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Shadows with the Sun and coloured shadows[1]

Introduction

Some typical difficulties about shadows and coloured shadows are addressed [2] via simple experiments.

The activities **"What a shadow is"** and **"Shadows produced by light from the Sun"** connect with daily life common experiences and discuss: shadow and penumbra, light beams from different areas of extended light sources, etc… The activities **"Coloured shadows by coloured lights"** via experiments using a Colour Mixer (Red, Blue, Green LEDs in a ping-pong ball) discuss colour, colour algebra, additive and subtracting colour mixing, shadows produced by coloured lights, etc…

The Added Value for Education (AVE)[3] here consists mainly in analysing some situations well known in terms of common-sense knowledge. The experiments allows to explore the phenomenology of shadows; observe what happens when the number of LEDs switched-on in the colour mixer change; implement the Prediction Experiment Comparison (PEC) learning/teaching cycle; familiarise with formulating questions and search procedural answers; … The staging of the activities is based on this AVE.

Materials

Simple materials are needed: a sunny day and a ball on a stick (ex. an old tennis ball, a toy ball, an apple or orange …); a LEDs colour mixer (cfr. Do it yourself in Appendix), tooth pick, paper strips.

Important notes

Often the term "ray" is used in textbooks and teaching practice as if it were physical object and not a mathematical model for a path of light. The physical object beam of light can be made by using a light source and a mask with an aperture (ex. a piece of cardboard with a hole) or by a low-cost laser pointer.
The term "shadow-image" is used to highlight the difference with respect to optical image.
We propose the following definition of a shadow: *Shadow is an area that is partially or not at all illuminated by the light source due to interception of an object which is placed between the light source and the area*. Note that definitions of shadow and penumbra in dictionaries may not agree with physics knowledge.

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[1] The MUSE group (G. Planinsic, E. Sassi, L. Viennot) takes responsibility for the content of this paper (July 2011). The intellectual property remains with the authors.

[2] "Shadows: stories of light" by G. Planinšič and L. Viennot, 2010 http://education.epsdivisions.org/muse/example-shadows-documents/SHADOWS_stories_of_light.pdf

[3] AVE http://education.epsdivisions.org/muse/AVE.pdf

Penumbra is often linked to the case of an eclipse; note that a penumbra appears any time a shadow (umbra) is produced by an extended light source. Several textbooks presenting penumbra in relation with eclipses often use sketches that don't help in learning/teaching shadows. Figure 1 shows a representation of a solar eclipse with sharp boundary between shadow and penumbra caused by the Moon. The transition is indeed continuous, as in all cases when light from an extended source is partially blocked.

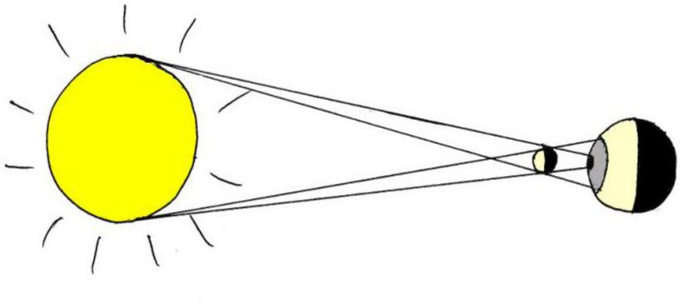


Figure 1: Sketch of a solar eclipse. The shadow and penumbra are erroneously drawn as sharp areas

Typical answers to Activity 2a "Shadows produced by light from the Sun": *On a sunny day, when the Sun is right above, you are holding a ball on a stick above the ground. Sketch the beams of light (rays) reaching the ball and how its shadow is formed on the ground."* are shown in Fig.2 (**a** is compatible with a correct answer).

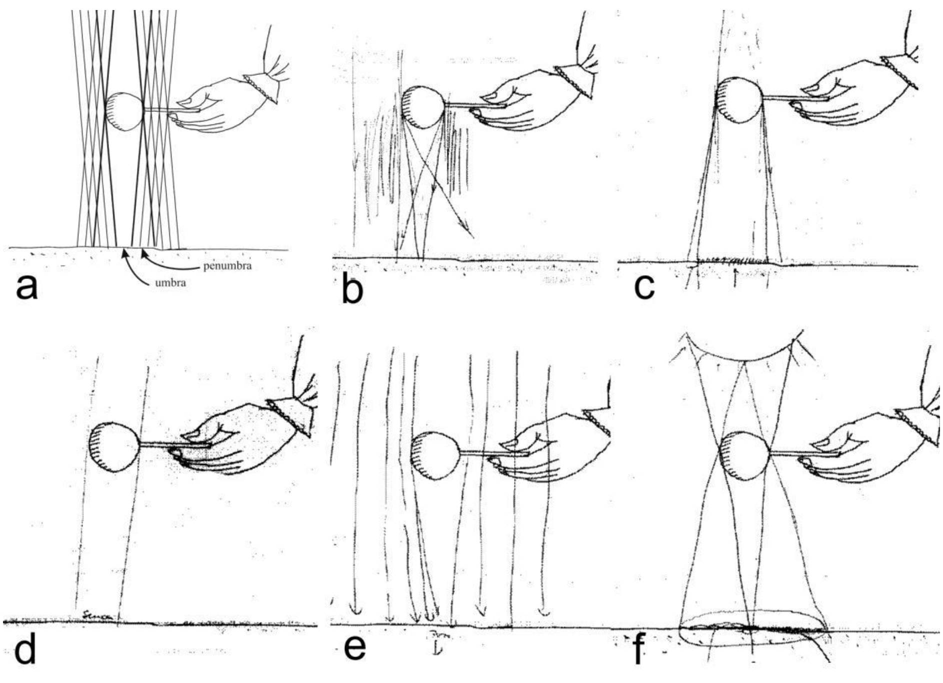


Figure 2: Students' responses to the question on shadow formation: a) compatible with correct answer, b) to f) different types of responses.

The difficulties may be due to various reasoning as, for instance:

- The Sun is very far from the Earth, so the beams of light coming from it are always parallel. The correct idea of parallelism has to be completed by the fact that parallel beams from a small area of the Sun disk are not parallel to beams coming from another small area of the Sun disk.
- A shadow is erroneously thought of as a travelling physical object that reaches the place where it is observed (ground, screen, …), instead of an area of darkness or decreased luminosity produced by an opaque body blocking part of the light beams coming from the light source. The idea of a travelling shadow may come from or be linked to the idea of an optical image as a travelling physical object that reaches the screen, instead of an image produced by an optical system (ex. camera obscura, lens, …) through a correspondence object - image.
- A shadow is full darkness, a kind of "all or nothing" idea that denies penumbra.
- The transition between darker and less illuminated parts (shadows and penumbra) as due to diffraction phenomena that are not present here given that the dimension of the ball are much larger than the visible light range of wavelength (about 400 -700 nanometers).
- Confusion with the diffraction phenomenon

Colours and colour algebra

Colour is a perceptive reaction of the visual system to a light entering the eye.

Red (R), Blue (B) and Green (G) lights have a bandwidth of approximately a third of that of the spectrum of white light. R, B and G are named basic colours. The rules of colour algebra are, with Cyan (C), Magenta (M), Yellow (Y), White (W) lights: R + G + B = W; R + G = Y; G + B = C; R + B = M. The mixing of colours can be additive (combining beams of light) or subtractive (cfr. due to filters or pigments): see below Additive and Subtractive Colour Mixing.

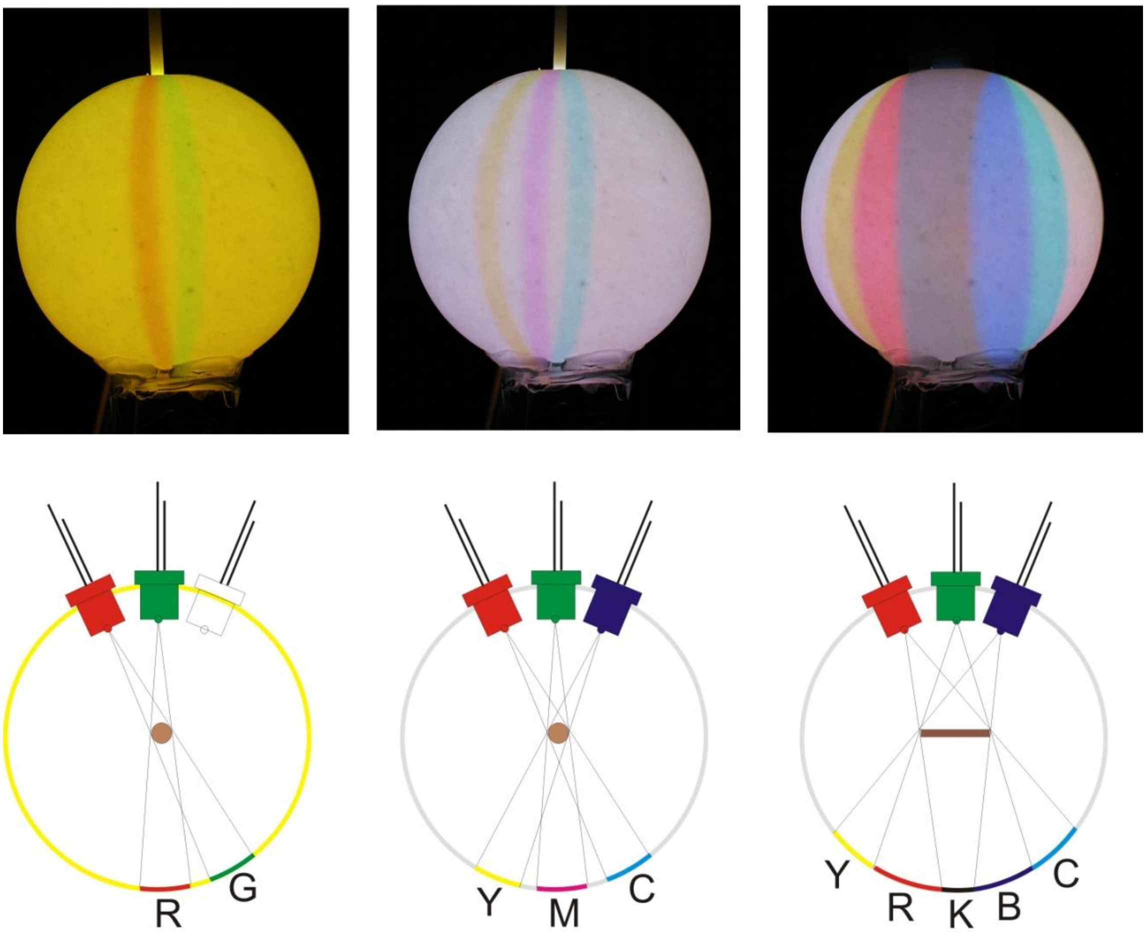
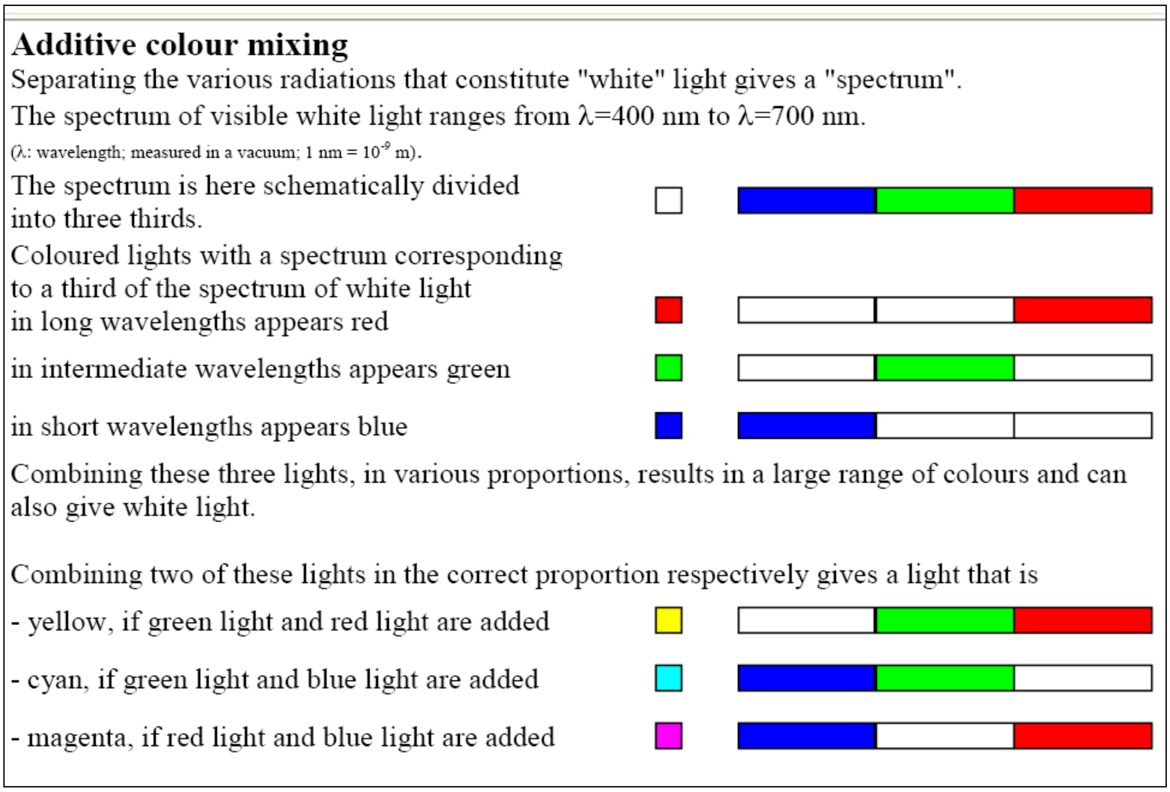
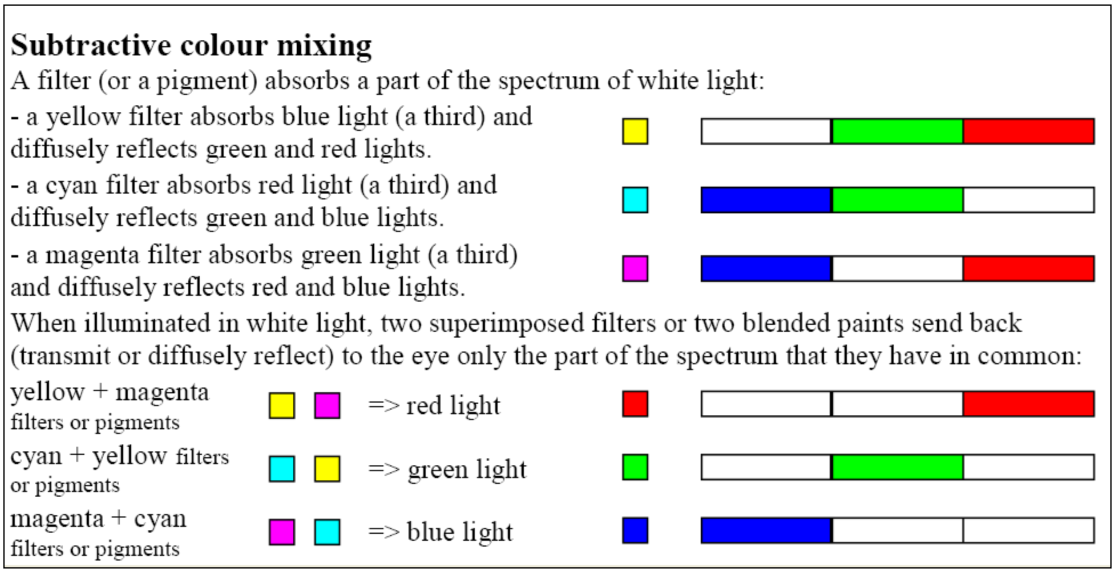


Figure 3: Typical experimental results, with explaining schemas, of "Light and Shadow – Activity No. 3" when Red (R) and/or Green (G) and/or Blue (B) LEDs are switched-on and a toothpick or a paper stripe is inserted into the colour mixer

Additive and Subtractive Colour Mixing

The schemas[4] summarise the topic. The subtractive mixing holds when coloured pigments or filters are combined.



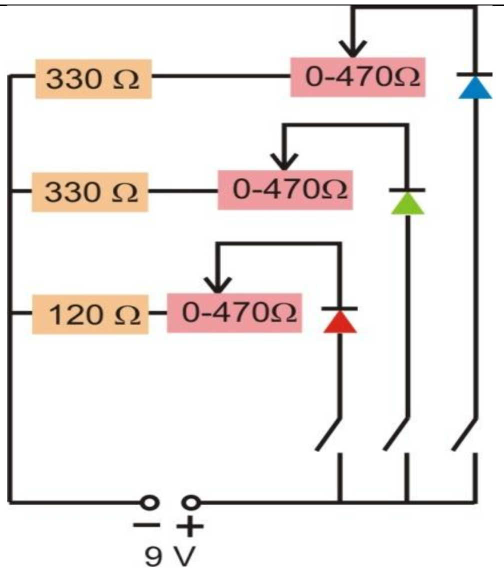


If these lights are observed as a result of diffuse reflection from an object, its colour matters. The colours in the schemas are only observed if this diffusing object is white.

[4] At http://www.lar.univ-paris-diderot.fr/sttis_p7/color_sequence/page_mere.htm a sequence on teaching colours, freely downloadable also in English

Appendix

Do it yourself: how to make a LEDs colour mixer



Schema of the electronic circuit of the LEDs colour mixer.

The values of the fixed and variable resistors may vary depending on the voltage of the battery and type of the LEDs. The value of the resistors should be chosen so that the current through each LED does not exceed the maximal forward current as specified by the LED manufacturer (normally 20mA) at the lowest setting of the variable resistor. LEDs in our colour mixers are taken from a flexible LED strip that utilizes square LEDs without lens.

In case you cannot obtain LEDs without lens you can make yourself an equally good point-like light source by modifying conventional LEDs. Most commercially available LEDs have an epoxy drop lens above the PN junction — the light-emitting element. Unlike point light source such LEDs emit light in a limited cone. In addition, imperfections in lens design cause the angular distribution of light intensity to be non-uniform. With a simple modification the LED can be converted into a light source that is a good approximation of a point light source. Start with LEDs that are encased in clear plastic. Using a hacksaw carefully saw off the part of the LED body that makes the lens, as shown in the figure.

Transforming a conventional LED into a point light source: (1-2) saw off part of the LED that makes the lens, (3) brush the sawed surface with fine sandpaper and (4) finally with a white toothpaste.