Colour and Colorimetry Multidisciplinary Contributions

Vol. IX B

Edited by
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Inside the didactics of colours - red-cabbage juice as a teaching tool

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1. Introduction

Didactical understanding of colours, even within university staffs, is frequently very poor. People hardly recognize differences between the basic colours in emission (RGB) and in printing (CMYK), they do not realize that the violet (i.e. 380 nm) colour can not be reproduced in TV, they do not understand that the red-green perfectly simulates the yellow.

In a series of didactical initiatives on an international level [1] which were triggered by common initiatives with prof. Vittori Zanetti from Trento University under the name “Physics and Toys” [2] we started exploring the world of didactics of colours. He proposed [3] to use a CD as an optical spectrometer; a clear difference between incandescent and fluorescent lamps (including Na and Hg vapour) can be identified [4]. Then, we have developed the subject of colours into independent thematic [5].

2. “Pink glasses” – inside the realm of colours

A departure point for showing that the real colours extends well outside the Newton spectrum are simple objects that we found in Murano glass shops, pyramids and multi-facets spheres [6], see in fig.1 the objects on the right side.

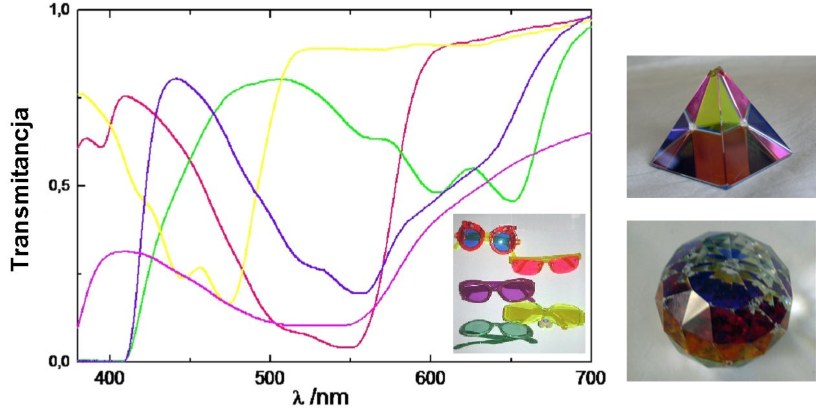

Fig. 1 – Toy sunglasses show quite complicated absorption spectra - colours of the lines correspond to the apparent colours of glasses (left). Svarowski-like pyramids and spheres show richness of colours well outside the basic colours of Newton’s spectrum; binary (or triple) mixing is evident (SPECORD Carl Zeiss, spectra AK, objects GK).

These spheres “produce” unusual colours varying, depending on the angle of observation, from a deep blue to brown. The pyramid is simpler for analysis, as it shows only yellow, magenta and dark cyan. The production technique, applied also in numerous Svarowski objects uses a high refraction coefficient of the glass but it is coupled to a diffraction-like mirror in the basis of the pyramid (or sphere). Clearly, the "Svarowski" pyramids perform an additive synthesis of two colours and the spheres an even more complex synthesis depending on the angle of observation.

We brought the didactics of colours to a higher scientific level by the analysis of transmission spectra of simple, toy-like sun glasses for kids, see fig.1. Differently from the sunglasses for adults, those are made of some plastics coloured with strange pigments, probably organic ones. The analysis of spectra shows that naked-eye impression of colours is a complex task – what seems to be blue transmits also the red part of the spectrum, what seem to be yellow transmits from red to green and also somewhat in violet and so on. We come back to this subject in par. 4.

3. Physics, Chemistry and Biology

Obviously, performing the analysis of colours with professional spectrometers it is outside the possibility of simple didactics. Therefore, within our successive initiative, an interactive exhibition "Fiat Lux! Playing with light" [7] we came back to the analysis of the eye-impression of colours with a story [8] "What is the colour of this pink lamp?" A starting point is the comparison of two Plücker discharge tubes – with He and N_2, both of them giving numerous emission lines, somewhat diffused in nitrogen due to the vibrational excitations of the molecule. The audience watches the tube first with the naked eye and then, after the "hook" question, they watch it again with a cheap diffraction glasses, see [6].

The didactical *scenario* consists in presenting the He lamp and asking about the pink lamp with an additional thesis: "I bet that this is not only pink but also the green one!" Obviously, nobody believes and this is the *cognitive* hook to catch the attention of the pupils on the subject of colours, emission spectra, electronic levels, quantum mechanics, vibrational excitations and so up, with the rising difficulty. The spectrum of a Ne lamp obtained with that simple diffraction "glasses" and a cheap digital camera is shown in fig. 2, left panel. But one does not need Plücker tubes to make the optical *spectroscopy* – the fireworks in Paris on July 14th do the same.

Fig. 2 – Chemical spectroscopy: the neon Plücker tube seen with a simple toy diffraction '"glasses" (left). The naked-eye analysis of colours allows to identify Rb and Cu in fireworks on July 14th in Paris (rigth, photo Piotr P. Karwasz).

The analysis of atomic spectra is already half-way between Physics and Chemistry. It is really difficult to find-out the *physical* ways of getting colours in nature (apart from the rainbow and the diffraction on the spider's web). The colours appearing on feathers of pigeon that depend on the angle of observation (fig.3 a) are due to the diffraction. An even more evolved mechanism – a 3D photonic-crystal like structure [10] is responsible for the intense blue colour of the *Morpho menelaus* butterfly, photo 3b. A more greenish blue in the light "diffused" by a Berlin red-glass ash tray has a completely different origin. This is the exciton light emitted by the nano-gold droplets inside this very special (and expensive) kind of glass, invented in XVII and kept as secret in Pfauisland in Berlin. The subject belongs to Solid State Physics theory.

However, it is not easy to perform somewhat more precise analysis of these colours.

Fig. 3 – Physical spectroscopy: colours on pigeon's neck are due to diffraction (left); colours on *Morpho melenaus* wings (males only) is due to a regular 3D photonic-crustal like structure (central); the blue emission in the bowl from Berlin is due to exciton mechanism in nano-droplets of gold excited by the sun light (source GK).

An unexpected support to "handy" analysis of absorption and emission spectra comes from biology, mainly the most-common ever dye – chlorophyll. Differently from common believes, the chlorophyll does not absorb the green light; it is to much the green light in Sun spectrum and leaves would be burnt. Chlorophyll absorbs in the red (660 nm) and the additional band absorption band lays in the violet (430 nm) range. This configuration of bands allows to use efficiently a wide range of Sun spectrum. The main source of energy for metabolism is the red band, present also without direct sun. The violet band is somewhat additional; in the intense light the chlorophyll absorbs in the violet range but re-emits the excess energy in the red band. In other words, the leaves illuminated by the violet laser emit in red. We show a didactical path on this subject in fig. 4, using cheap laser indicators.

The chlorophyll in solution (80% acetone with water) seems green in the diffused light (A) but does not absorb the green-laser light. It absorbs the red-laser light and, surprisingly, the violet laser light. This reflects the position of the absorption bands of chlorophyll: red and violet. The exact bands are easy to be found in internet, but are not easy to be shows without professional spectrometers. Our experiment perfectly explains these bands. Moreover, we get a kind of colour standard. One has to remember that chlorophyll exists in two slightly different forms, which can be distinguished easily by the human eye. Chlorophyll, with relatively simple absorption bands is a good introduction to more complex organic dyes.

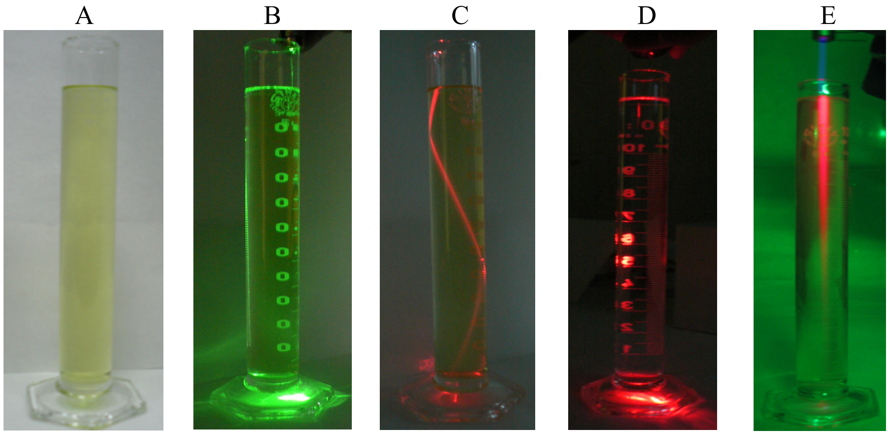

Fig. 4 – Absorption and emission spectroscopy with a "handy" equipment – cheap red, green and violet laser pointers and the chlorophyll 80% acetone/ water extract. The laser beam comes from above. A) Chlorophyll in the diffused light is green. B) chlorophyll does not absorb the light of the green laser – only the light diffused inside the glass container is visible. C) Chlorophyll absorbs (note the diminishing intensity of the beam) the red laser light; it reemits also in the red (note also the reflection of the light on the glass walls as a collateral effect in this photo). D) Water without chlorophyll does not absorb – only the light diffused in glass is visible. F) The second absorption band of chlorophyll is in **violet** – a faint bluish point of the laser beam above the liquid can be noticed; however, chlorophyll does not re-emit in violet, but in the primary, i.e. the **red** band; the fast extinction of the laser beam is well visible (experiment and photo MG).

4. Red-cabbage juice

A weak point of the "pink glasses" analysis from par. 1. is that it does not fall into the methodology of the modern science, as introduced by Galileo: the experiment should be possible to repeat in any lab and any time. The toys sunglasses were found at some flea-markets so the experiment cannot be done by other researchers. An unexpected solution comes from the red cabbage.

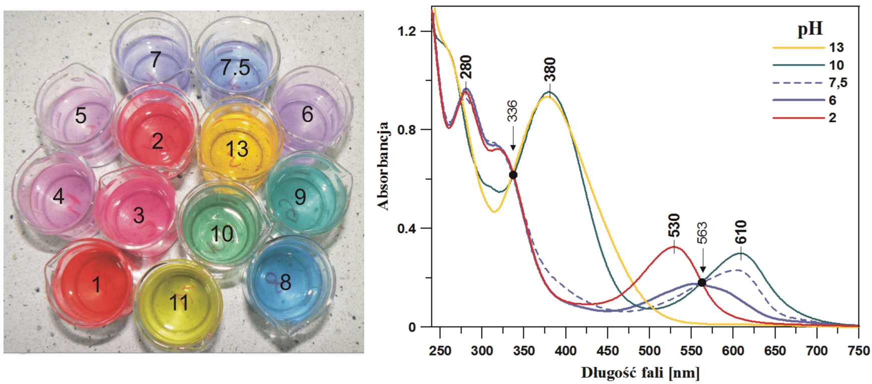

Fig. 5 – Red-cabbage juice at different pH (pH values shown in glasses) and the absorption spectra at selected pH values (experiment and spectra MG).

The Google call "red cabbage chemistry didactics" returns more than 7,000 replies – the red-cabbage juice is commonly used in school didactics (especially in USA) as the pH indicator. In spite of the richness of pH indicators, see for ex. [11], little is known on their optical properties. The red-cabbage juice (a water extract from chopped leaves) shows a wide range of colours under different pH: from intense red at pH=1 to intense yellow at pH=13, passing through different shades (ita. *sfumature*) of pink and bluish, see left panel in fig. 5.

The analysis of absorption spectra shows that in the VIS range three absorption bands appear. The first one visible only in very acidic solutions, at pH=1-3 is located at about 530 nm and it disappears at higher pH. Up to pH=10 a band at 610 nm is active and in very alkaline solutions (pH=13) the juice absorbs only in the violet (and UV), see fig. 5 right panel. The two points of intersections (so called isosbestic points) indicate co-existence of at least three forms of the dye. These forms transform from one into another by chemical changes in some chemical sub-groups, i.e. attaching OH or detaching electrons O/O^+ in some positions of the complex organic structure. In this way the electronic levels for the optical absorption change, see for ex. [12] for detailed explanations of the chemistry of typical biological dyes.

In red cabbage this is anthocyanin subject to changes of the structure. For the colour analysis it is interesting to compare the transmission spectra rather than absorption spectra. We do so in fig. 6. The analysis is surprising: the juice acts as (100% red & orange + 80% violet) filter at pH=2, as (100% red + 80% green) filter at pH=10 and so on. In fact, the red colour at pH=2 even for naked-eye does not seem to be "Newton's red" and the colour at pH=13 is rather a "non-violet" shade than the sunny yellow.

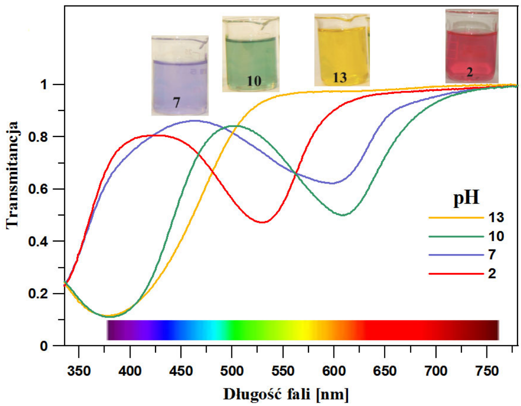

Fig. 6 – Transmission *T* spectra derived from absorption (*A* = -log *T*) in fig. 5 for the red-cabbage juice at different pH.

5. Conclusions

The discussion on colours leads to interdisciplinary learning competences in Atomic (and Solid State) Physics, in Chemistry and Biology. The didactical path is long and many-branched but fruitful. From single emission lines in helium we pass to broad absorption spectra in organic dyes. Common efforts of mixed scientific and didactical groups are desirable and next step is Arts [13].

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