Colours in your pocket: smartphone-based spectrometers to investigate the quantum world

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Abstract. We designed a low cost spectrometer to be used by groups of students with an inquiry approach. This simple equipment allows to investigate the additive and subtractive models of colour formation, to study the selective absorption of a material and explain it from a microscopic point of view. The Home made apparatus was used in several experiments showing the quantum nature of the absorption and production of light with the aim of bridging optics and modern physics.

One of the aims of the recent researches carried out by the Physics Education Research Groups at the Physics Departments of the Universities of Pavia and Trento (Italy) is to design and test approaches and materials for introducing basic concepts of modern physics. In our approach, some experimental activities play a central role. Since these activities are mainly focused on optics and specifically on spectroscopy [1-8], we designed and tested low-cost spectrometers to be assembled and used by high school and undergraduate students.

The spectrometer is based on the use of diffraction gratings and a smartphone [1,2,3]. Such spectrometer can be assembled by students very quickly (about one hour) using inexpensive materials (black cardboard) allowing to make wavelength and light intensity measurements with good accuracy. A slit is opened at one end of a collimating tube, resulting in a narrow beam of light entering the tube. A low-cost transmission grating is placed on the opposite side and disperses the beam of light into spectral lines with different colours at different angles. The tube, in combination with the slit, acts to ensure that only approximately collimated light be focused by the camera lens on the smartphone. After a simple calibration procedure [1], the spectrophotometer can be used to obtain quantitative measurements of spectra from different sources, thus allowing exploration of the physical mechanisms governing light emission.

Initially our spectrometers were used to study light transmission with two different aims:

1) to investigate the additive and subtractive models of colour formation
2) to study the selective absorption of a material and explain it from a microscopic point of view

Then they were used in several experiments showing the quantum nature of the absorption and production of light. In particular:

- The spectrum of an incandescent bulb measured at different temperature shows the typical features of the blackbody emission [8].
- The spectrum of fluorescent lamp highlights the two mechanisms underlying light emission, the de-excitation of gaseous Hg atoms and the fluorescent emission of the lamp's coating [1].
- The wavelengths of visible lines of Balmer series can be measured, and the obtained values allow to estimate the value of Rydberg's constant with an error difference of few tenths [2,7,8].
- The fluorescent emission spectrum of commercial ink highlights the quantum nature of light emission and allows a discussion about elastic and inelastic scattering of photons on materials [3,8].

The experiments above have been tested with high school students, undergraduates and with student teachers in a postgraduate course for physics teacher education. Our results testify a related deep satisfaction of students, who were able to carry out a significant analysis of their data.

Spectroscopy measurements were also employed to evaluate the Planck's constant by measuring the wavelength of the light emitted by diodes of various colours. During this activity, which we usually combine with measurements of photoelectric effect, students estimated the ratio h/e using the emission wavelengths and the "turn on" voltages of LEDs. [8,9]
The latest experimental activity, introductory to modern physics, has been carried out for two consecutive years at the University of Pavia with final year students from science-intensive high school (Liceo Scientifico). Data about this implementation will be presented at the symposium. The activity, based on LEDs and the photoelectric effect, heavily brings into play as a prerequisite students' knowledge of the structure of the electromagnetic spectrum, in particular the visible band and its bordering zones. Both the direct experience of the researchers, based on discussion with students, and quantitative data, based on a test given to students at the end of the activity, reveal that students' knowledge is largely insufficient in this area.

References

[1] The photoluminescence of a fluorescent lamp: didactic experiments on the exponential decay" Onorato, Pasquale; Gratton, Luigi; Malgieri, Massimiliano; Oss, Stefano Physics Education, v. 52, n. 1 (2017), p. 015011-015018.

[2] Measuring the hydrogen Balmer series and Rydberg's constant with a homemade spectrophotometer P Onorato, M Malgieri, A De Ambrosis European Journal of Physics 36 058001 (2015).

[3] Quantitative analysis of transmittance and photoluminescence using a low cost apparatus, Onorato, P; Malgieri, M; De Ambrosis, A European Journal of Physics, 37, 1, 015301 (2015)

[4] What are we looking at when we say magenta? Quantitative measurements of RGB and CMYK colours with a homemade spectrophotometer, Rosi, Tommaso; Malgieri, Massimiliano; Onorato, Pasquale; Oss, Stefano; European Journal of Physics,37,6,065301,(2016)

[5] Studying colours with a smartphone T. Rosi on behalf of M. Malgieri, P. Onorato, A. De Ambrosis and S. Oss IL NUOVO CIMENTO 40 C (2017) 104

[6] Onorato, P., Malgieri, M. and De Ambrosis A. (2016) "Home made spectrophotometer for a laboratory bridging optics and modern physics" in Thoms, Lars-Jochen; Girwidz, Raimund (eds.) (2016): Selected Papers from the 20th International Conference on Multimedia in Physics Teaching and Learning. September 9–11, 2015 at LMU Munich, Germany. 20th International Conference on Multimedia in Physics Teaching and Learning, 9 - 11. September 2015, München, Deutschland ISBN 978-2-914771-95-5

[7] Malgieri, M., Onorato, P., and De Ambrosis, A. (2016) "A learning path on quantum physics including simulations, low cost experiments, online resources" in Thoms, Lars-Jochen; Girwidz, Raimund (eds.) (2016): Proceedings of the 20th International Conference on Multimedia in Physics Teaching and Learning. 20th International Conference

[8] De Ambrosis A., Malgieri, M. and Onorato P. (2017) Uno spettrometro a basso costo per esperimenti introduttivi alla fisica moderna - A low-cost spectrometer for introductory experiments to modern physics Il Giornale di Fisica 58,281

[9] Malgieri M., Cattaneo C. and De Ambrosis A., "Evaluation of an experimental sequence on introductory quantum physics based on LEDs and the photoelectric effect", GIREP-ICPE-EPEC. Dublin, 3-7 luglio 2017.