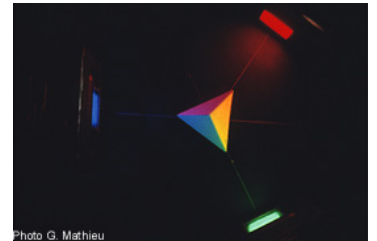




## The role of the thickness of absorbing medium

### Preliminary: recalling some classical rules

Consider the first sheet (I),  
 which outlines the rules of additive colour mixing  
 Ask any question you feel necessary to understand these rules.



#### Sheet I: Additive colour mixing

Separating the various radiations that constitute "white" light gives a "spectrum".  
 The spectrum of visible white light ranges from about  $\lambda=400$  nm to  $\lambda=700$  nm.

( $\lambda$ : wavelength; measured in a vacuum; 1 nm =  $10^{-9}$  m).

The spectrum is here schematically divided into three thirds.



Coloured lights with a spectrum corresponding to a third of the spectrum of white light  
 in long wavelengths appears red  
 in intermediate wavelengths appears green  
 in short wavelengths appears blue



Combining these three lights, in various proportions, results in a large range of colours and can also give white light.

Combining two of these lights in the correct proportion respectively gives a light that is

- yellow, if green light and red light are added
- cyan, if green light and blue light are added
- magenta, if red light and blue light are added



These rules stem from the existence of three kinds of receptors – cones - on the retina and of a complex integration of the corresponding responses in the visual system.

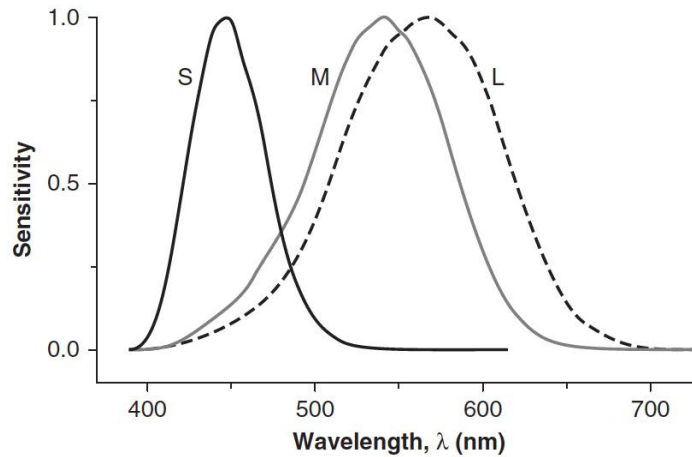
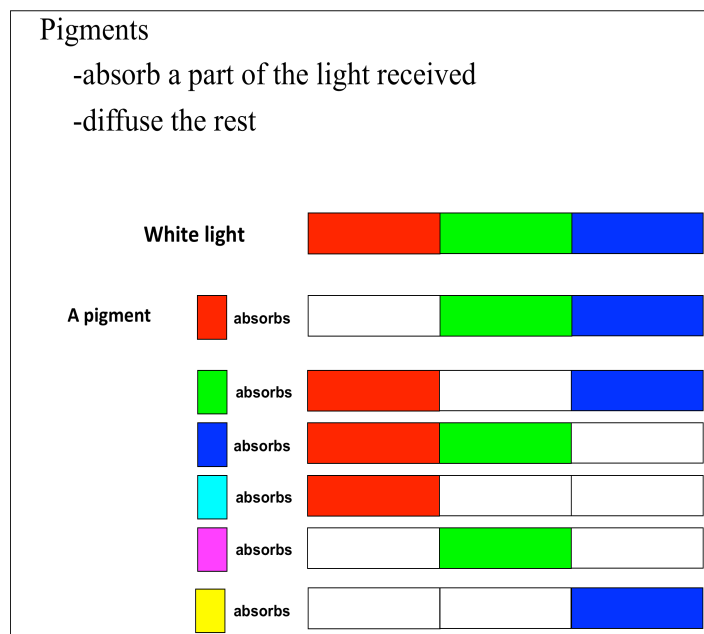


Figure 1. The sensitivity of cones for, respectively, short (S, “blue”), medium (M, “Green”) and long (L, “Red”) from Encyclopedia of Perception E. B. Goldstein (Edt) Sage Publications, Thousand Oaks, 2010.

### Pigments or filters

Pigments and filters absorb some parts of the spectrum of white light.

**Consider the second sheet (II).** Ask any question you feel necessary to understand these rules, which hold for filters as well as for pigments.



Sheet II. The classical rules of the absorbing role of pigments, also valid with filters

**Which operation do you associate to the action of filters: -, +, \*, : ? Explain your reasoning.**

### Activity 1

The reflectance by pigments and transmittance by solid or liquid filters share many characteristics and can be modeled with similar rules. Thus the model in sheet II can be used, as a very preliminary approach, to analyse the absorption of light by a transparent filtering medium.

In order to analyse the role of thickness of the absorbing medium, we made an object like the one in Figure 2.

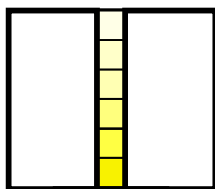


Figure 2. A slide (5cmx5cm) holding a strip made of a series of yellow filters of same material but different thicknesses (one to six times the same value)

The material can be considered as transmitting preferably red and green parts of the spectrum but also other parts of the spectrum of white light, hence the “washed” appearance (low “saturation”).

Using a grating (600 l/mm) like in Figure 3, it is possible to make a spectrum of the light emerging from each part of this composite filter illuminated with white light.

For one layer, the spectrum is analogous to the curve in Figure 4a. **What do you predict** the spectra of others parts (two layers, three layers, ...) will be like?

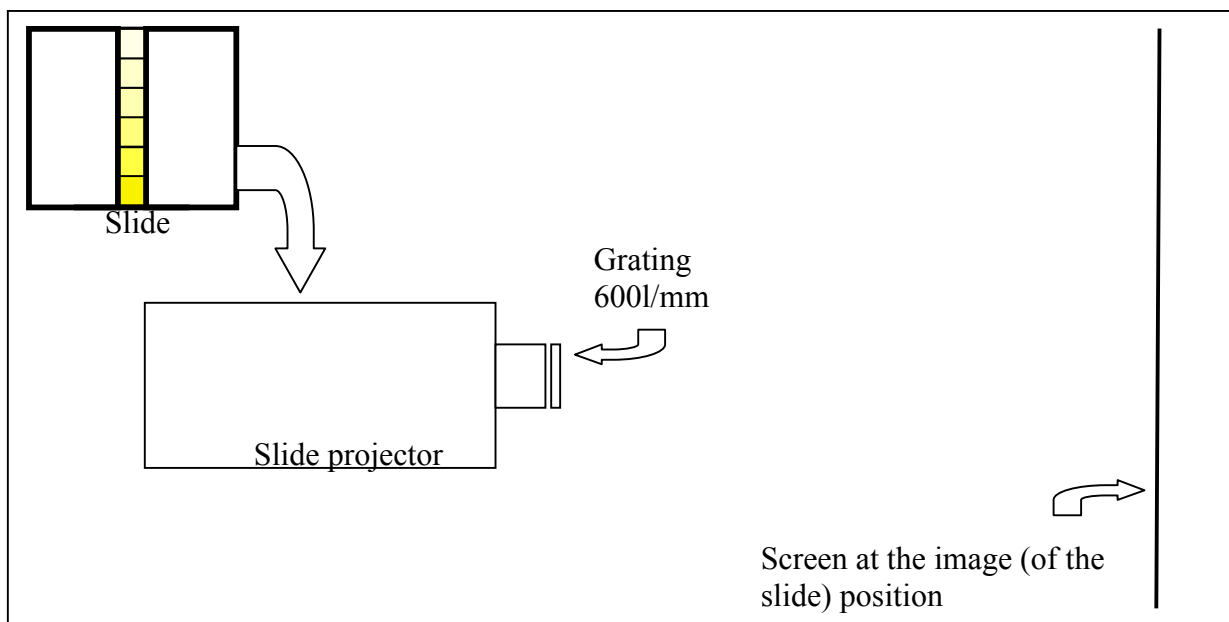


Figure 3 Sketch of the setting used to make the spectra shown in Figure 5

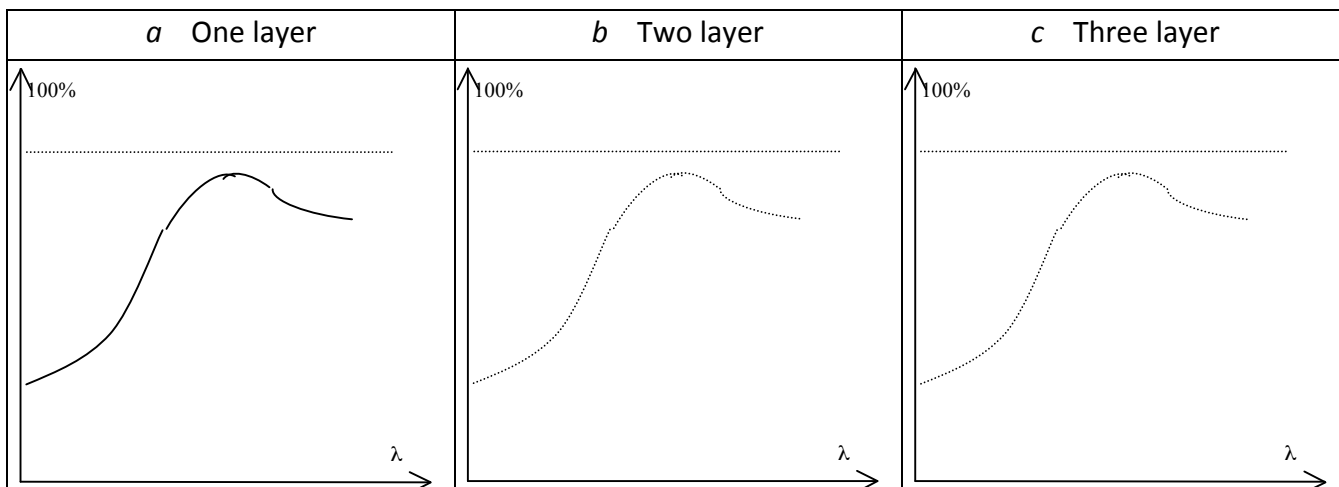


Figure 4. Given the transmission spectrum obtained with one layer (Fig. 4a), what is the shape of the transmission spectrum in the other cases, compared to the case in *a* (repeated in dashed line as a reference in *b* and *c*)?

**Explain your answer**

## Activity 2

The **spectra** discussed in activity 1 are now observed. The photos in Figure 5 give an idea of the outcome of this experiment, while introducing some deformation.

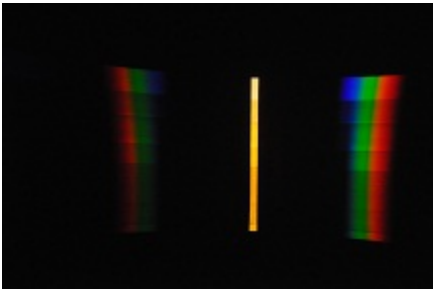
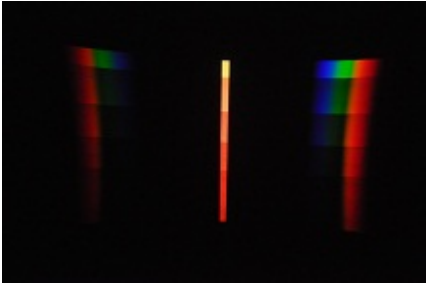
Yellow	
Magenta	

Figure 5. Photos of spectra obtained for two slits equipped with transversal strips (resp. yellow and magenta) of increasing thickness: one, two, three, ... layers superposed. (Grating 600 l/mm)

### Compare the experimental results with your predictions

**Explain possible differences with your predictions** (hint: consider the effect of successive multiplications of incident intensity of light by a large coefficient v/s a small coefficient).

**Represent graphically how the colour of the emerging light changes according to the number of layers superposed. Propose a possible explanation for the observed dependence of colours of the emerging light on the number of layers.**

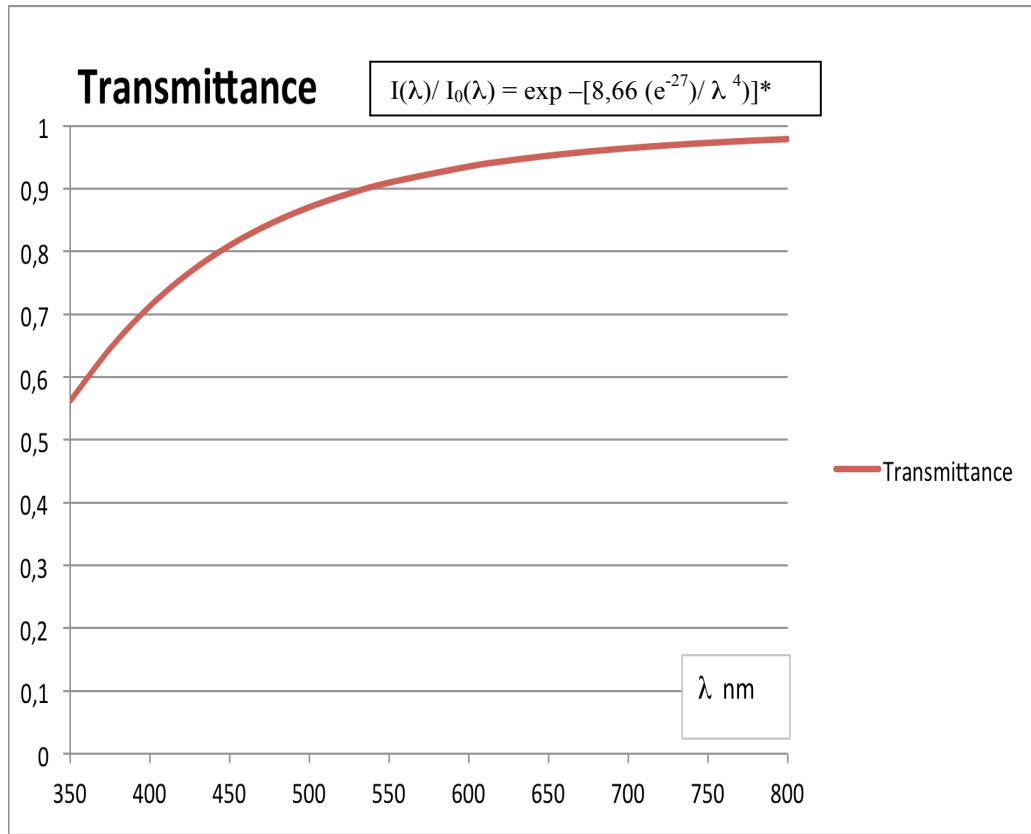
### **Activity 3**

#### **Some analogous situations**

**Can you think of other cases in which different thicknesses of a gas or a liquid produce the same effect?**

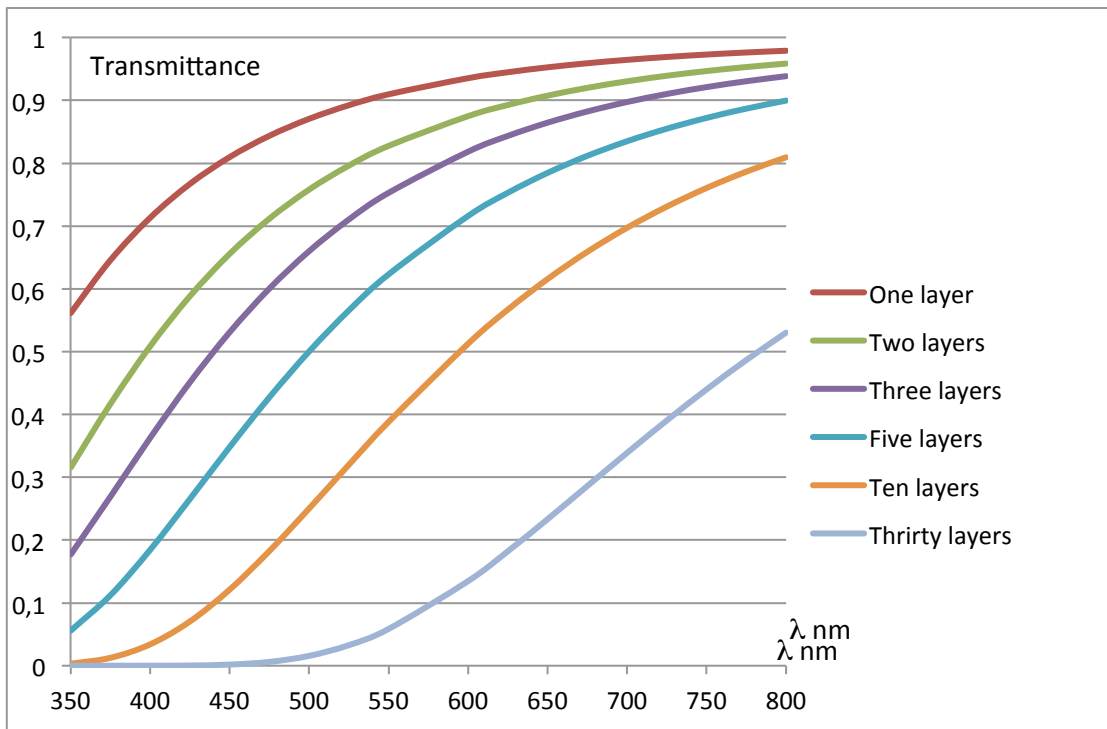
**How can you adapt the preceding analysis to a gas?**

**Transmittance of a “molecular” atmosphere (air only) for sun at Zenith\***



\* Figure 6 : This diagram has been made drawing on: Vollmer, M. & Gedzelman, S.D. (2006) p. 300.

Using this model, draw the transmittance curves of two, three, four, five, six successive layers of such an atmosphere (“One layer” means: a thickness of atmosphere like when the Sun is at zenith), and predict the corresponding colours. Explain your answers.



“One layer” means: a thickness of atmosphere like when the Sun is at zenith.

The goal is now to interpret the outcome of **an experiment with a particular liquid: pumpkin seed oil**. A transparent cylindrical recipient is placed on a overhead projector. According to the height of the liquid in the recipient, the observed colour passes from yellow to brownish red.

**How to interpret the various colours observed?**



**Consider the absorbance and transmission spectra** shown in a paper about pumpkin seed oil:

Kreft, S. & Kreft, M. 2007. Physicochemical and physiological basis of dichromatic colour. *Naturwissenschaften* 94, 935-939.

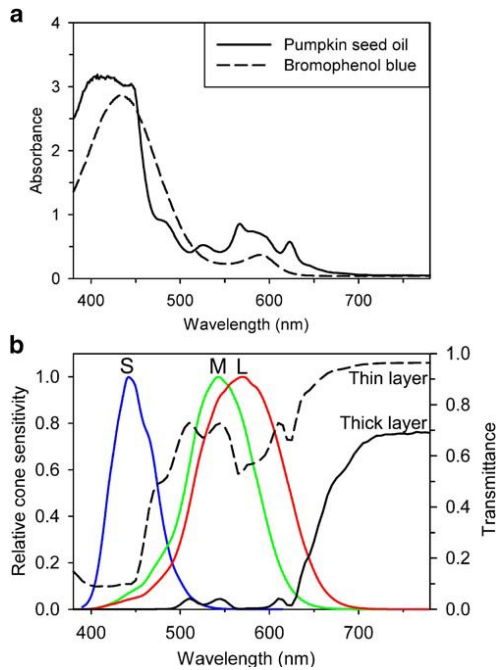


Fig. 2 Absorbance and transmission spectra of the pumpkin seed oil and the cone sensitivity functions. a Absorbance spectra of the pumpkin seed oil (solid line) and the aqueous solution of bromophenol blue (dashed line). Both substances display dichromatic properties due to one wide shallow local minimum around 540 nm and one narrow deep local minimum above 650 nm on the absorption spectra. b Transmission spectra of pumpkin seed oil in thin (dashed line) and thick layer (solid line), and the normalized long-wavelength (L), medium-wavelength (M) and short-wavelength (S) human cone sensitivity functions (three solid lines; Stockman and Sharpe 2000). Both transmission spectra were calculated from the same absorption spectrum measured in thin layer (presented in a). A transmission spectrum for thin layer was calculated directly from the absorption spectrum, while a transmission spectrum for thick layer was calculated from the absorption spectrum after its multiplication by factor 10.

**A very simplified model can help understand observations.**

Figure 7 shows the transmittance of a thin layer of a liquid. This curve is inspired by the one shown in Kreft & Kreft's Figure 2b.

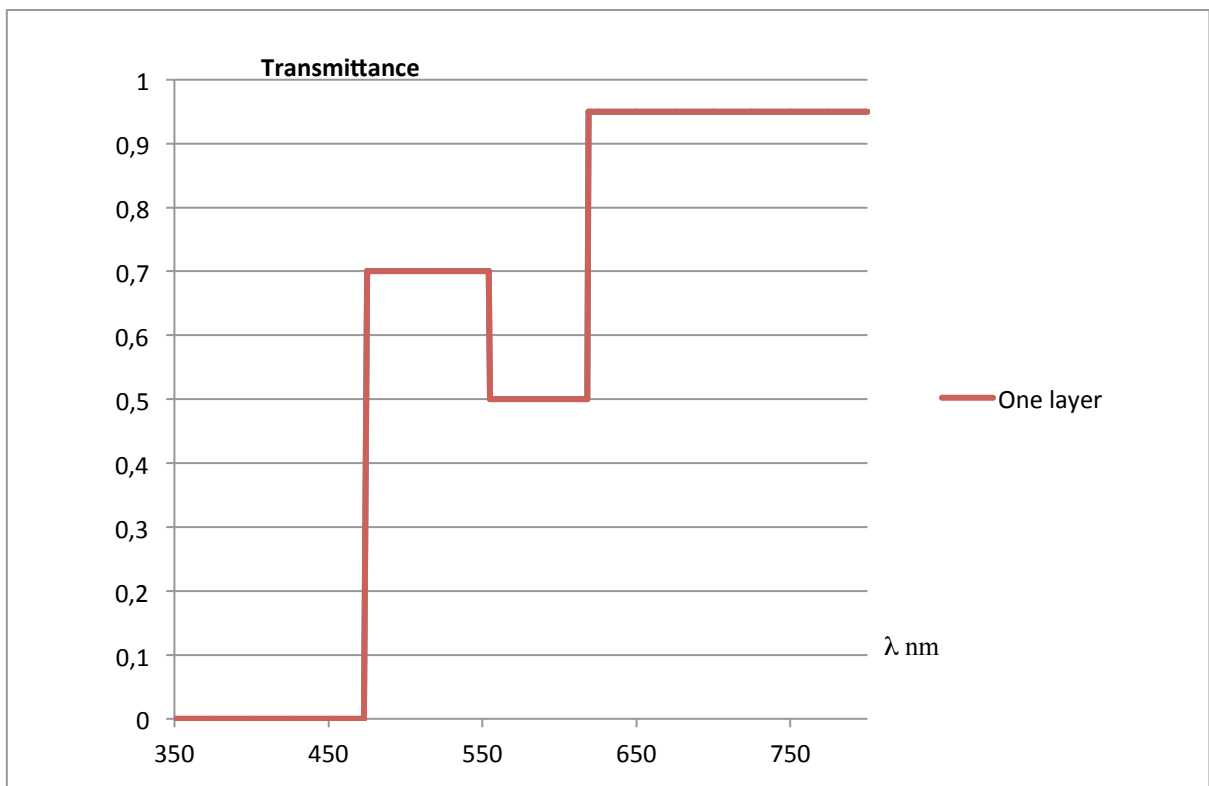
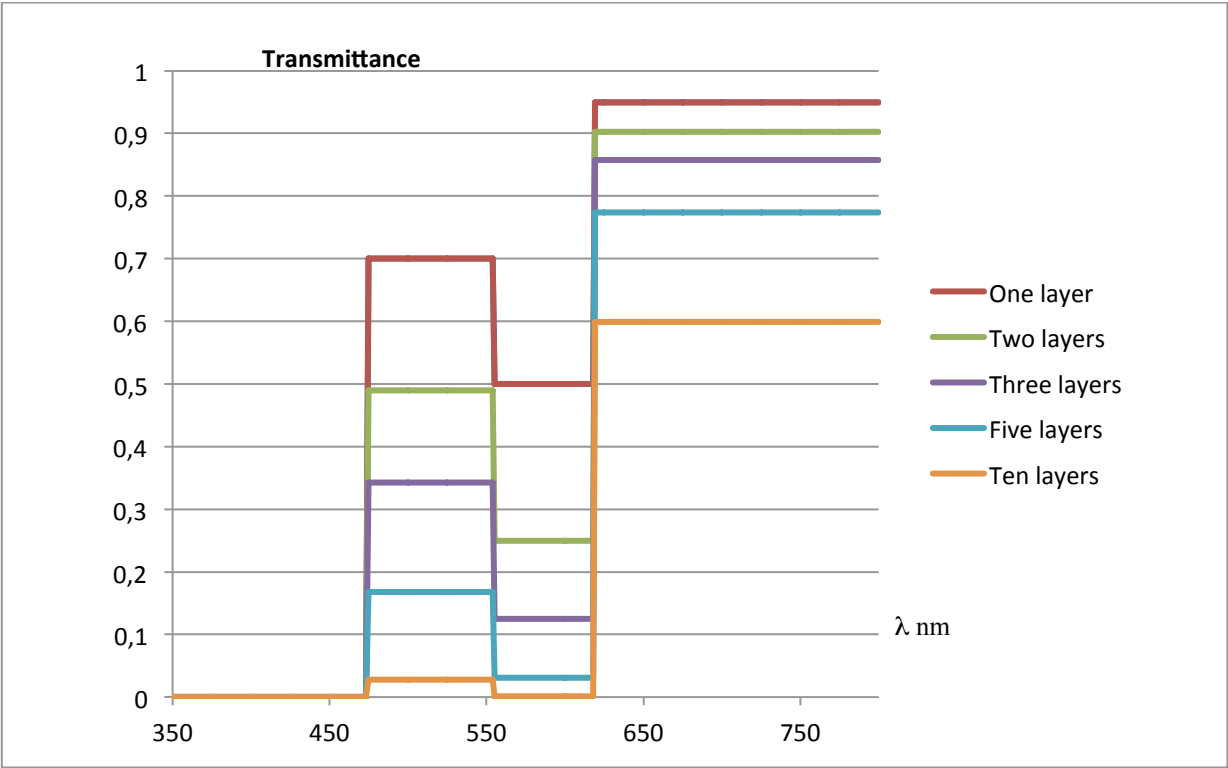
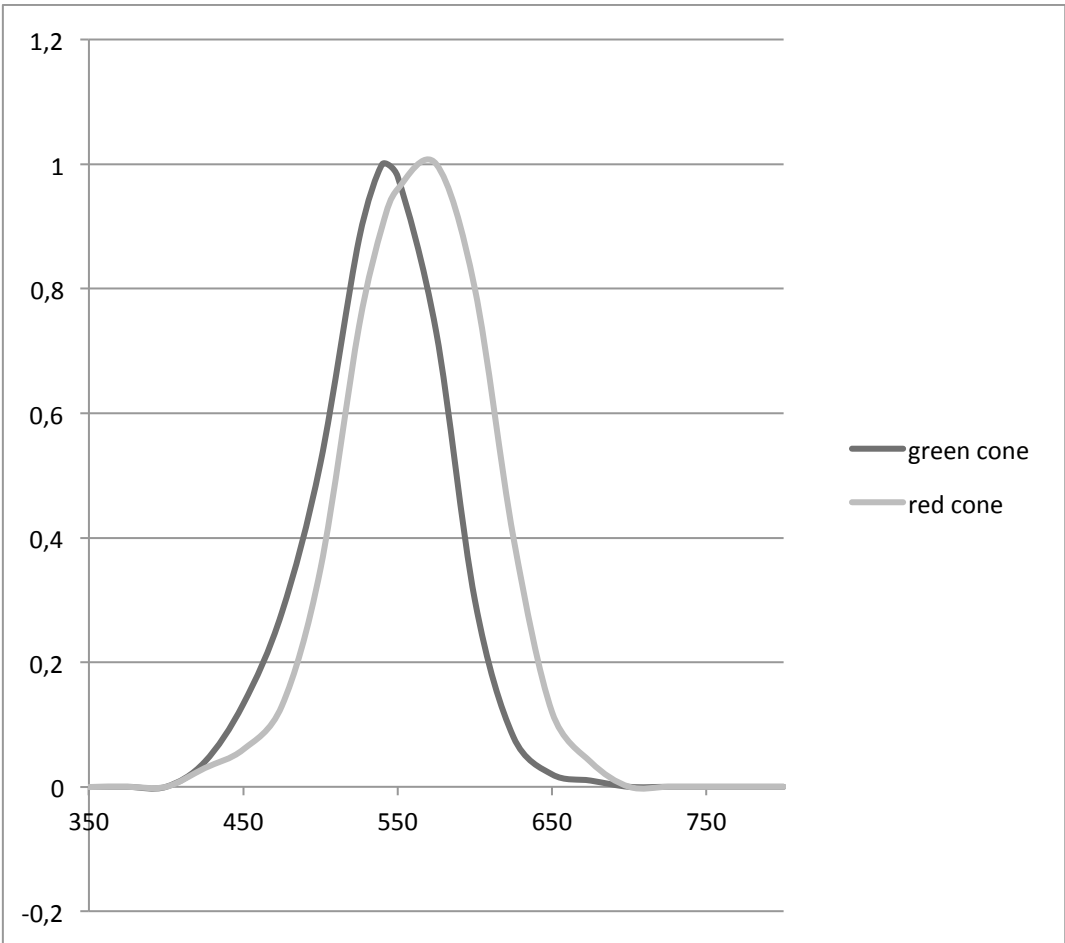


Figure 7. Transmittance of a thin layer of pumpkin seeds oil. This curve is inspired by the one shown in Kreft & Kreft’s Figure 2b.

Using this model, draw the transmittance curves of two, three, four, five, six successive layers of this liquid, and predict the corresponding colours. Explain your answers.



**Reminder: Sensitivity curves of “red” and “green” cones (same scale as the transmission curves above)**



## Activity 4

### Conceptual generalisation

**Can you explain in words in which case an extensive physical quantity changes in space or time according to an exponential decreasing function?**

**Consider for instance the case previously analysed:** For a given objet (e.g. liquid in a recipient of thickness  $L$ ), the spectral density of the emerging light writes  $i_{\lambda}(L) = i_{\lambda}(0) e^{-\mu_{\lambda}L}$

**Which** of the quantities involved in this relationship do you consider as **characteristic of the physico-chemical composition of the solution?**

**This quantity is the absorbance of the solution.**

---

### Final comments

What have you learned?

What idea stayed in your mind after this workshop, that would you like to discuss?

---

### References

- Chauvet, F. 1999. STTIS Project, *Colour sequence* University " Denis Diderot ", LDAR (Laboratoire de didactique André Revuz); and STTIS (Science Teacher Training in an Information Society) web sites: (retrieved 1.7.2010): [http://www.lar.univ-paris-diderot.fr/sttis\\_p7/color\\_sequence/page\\_mere.htm](http://www.lar.univ-paris-diderot.fr/sttis_p7/color_sequence/page_mere.htm) or <http://crecim.uab.cat/websttis/index.html>
- Kreft, S. & Kreft, M. 2007. Physicochemical and physiological basis of dichromatic colour. *Naturwissenschaften* 94, 935-939.
- Planinsic, G. 2004. Color Light mixer for every student, *The Physics Teacher*, 42,138-142
- Planinsic, G. & Viennot, L. 2010. *Shadows: stories of light*. [http://education.epsdivisions.org/muse/example-shadows-documents/SHADOWS\\_stories\\_of\\_light.pdf](http://education.epsdivisions.org/muse/example-shadows-documents/SHADOWS_stories_of_light.pdf)
- Viennot, L. & de Hosson, C. 2012. Beyond a Dichotomic Approach, The Case of Colour Phenomena, *International Journal of Physics Education*, 34:9, 1315-1336.
- Viennot, L. 2013. *Absorbance: the role of thickness of absorbing medium*, project More Understanding with Simple Experiments, <http://education.epsdivisions.org/muse>
- Vollmer, M. & Gedzelman, S.D. (2006) Colours of the Sun and Moon: the role of the optical air mass, *Eur. J. Phys.* 27 , 299–309.

EPEC-ICPE, August 5<sup>th</sup>-9<sup>th</sup> 2013 , Prague  
Laurence Viennot, Andreas Mueller  
Gorazd Planinsic and Elena Sassi

Concept driven activities with simple experiments  
a MUSE workshop about selective absorption of light