Looking at the sky with a digital spectrophotometer

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Abstract

Digital spectrophotometers allow a variety of educational measurements of emission and absorption spectra of light sources. As an example we report the observation of the skylight under different conditions, showing both the most prominent absorption Fraunhofer lines and the slight differences which can be observed in the spectral composition of the light for different orientations and time during the day. The measurements can be carried out with a simple digital spectrophotometer - now available at a reasonable cost - as an educational activity for college or undergraduate physics students.

1. Introduction

Digital spectrophotometers operating in the visible range are now a common and reasonably accessible tool even in the college or undergraduate physics laboratory.Spectral analysis in these devices is usually accomplished by letting the light from outside enter through an optical fibre into a mirror which focuses it on a diffraction grating. The different wavelengths of the composite light are then dispersed and focused on a segmented CCD, which gives the intensity spectrum, i.e. the light intensity as a function of the wavelength.

Such instruments provide an easy and fast way to measure the composition of the light emitted by a source, either by those producing continuous spectra (for instance incandescent lamps) or by those emitting discrete spectra, as for instance for spectral lamps. The comparison between the spectrum measured directly looking at the source and that obtained interposing a material (either solid or liquid) between the source and the detector also permits the investigation of the transmission properties of that material, and to extract the absorbance curve for chemical solutions, which is in turn related to the structure of the energy levels of that compound. Several of these measurements are now carried outsince many years in our lab for third year physics students.

Looking at the sky with a digital spectrophotometer may result in additional educational applications of such devices, since many features of the spectral composition of the skylight provide a way to discuss with students several aspects of classic and modern physics. One of these aspects is the emission and absorption of spectral components, either due to phenomena occurring in the Sun or in the Earth atmosphere.Absorption lines in the spectrum of the light emitted by the Sun were observed for the first time at the beginning of 1800 byJoseph von Fraunhofer,who carried out a detailed investigation of this phenomenon, measuring and classifying several hundred lines, which are now called Fraunhofer lines. Such absorption lines are now believed to originate from atomic transitions in the various chemical elements or molecules, either in the Sun or in the Earth atmosphere. Additional observations of the sky may be carried out looking at the spectral composition of the daylight along the day or – at a given hour – at the light originating from different orientations.

2. Experimental results

To carry out the measurements discussed here, we employed the 3B Scientific Mod.U17310 digital spectrophotometer [1]. It allows the measurement of the light spectrum in the approximate range 360-940 nm by means of a 2048 pixel CCD with a pixel resolution of 0.5 nm and a precision of 2 nm. Similar devices are produced also by different Companies.

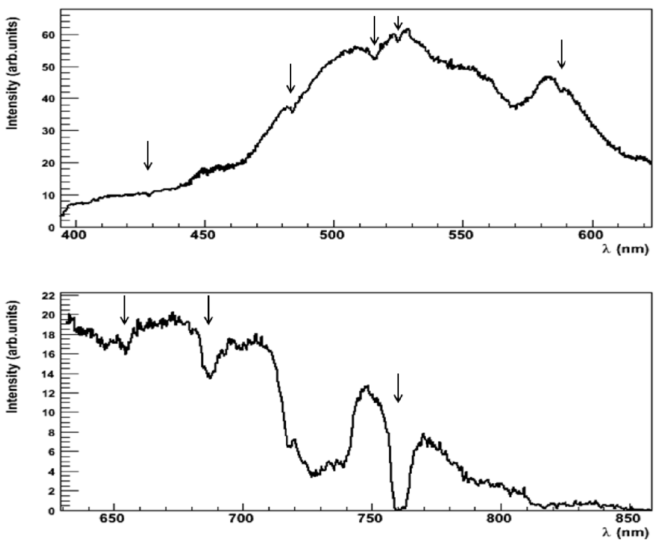

FIG. 1: A spectrum of the skylight obtained during a sunny day with the digital spectrophotometer employed in the present investigation. Arrows mark the wavelengths where observed absorption lines or bands are known (see text).

Fig.1 shows a typical spectrum which can be obtained pointing towards the sky (not directly to the Sun) the optical fibre through which the light enters into the instrument.

The spectrum which can be measured is broad, with a maximum located around 500-550 nm, and extends from the violet region to the red. Even though the shape of light spectra, as measured with basic digital spectrophotometers, is distorted by the spectral response of all such instruments, and needs to be corrected for this effect, it is apparent that the observed spectrum contains roughly all the components in the visible range. The old question of understanding why the sky is "blue" is discussed in many introductory textbooks, and it is usually related to the influence of Rayleigh scattering which is strongly dependent on the wavelength. However, the interpretation of the color of the sky has produced many discussions on the topic, and the question has been addressed by several authors in the past. Among these, Raman has long discussed this topic also in educational lectures [2], in terms of the absorption of the yellow components and the relative intensities of the blue and violet with respect to the red, yellow and green components.

Another important feature of a typical daylight spectrum is the presence of several absorption lines (or bands).These manifest themselves as narrow (or broad) dips in the spectrum, whose position may be interpreted according to the known list of Fraunhofer lines [3] and it is related to the possible atomic or molecular transitions taking place either in the Sun or in the Earth atmosphere. The detailed shape of such dips depends however on several factors, including the scattering of light in the atmosphere and the quality of the measuring instrument. By a comparison to the known absorption features in the skylight, several lines may be identified in the spectrum shown in Fig.1. For instance, the band around 430 nm is known to be due to the elements Ca and Fe,while the broad band around 760 nm is due to Oxygen.Other lines which can be easily identified even with an educational tool like that employed in the present work are some of the

Hydrogen lines (H_α at about 656 nm and H_β at about 486 nm), which are due to Hydrogen atomic transitions following the Balmer series. The same lines were observed in the lab with the same instrument, as emission lines, by the use of a Hydrogen spectral lamp.Table I shows the correspondence between the observed absorption features marked by arrows in Fig.1 and the known transitions [3]. A more detailed study of the spectral Fraunhofer lines which can be observed by such instrument, including also the presence of several elements in the outer regions of the Sun, waspreviously reported by us [4].

Wavelength (nm)	Elements (Notation)
430	Ca, Fe, H_γ (G, G’)
486	H_β (F)
518	Mg, Fe (b)
527	Fe (E2)
588	He, Na (D, d)
656	H_α (C)
687	O_2 (B)
759	O_2 (A)

Table I: List of the main observed Fraunhofer lines in Fig1 (marked by arrows), together with their common spectroscopic notation and the involved chemical elements.

To check for possible small differences (if any)in the spectral composition of the skylight when pointing to different regions of the sky or at different hours along the day, several measurements were taken at different orientations, in the morning, at noon and early afternoon, pointing at the main geographical orientations (North, South, East and West) with an angle of approximately 45º from the horizon. Since the measurement of the complete spectrum with these instruments takes a very short time (fraction of a second), an additional series of measurements was taken at the same time pointing with the instrument to the East, for different polar angles (from the Zenith to 70º with respect to Zenith). Some of these measurements were repeated in the same day at 12.00 and 15.00 local time.

Fig.2 shows the spectra measured to the same (East) direction at approximately 9:30 a.m., 12.00 and 3.00 p.m. . Though reported in arbitrary units, as given by the instrument, the integrated intensity reflects the different luminosity measured in the morning, at noon and in the early afternoon on a December day. The main features are seen on all spectra; however small differences in the shape may be observed,especiallyat wavelengths larger than 600 nm. Small differences in the relative intensity of various absorption lines with respect to the smooth trend of the spectrum in that region may be also observed in the three spectra.

The overall intensity of the skylight spectrum in a given moment depends of course on the orientation with respect to the Sun apparent position in the sky.

Although in December thesunrise is not exactly in the East direction, one expects that the largest intensity in the morning come from observing the sky towards approximately East, which is indeed observed in Fig.3, showing three spectra measured at 9:30 a.m. local time at the Zenith, 20º and 45º from the Zenith. Apart from the different integrated intensity, even in this case small differences may be observed in the spectrum measured at the Zenith with respect to the other two, particularly in the region above 600 nm (red and infrared components).

Finally, a comparison between the spectra taken at the four geographical orientations, with a polar angle of approximately 45º from the horizon and at the same time (9:30 a.m.), is shown in Fig.4. Again, while the central region in all the spectra has nearly the same shape, small differences may be noted around 450 nm, where the spectrum is flatter for the North and West orientations, and above 600 nm, where the North and West spectra do not exhibit in a clear way the absorption features which are observed at East and South.

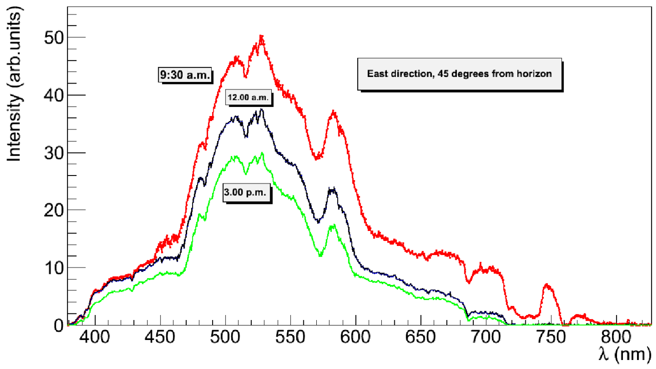

FIG. 2: Spectra measured at different times during the day, towards the East direction, approximately 45°from the horizon.

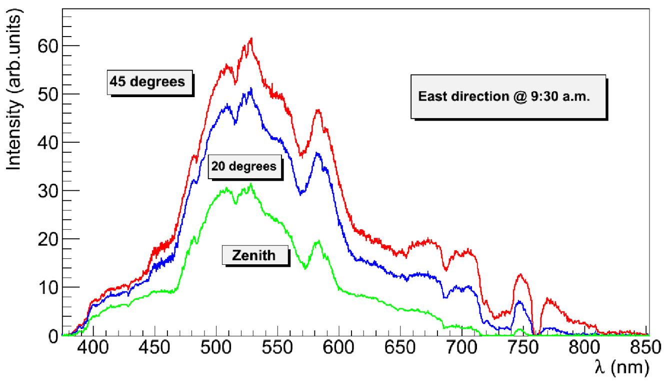

FIG. 3: Spectra measured at different inclinations with respect to the zenith, pointing in the morning to the East direction.

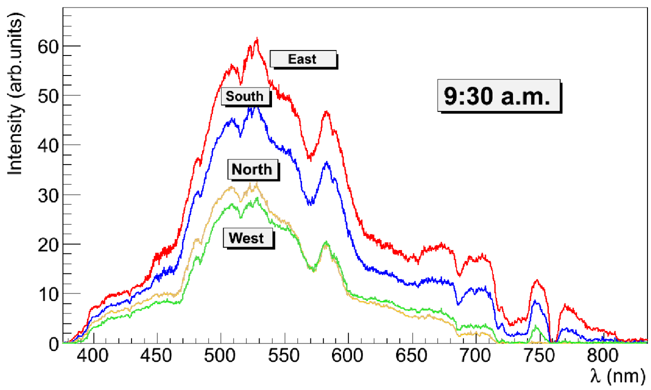

FIG. 4: Spectra measured at the same time, pointing at different geographical orientations in the morning.

3. Conclusions

The use of a modern, low-cost digital spectrophotometer in educational experiments allows a variety of measurements to be carried out in classical and modern physics. The characterization of continuous and discrete light sources may be an important part of undergraduate activity, which allows to quantitatively measure the light spectra originating from various sources of natural and artificial light. In comparison to traditional spectrometers based on a diffraction grating, as the Kirchoff-Bunsen spectrometer, where the values of each observed wavelength must be evaluated by the measurement of the diffraction angle with a goniometer, digital instruments based on the use of a CCD allow to obtain the overall spectrum in a single step, thus permitting a fast way (although not so precise as classical instruments) to visualize the spectrum.

In addition to a long list of activities which can be done by such instrument in the lab, including the quantitative study of various emission spectra and of the transmission properties of solids and liquids, the observation of the sky through digital spectrometers is able to reveal many details of the skylight. The absorption of the light either in the Sun or in the Earth atmosphere with the observation of the main Fraunhofer lines, or the search for differences in the intensity or in the spectral composition of various regions of the sky are among such investigations. More quantitative studies for the observation of such differences could be carried out by the use of a more sophisticated setup, with the measurement of the light originating from a small portion of the sky through a collimation system and a telescope mounting, allowing to measure the polar and azimuthal angles with better precision.

References :

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