss and complete Zeeman photometer with all the mounts but without the electronics. The physical principles of operation are

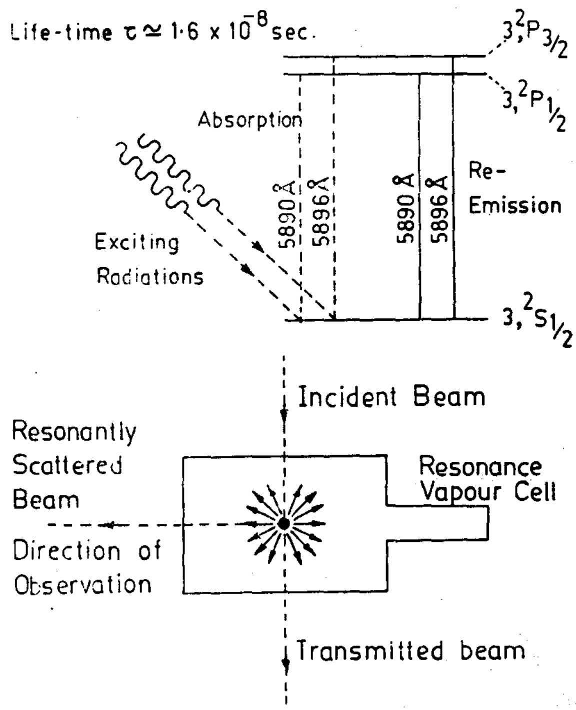

Fig. 2—Resonance scattering of sodium D-lines and the working of resonance vapour cell

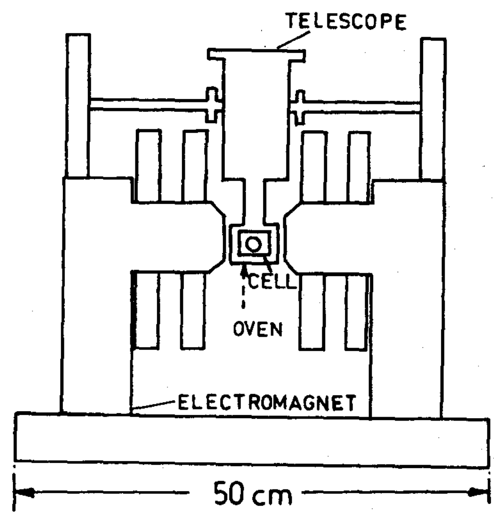

Fig. 3—Zeeman photometer (front view) showing the magnet and the mounts

illustrated in Fig. 4. For the sake of simplicity, we treat the strong field Zeeman effect. In actual calculations one has to take into account the Back-Goudsmit effect for all the hyperfine components.[10,14] When the Zeeman effect sets in, the passband of the resonance cell changes from the original single wavelength to the pattern corresponding to the field strength. When the polaroid is parallel to the field direction, the central components are cut down and the cell then responds to the wavelengths corresponding to the outer components. Thus, when the magnetic field is on, the detector responds to the

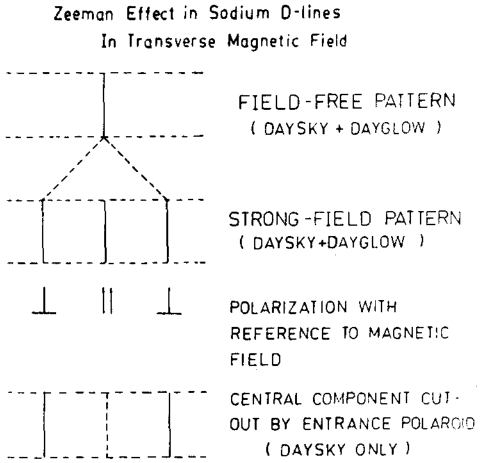

Fig. 4—Magnetic scanning for separating the dayglow from the daysky background

background only, whereas in zero field, one gets signals proportional to background as well as emission.

The details of the complete experimental set-up including the electronics as well as the difficulties encountered in fabrication have been described earlier.[13]

3. Observations

First few field trials of this set-up usually known as Zeeman photometer were reported at the Solar-Planetary Physics Symposium[13] in Jan. 1976 and, after some modifications and improvements, this was in operation continuously for all the clear sky days during Mar.-May 1976. These were naturally stopped as monsoon conditions were set in from June 1976 till Oct. 1976 and were resumed again in Nov. 1976. We have already secured observations for 68 clear sky days during Jan.-Dec. 1976. Table 2 shows the monthly distribution of days for which observations are available. These observations also include the day of solar eclipse in Apr. 1976 (viz. 29 Apr. 1976).

4. Method of Reduction

The observed signal for zero field conditions, consists of the following three components, viz. (i) dayglow emission, (ii) Fraunhofer residual background, and (iii) parasitic signal due to instrumental scattering, whereas the signal corresponding to field of 4 kgauss consists of latter two components only. Because of the parasitic light and differences in responses of the cell for field on- and off-conditions, the method of reduction is extremely involved and several supporting procedural calculations are necessary.[10,14] We, however, follow here the working procedure adopted by Gasden and Purdy[4] which is applicable to our experimental set-up, to obtain relative intensities of sodium emission. If I_0 and I_H represent the observed intensities for "field off" and "field on" conditions for skylight and I_0 (sun) and I_H (sun) the corresponding intensities for the sun, then the dayglow emission I_{em} is given by

$$I_{em} = I_H \, [I_0/I_H - I_0/I_H \, (\text{sun})] \quad \ldots (1)$$

Eq. (1) suggests that the difference between the I_0/I_H ratios for skylight and sunlight should give the dayglow emission. This experssion takes care of both the factors mentioned before, but one, therefore, needs additional observations of solar disc using neutral density filters. Because of massive set-up of magnet etc. we have no provision, as yet, for tilting the photometer bodily for each observation. We, however, obtained observations of the sun on several occasions during the month of Apr. 1976, when it passed overhead around local noon. Although the observations involve a considerable instrumental error (approximately 5%) for a single determination of I_0/I_H the standard error of the mean I_0/I_H for sun is remarkably low, indicating the consistency of the observations (see Fig. 6).

Table 2—Observations of Sodium Dayglow at Poona during 1976

Month (1976)	Number of days	Number of hourly sets
Jan.	6	72
Feb.	5	60
Mar.*	5	60
Apr.*	16	192
May	20	240
Nov.	3	36
Dec.	13	140
Total	68	800
*Used in analysis	21	252

5. Results and Discussion

5.1 Choice of Suitable Data

Because of intrinsic difficulties of line width detection, Zeeman photometer is not amenable to direct calibration.[4] Next, as the sensitivity of the photometer was not enough to detect the weaker twilight signals, we found that we are not in a position to provide indirect calibration of the observations as done by earlier workers.[8-12] We, therefore, had an immediate problem of testing whether our instrument is capable of detecting the dayglow emission or not. As suggested in Table 1 the signal to noise ratio is barely 2% in terms of expression in Eq. (1).

This suggests that the factor

$$\Delta = I_{em}/I_H = I_0/I_H - I_0/I_H \text{ (sun)} \qquad ...(2)$$

is hardly 2% of the background reading. In view of the instrumental uncertainties of about 5% for each single observation, we thought it necessary to test whether the dayglow signal is really detected or not.

To test this hypothesis, we, therefore, primarily selected a set of data of about 21 days, mutually consistent with each other (i.e. no intermittent instrumental changes) and of extremely good sky conditions. This further covered the solar observations, so veiy necessary for the analysis.

5.2 Intensity Variation of Sodium Emission

We, therefore, scaled all our hourly observations and obtained ratios I_0/I_H. These hourly values were averaged over the total number of available observations and average ratios $\overline{I_0/I_H}$ were obtained. We then subtracted the average solar ratio from each hourly averages and obtained hourly average values of $\overline{\Delta}$ factors. Using Eq. (1) we further obtained hourly average values of the emission intensities as

$$I_{em} = I_H \times \overline{\Delta} \qquad ...(3)$$

We plot in Fig. 5 hourly average values of $\overline{I}_{em}$ as deduced by us for the above mentioned 21 days of observation. We may mention that hourly values do show a large internal variability from a minimum of 30% to a maximum of 110% of the average value.

5.3 Statistical Treatment for the Detection of Dayglow

We further find from these analyses that $\overline{\Delta}$ factors vary from 0·7% to 3·3% during its diurnal variation. Looking at the large variability mentioned above and instrumental errors of 5% for each single determination of I_0/I_H, we thought it necessary to test the reliability of the $\overline{\Delta}$ factors for testing whether

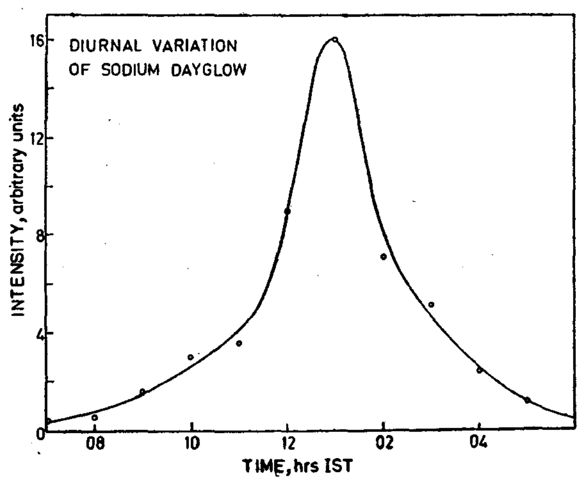

Fig. 5—Diurnal variation of sodium dayglow in arbitrary units

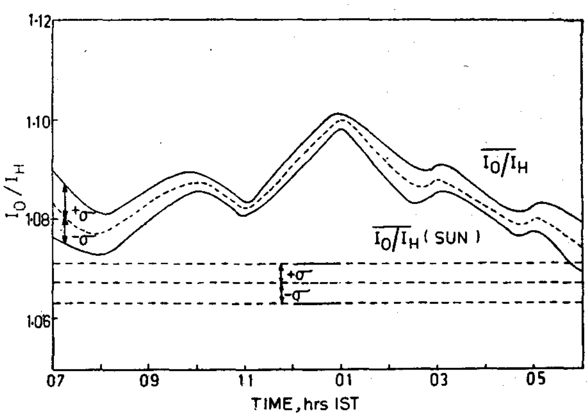

Fig. 6—Statistical test for the detection of sodium dayglow

the dayglow is really detected or not. For this we obtained the standard errors of average $\overline{I_0/I_H}$ values and those for solar ratios. These are shown in Fig. 6 with respective confidence limits $\pm\ \sigma$. We find that curves of $\pm\ \sigma$ for these ratios do not at all overlap except for the values close to the sunset. As our determinations of solar ratios are restricted to noon values only, this overlap at the ends of curves are not considered to be significant. All the same we made further statistical analysis to test whether the differences $\overline{\Delta}$ are significant or not. Except for the extreme values we find that differences $\overline{\Delta}$ are highly significant (0·01 level) and even for the extreme values differences are significant at 0·1 level. This test thus clearly established that the present Zeeman photometer has detected dayglow irrespective of relatively large adverse signal-to-noise ratio, instrumental errors and day-to-day variability.

5.4 Diurnal Variation of Sodium Abundance and Ground Reflection

Relative intensities can lead to estimation of variation of sodium abundance if the supporting theoretical calculations are available.[14] At this moment we consider this exercise unnecessary till we get more confidence in our observations by extending the analysis to entire data. However, at this moment, we think, that it will suffice to compare our present diurnal variation with the earlier observations. We notice that present pattern is symmetrical about the local noon as observed by Gadsden and Purdy[4] and we do get an enhancement by a factor of five or more, from local sunrise to noon and corresponding decrease in the later half. These are comparable with the iesults of the above mentioned authors.[4] The behaviour is different in details such as the rate of increase or decrease towards the extremes and towards the maximum.

Very recently some doubts have been expressed regarding the observed diurnal variation of sodium emission.[15] According to these authors the observed diurnal variation is a function of the ground reflection itself. We plan to test these considerations with suitable ancillary measurements for ground reflection in the near future.

5.5 Importance of Routine Solar Observations

We notice that we can lay more confidence on our observations around noon for which solar readings are available. To improve upon these factors, we plan to increase the frequency of solar observations in future observations. A suitable modification of experimental set-up is now thought of and will be introduced when developed. This will improve the reliability of observations towards the sunrise and the sunset.

5.6 Sensitivity of the Experimental Set-up

Although statistical tests have established the capability of experimental detection of dayglow, we feel that there is further need of reducing the instrumental errors and day-to-day variability which is perhaps due to high level of parasitic signals and inadequate magnetic scanning. We have already made some progress in this direction and we feel that our recent observations in Nov.-Dec. 1976 are being obtained with increased sensitivity. These observations could be processed in due course after corresponding solar observations are secured. With these improvements, we further hope to extend observations in twilight period, which will provide indirect calibration.

6. Conclusions

A novel, extremely delicate technique of resonance detection alongwith magnetic scanning is exploited to fabricate Zeeman photometer for the detection of sodium dayglow. These observations are expected to provide a complete diurnal variation extending over 24 hr for understanding the photochemical model of sodium in the D-region. Several difficult instrumental problems are surmounted and extensive observations over the year 1976 are obtained in this endeavour. A suitable sample of this data is statistically treated to establish the capability of the instrument. The diurnal variation of sodium dayglow is brought out irrespective of the large day-to-day variability (minimum 30% to maximum 110% of average value). This pattern is symmetrical about the local noon. Suitable methods for improving the quality of the data and its utility are suggested and are being pursued.

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