Observation of absorption Fraunhofer lines in the sky with a digital spectrophotometer

Valeria Indelicato[1], Paola La Rocca[1,2], Francesco Riggi[1,2], Gianluca Santagati [1,2], Gaetano Zappalà[1]
[1]*Department of Physics and Astronomy, University of Catania, Via S.Sofia 64, 95123 Catania, Italy.*
[2]*Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Via S.Sofia 64, 95123 Catania, Italy.*

E-mail: Francesco.Riggi@ct.infn.it

(Received 30 July 2013, accepted 27 December 2013)

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 most prominent Fraunhofer lines from the sky, due to absorption either by chemical elements in the Sun or to molecules in the Earth atmosphere. 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.

Keywords: Digital Spectrophotometers, Fraunhofer absorption lines, Light spectra.

Resumen

Los espectrofotómetros digitales permiten una variedad de medidas educativas de los espectros de emisión y absorción de fuentes de luz. Como ejemplo se presenta la observación de las líneas de Fraunhofer más prominentes desde el cielo, debidas a la absorción ya sea por los elementos químicos en el Sol o moléculas en la atmósfera de la Tierra. Las mediciones se pueden realizar con un sencillo espectrofotómetro digitales - ahora disponible a un costo razonable - como actividad educativa para la universidad o estudiantes de física de pregrado.

Palabras clave: Espectrofotómetros digitales, líneas de absorción de Fraunhofer, espectros de luz.

PACS: 01.40.E, 01.50.My, 07.60.Rd **ISSN 1870-9095**

I. INTRODUCTION

Absorption lines in the spectrum of the light emitted by the Sun were observed for the first time at the beginning of 1800. A few years later, in 1812, Joseph von Fraunhofer 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. Absorption lines are produced whenever a broad photon spectrum interacts with a cold gas. In such case a decrease of the light intensity is observed when the photons are absorbed by the atoms or molecules and then re-emitted over all directions. Near the end of 1800 H. A. Rowland published a comprehensive atlas of the solar spectrum wavelengths, which was updated in 1928 and then again in 1966 [1], including now more than 20000 lines in the wavelength region from 293 nm to 877 nm. An updated on-line version of the database reporting the absorption Fraunhofer lines is also available [2]. Many other sites report a list of the main Fraunhofer absorption lines [3]. In the Sun, Fraunhofer lines are the result of the photon absorption from the gas in the outer regions, where more than 60 chemical elements have been clearly identified [1]. While traversing the Earth atmosphere, photons can indeed undergo absorption due to air molecules, especially O_2. Absorption from molecules is mainly due to the Earth atmosphere. However, even lines due to molecules in the Sun, such as CH, OH and CO among others have been identified. Since a long time the observation of absorption lines in the Solar spectrum has proven to be a powerful tool to understand the abundance of elements. The original classification scheme employed by Fraunhofer made no reference at that time to the chemical symbols, but rather made use of letters to identify them. While high-resolution measurements of the Solar spectrum require sophisticated equipment, digital spectrophotometers operating in the visible range are now a common and reasonably accessible tool even in the college or undergraduate physics laboratory. For such reason we checked the possibility to measure and identify the most prominent Fraunhofer absorption lines just by looking at the daylight with such simple instrument. Spectral analysis in these devices is 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.

II. EXPERIMENTAL RESULTS AND ANALYSIS

To carry out this investigation, we employed the 3B Scientific Mod.U17310 digital spectrophotometer [4]. It allows the measurement of a 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. Fig.1 shows a picture of the instrument. Similar devices are also produced by different Companies [5].

FIGURE 1. A picture of the compact digital spectrophotometer employed in the present investigation (3BScientific, Mod. U17310), showing also the optical fiber through which the light enters into the device.

To measure the spectrum of the daylight we mounted the optical fibre in a simple holder pointing to the sky, approximately to the North direction, in order to avoid the direct sunlight. After various tests, several measurements were taken at intervals of a few minutes, in the early afternoon, around 3 p.m. local time. We checked that all the measurements gave similar results, looking at the ratio between the different spectra, which was constant around unity, with fluctuations in the order of a few percent. To compensate for possible small differences in different measurements, we averaged six spectra to obtain the overall intensity spectrum.

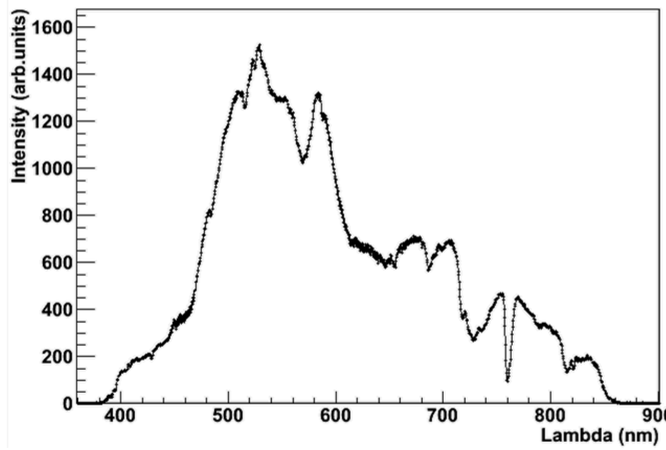

FIGURE 2. Intensity spectrum of the skylight, averaged over six different measurements taken approximately to the North direction on a sunny day around 3 p.m. local time.

The resulting spectrum is shown in Fig. 2. This is a broad spectrum, with a maximum around 500-600 nm, as it is known for the solar spectrum. Clearly visible are several absorption regions, such as that around 760 nm (corresponding to the “A” line, according to the original notation by Fraunhofer), and due to the light absorption by the O_2 molecule in the Earth atmosphere.

For the purpose of identifying as much lines as possible over the entire range of wavelengths, we plotted in Fig. 3 an expanded view of different portions of the spectrum. Table I shows a list of the lines (among the long list of known Fraunhofer lines) which may be identified in the measured spectrum, together with their original labels and the atomic species which are responsible of the observed transitions.

As it can be seen, the main Fraunhofer lines, which are labelled with the capital letters A, B, C,... are well identified in the various portions of the spectrum. Some of the observed bands are identified as due to absorption in the Earth atmosphere, in particular by Oxygen molecules (line Z at about 823 nm, and lines A and B, around 759 nm and 687 nm respectively).

Of particular interest are the well-known Hydrogen lines Hα (original label C, at about 656 nm), Hβ (original label F, at about 486 nm) and Hγ (original label G’, at 434 nm), which are due to Hydrogen atomic transitions following the Balmer series. Less intense, but still visible is the Hδ line (original label h, at 410 nm). The existence of these lines in the emission spectrum of a spectral lamp was also observed in the lab by the use of the same spectrometer.

In addition to the Hydrogen lines, the presence of several elements in the outer regions of the Sun may be inferred in the results shown in Fig.3, by the absorption lines due to Na, Mg, Ca, Fe and other elements.

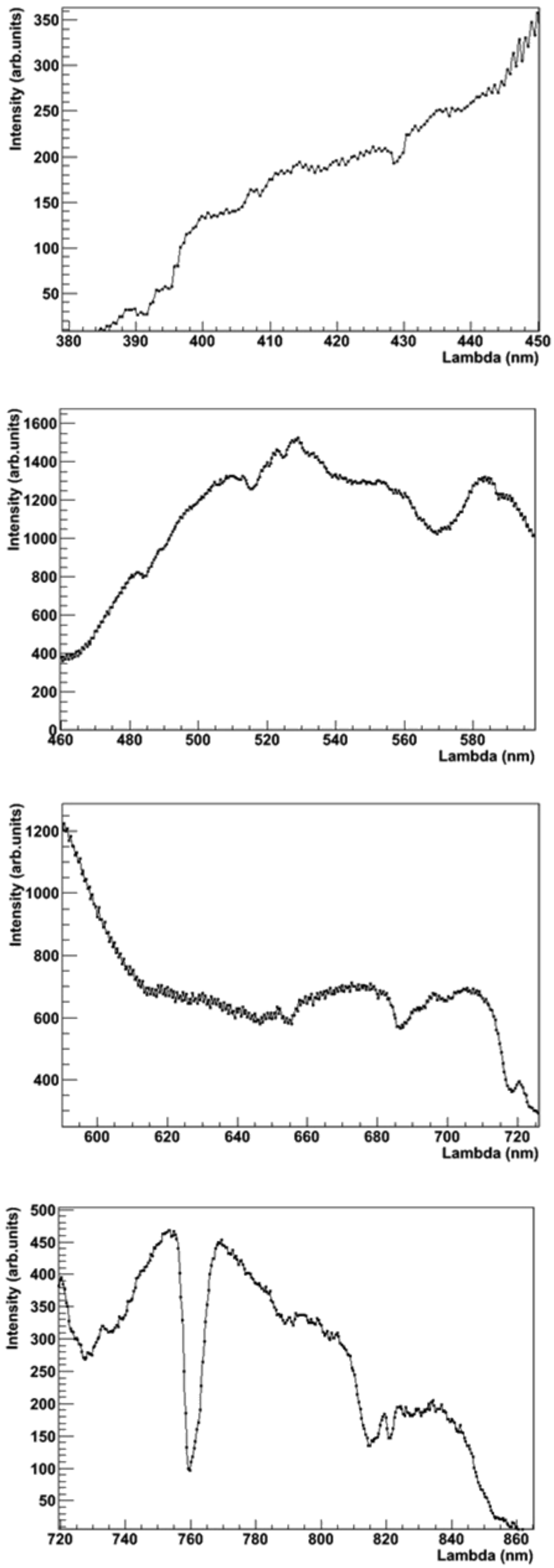

FIGURE 3. Expanded view of different portions of the intensity spectrum shown in Fig. 2.

TABLE I. List of the Fraunhofer lines identified in the spectrum. The first column gives the wavelength of the observed dip, while columns 2 and 3 report the original designation of the line and the associated chemical element or molecule.

Wavelength (nm)	Designation	Element
393	K	Ca^+
397	H	Ca^+
410	h	H_δ
431-434	G,G'	Ca,Fe,H_γ
486	F	H_β
517-518	b	Mg,Fe
527	E2	Fe
587-589	D, d	He, Na
656	C	H_α
687	B	O_2
759	A	O_2
823	Z	O_2

While the position of the absorption lines in the spectrum is measured in an easy way, the detailed shape of the intensity spectrum depends on various factors, which include the scattering of light in the atmosphere and the response of the spectrometer, which is usually not uniform in the overall range of wavelengths. These aspects go beyond the purpose of the present paper and do not alter the main point, concerning the possibility to observe the absorption lines of several atomic and molecular species with a simple instrument.

III. CONCLUSIONS

Digital spectrophotometers may be easily employed in the physics laboratory at different levels, from college to undergraduate physics curricula, since they provide an easy and fast way to measure the overall composition of a light source, either for continuous spectra (such as those produced by incandescent lamps or LEDs) or for discrete spectra, as those obtained from spectral lamps. The comparison between the light spectra measured directly looking at the source or 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 – in case of chemical solutions – the absorbance curve, which is in turn related to the structure of the energy levels of that compound. This technique is commonly employed in our lab for third year physics students since many years, to carry out a variety of measurements on such topics.

The observation of the daylight in the sky with such simple instrument gives access to additional possibilities of investigating and understanding physical phenomena of our everyday life, and related to important aspects of modern physics. Due to the reasonable cost of such equipment, many high schools and undergraduate labs have now the possibility to enrich the presentation of physics phenomena in the visible range of wavelengths.

REFERENCES

[1] See for instance the second revision of Rowland Table, by C. E. Moore, M. G. J. Minnaert and J. Houtgast, *The Solar spectrum*, National Bureau of Standards Monograhphs 61 (1966), available on line at http://www.astrosurf.com/spectrohelio/atlas-en.php

[2] http://bass2000.obspm.fr/solar_spect.php

[3] See, among others, www.coseti.org/9006-025.htm or www.columbia.edu/~vjd1/Solar%20Spectrum%20Ex.html

[4] www.3bscientific.it

[5] See, for instance, the following links: www.oceanoptics.com, www.phywe.com or www.campustore.it