Observing a colour and a spectrum of light mixed by a digital projector

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Abstract

In this paper an experiment studying a colour and a spectrum of light produced by a digital projector is presented. The colours and spectra were taken with a digital camera. The simultaneous study of colour and spectrum simplifies the understanding of the relationship between the colour and spectrum, additive mixing of colours, concept of complementary colour etc. The experiment is very attractive for students. It is also very easy due to the use of the standard digital projector.

Introduction

In optical experiments, which are concerned with mixing colours and with comparison of colour and spectrum, a digital projector is a very useful instrument. The spectrum of light it produces may be set simply from a personal computer by a standard application program. Since it is a common equipment at secondary school at present, we do not need to search for any special facilitation. Furthermore, the light flux of contemporary digital projectors is high enough so that the produced optical effects may be observed in the whole classroom (though the black-out is generally needed). Finally, since the human perception of colour is due to the three kinds of cone cells in the retina of the eye [1], plenty of colours may be produced by mixing three fixed (primary) colours. Thus, it does not make any difference, that the projector is equipped with three RGB colour filters (red, green and blue) only.

Experimenting with the digital projector we can simply demonstrate the answers for questions as: "Why is a blue colour complementary to yellow?", "What is the spectrum of a purple colour, when the purple is not present in spectrum?", "How can I obtain a white light from colour lights?" etc.

Experimental set-up

In order to make a spectrum of light produced by the digital projector common optical components as adjustable optical slit, lens and grating are needed (see scheme (a) in figure 1 and the real set-up in figure 2). However, since the projector is already equipped with object-lens and the slit can be simulated by the software, a simpler set-up is also applicable (scheme (b) in figure 1). Both arrangements are worth. Whereas the set-up (a) is due to a spectrum quality suitable for student lab experiments and taking pictures, the set-up (b) is for its simplicity and higher spectrum luminance useful particularly in teacher experiments.

In our experiment a DLP projector equipped with a very high pressure mercury discharge lamp (so-called UHP lamp [2]), was used. The optical grating was prefered to prism, since it enables to observe both non-dispersed light (mixed colour) and dispersed light (spectrum of the mixed colour). A special-purpose software, developed by the author of the paper and released for free use (downloadable at [3]), was used to control the screen colour. In the software each primary colour (red,

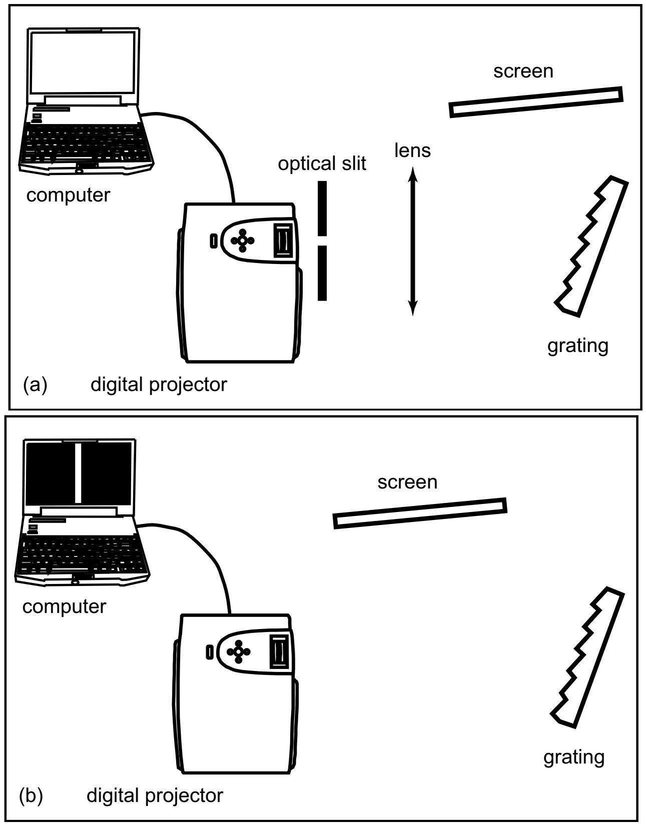

Figure 1: Schemes of two possible experimental set-ups. (a) with additional slit and lens, (b) with software slit.

green, blue) may be independently set in the range $\langle 0, 255\rangle$. The software can also simulate the optical slit by lighting up only a narrow area of screen pixels.

Typical results and discussion

Sample spectra projected on white plain paper and taken by digital camera are displayed in figure 3. All of these pictures show both the mixed colour (on the left) and the spectrum (on the right). The first three examples (a) – (c) show the spectra of red, green and blue colour, which were obtained by using only one colour filter (the light was not coming through the other filters). Since the wavelength ranges, in which colour filters transmit the light from the projector lamp, are quite large and they also overlap, projector cannot produce pure spectral colour only (see so-called chromaticity diagrams for explanation [1]).

The examples (d) – (f) illustrate the mixing of colours of lights from two colour filters. By mixing the equal amounts of blue and green colour a new colour – cyan is obtained. The spectrum of the cyan colour (d) looks as if we put the blue spectrum (c) with the green one (b) together. This is a typical result for *additive* mixing of colours. Similar results were obtained by mixing the equal amounts of blue colour (c) with the red colour (a), when a magenta colour is prepared (e), or by mixing the green colour (b) with the red one (a), resulting in the generation of a yellow colour (f). However, there is an important difference between the produced colours. Cyan and yellow are spectral colours, which

Figure 2: Experimental set-up built up according to the scheme (a).

means, that they can be found in visible spectrum. On the other hand, magenta (a kind of purple colour) is a non-spectral colour and it can be produced only by colour mixing.

If all three colour filters are used to transmit the light, a large variety of colours is available. When all three primary colours are set equally to their maxima (255, 255, 255), a white light is produced (g).

Using the spectra the concept of complementary colour can be also explained. If one colour is complementary to the other, additive mixing of both colours produces the white colour (or a grey if the luminances of the colours are low). Indeed, if we add spectrum of red (a) to spectrum of cyan (d), we obtain a spectrum of white colour (g). Accordingly, the red and the cyan are complementary colours. Comparing the other spectra, magenta clearly complements the green colour and yellow complements the blue colour (and vice-versa).

Spectra of various colours measured by professional spectrometer are plotted for comparison in figure 4. Except that they show similar behaviour as can be seen in the pictures, they enable deeper insight of structure of spectrum, consisting of broadened atomic lines of mercury.

Concluding remark

It is not simple to reproduce the truthful appearance of spectrum. Due to large range of intensities in spectrum together with small dynamic range of the camera chip the bright and dark colours may not be recorded correctly. Moreover, it is in principle impossible to reproduce the spectral colour with three-colour RGB devices (as e.g. computer monitor is). Thus, the reader should consider the published spectra only as small examples of what he can obtain when he repeats these experiments by himself.

References

[1] Wikipedia, The Free Encyclopedia. `http://www.wikipedia.org`.

[2] Derra G *et al.* 2005 *J. Phys. D: Appl. Phys.* **38**(17) 2995.

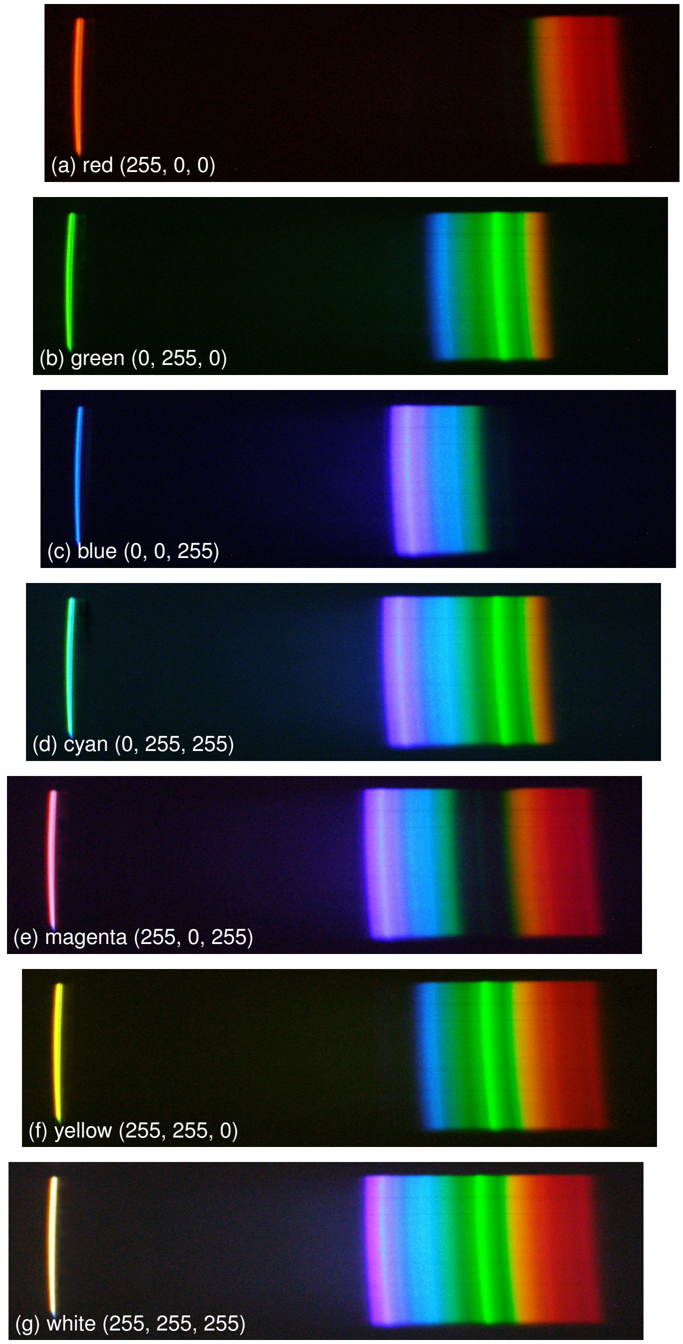

Figure 3: Various colours (on the left) and the spectra (on the right) of light mixed by a digital projector. The colours are given in R, G, B coordinates.

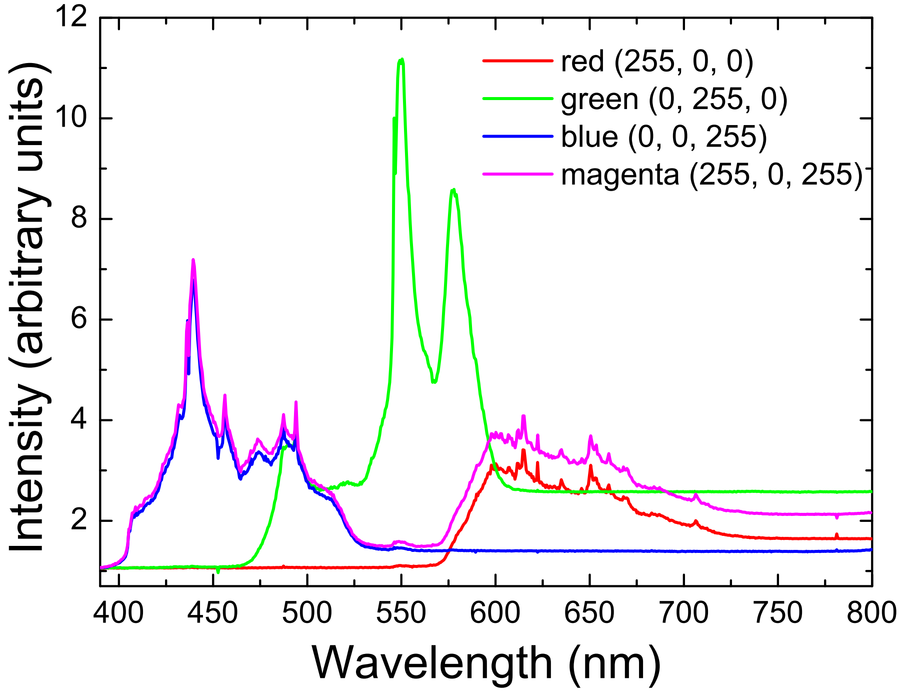

Figure 4: Spectra of some colours measured by a professional spectrometer.

[3] ColourMixer. Software for colour mixing and screen colour control. Download at `http://www.physics.muni.cz/~zdenek`.