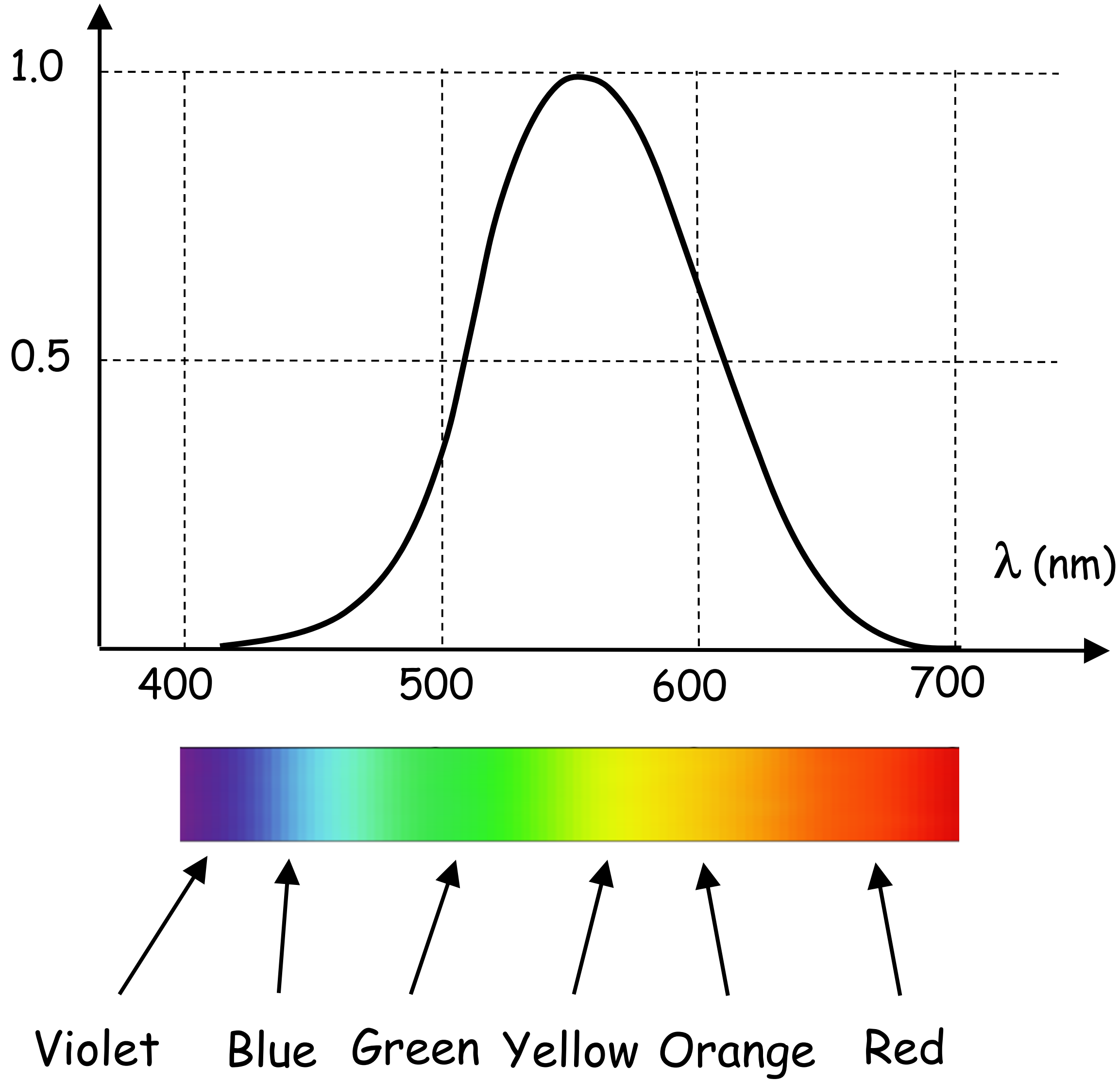
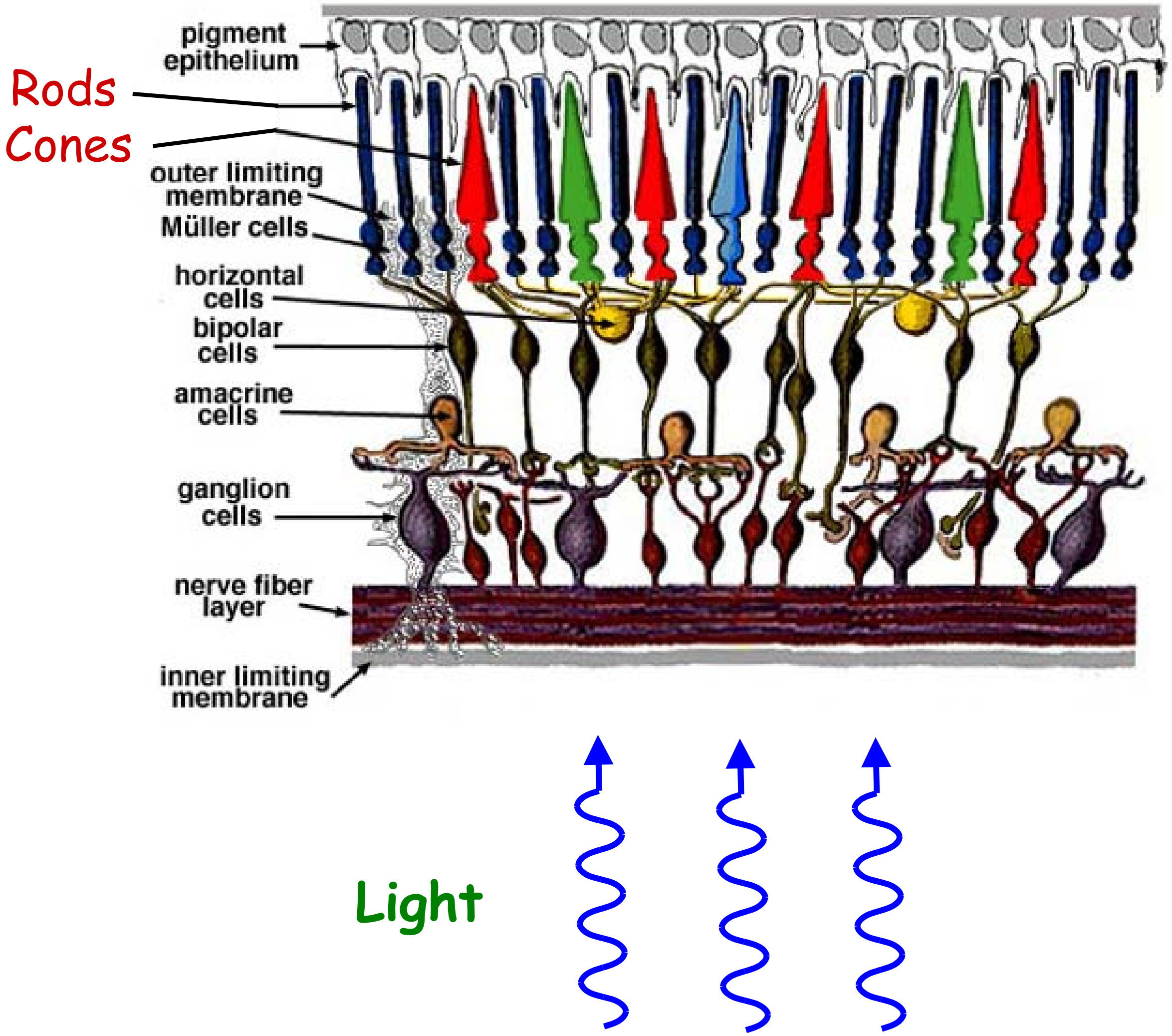
Spectral sensitivity of human eye



Human retina

(Figure credit: University Miguel Hernandez, Spain)

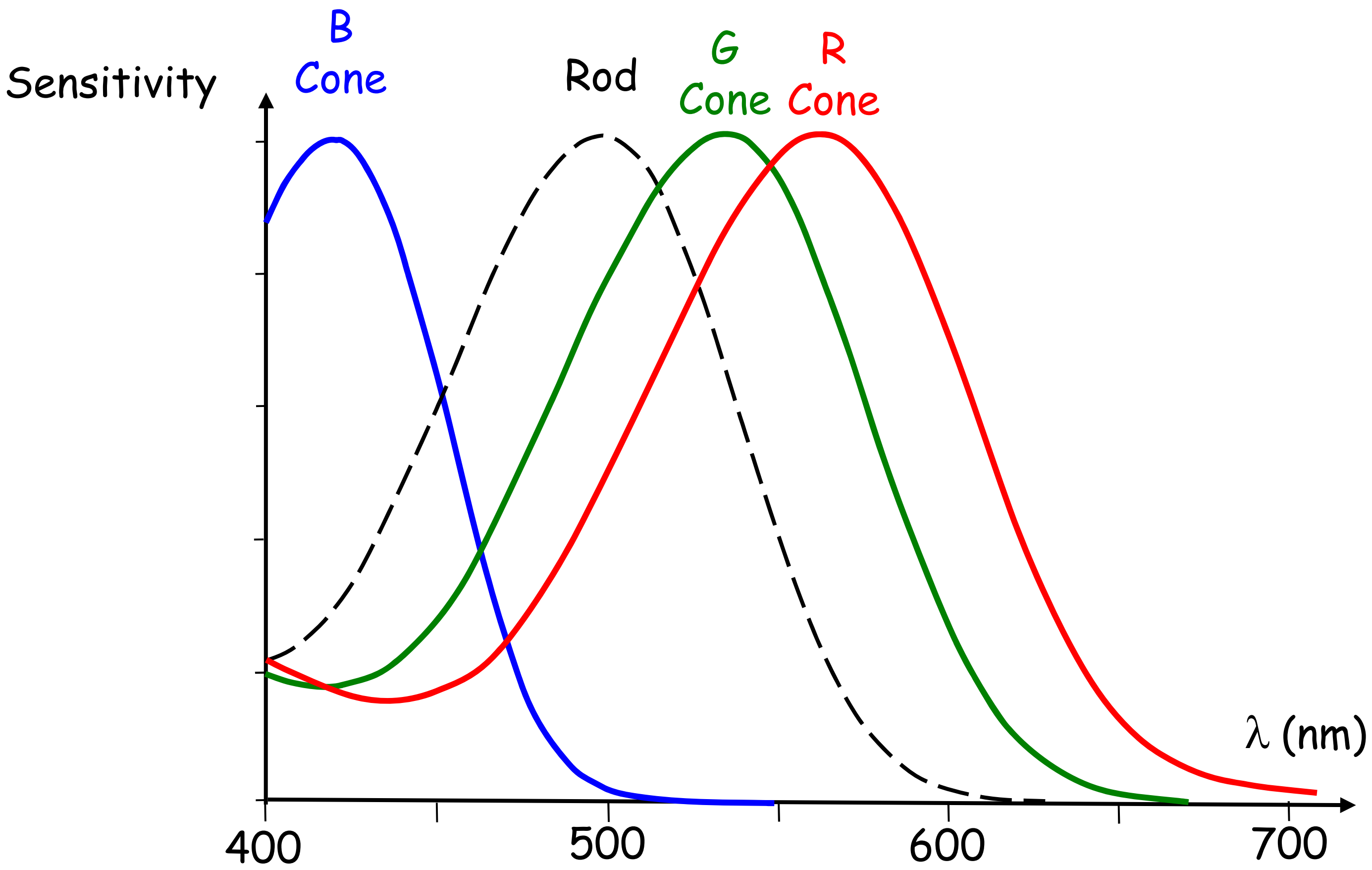


Svenska:

Rods = Stavar

Cones = Tappar

Spectral sensitivity of rods and cones



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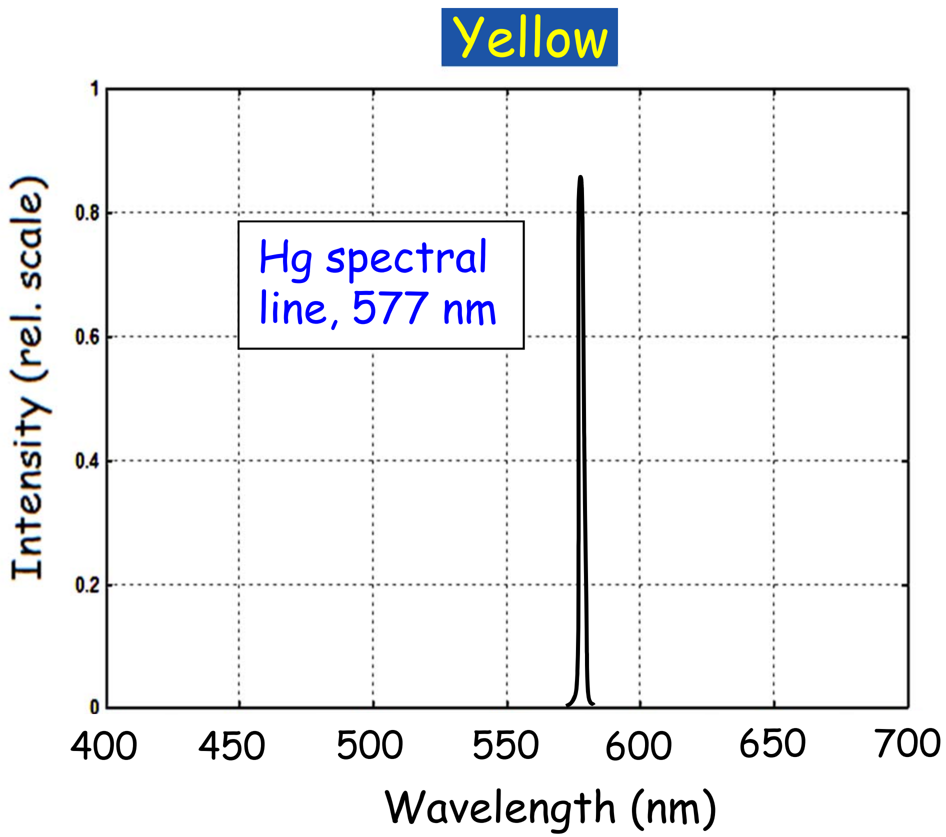
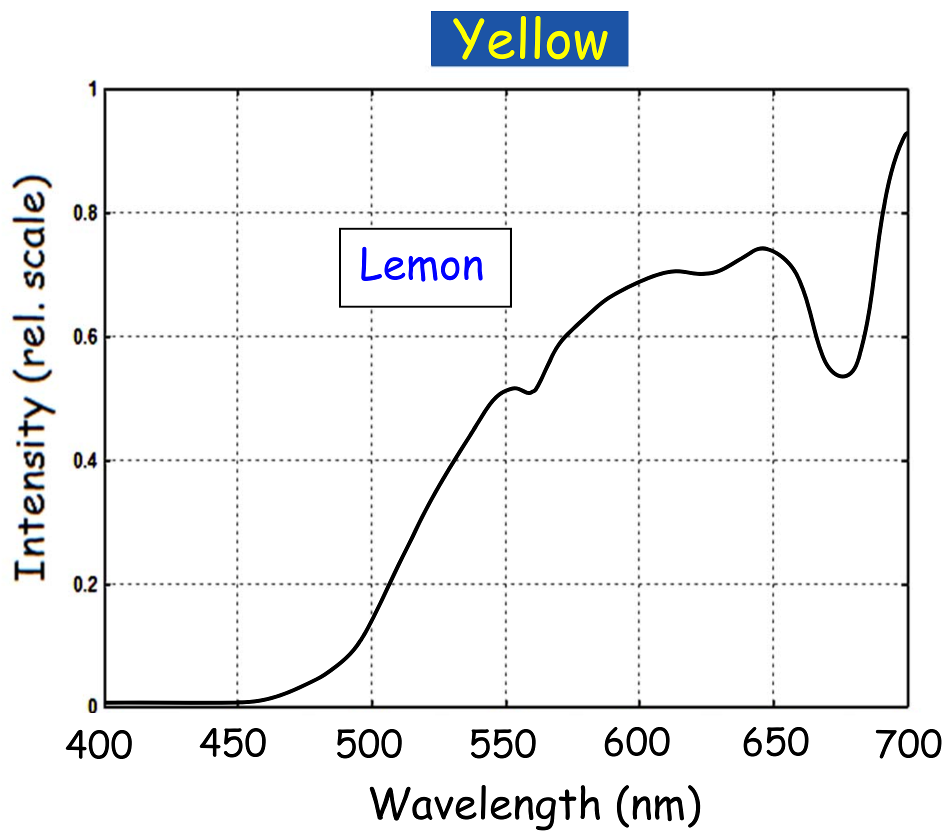
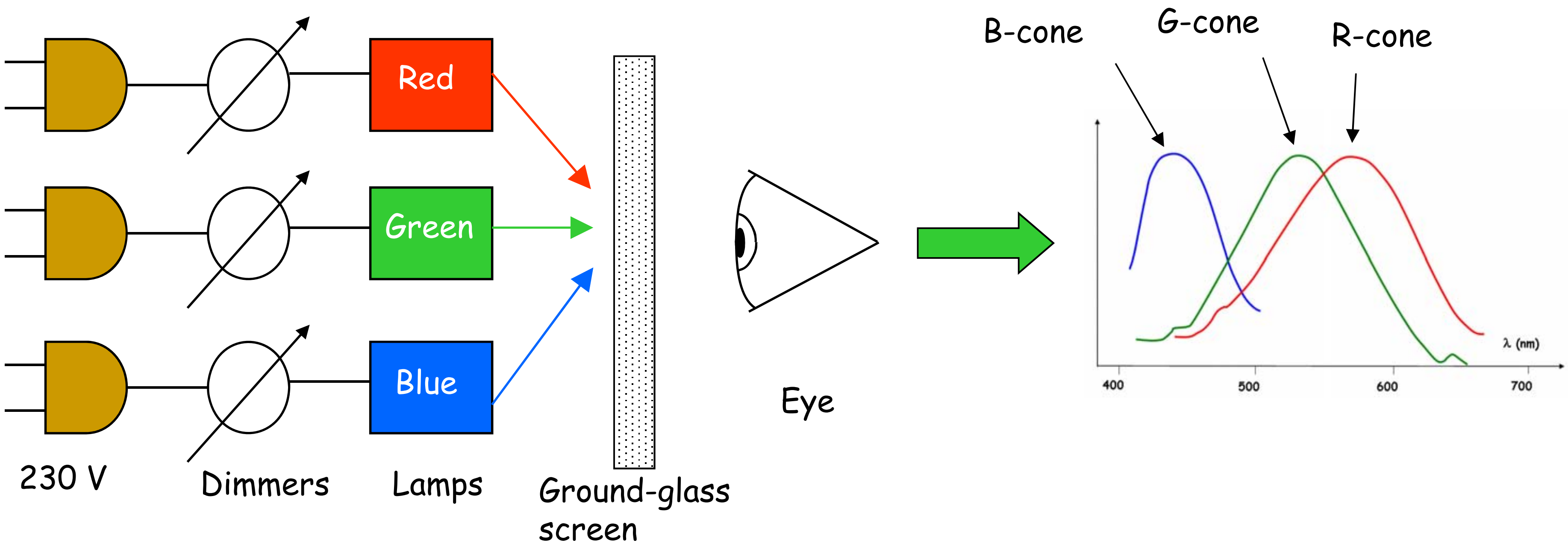
The eye is not a spectrometer





Additive color synthesis



By adjusting the lamp intensities, the output signals from the three types of cone can be controlled.

These signals determine the color and brightness we experience.

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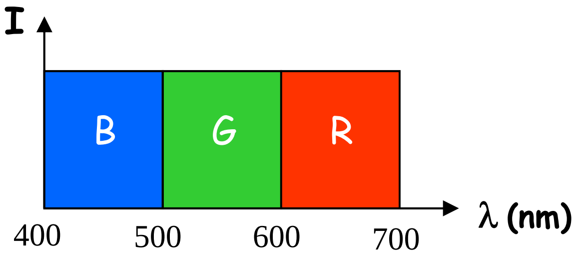
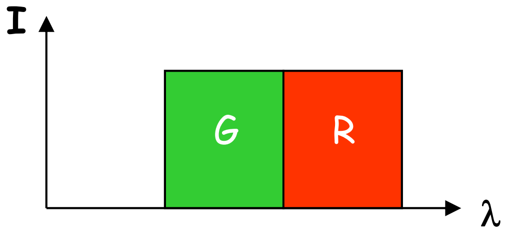
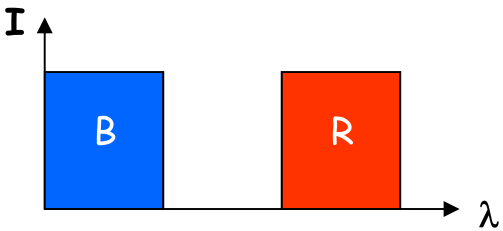
Intensity on retina and color impression



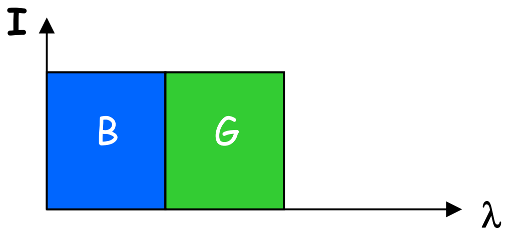
White



Yellow



Magenta
(blue-red)



Cyan
(blue-green)

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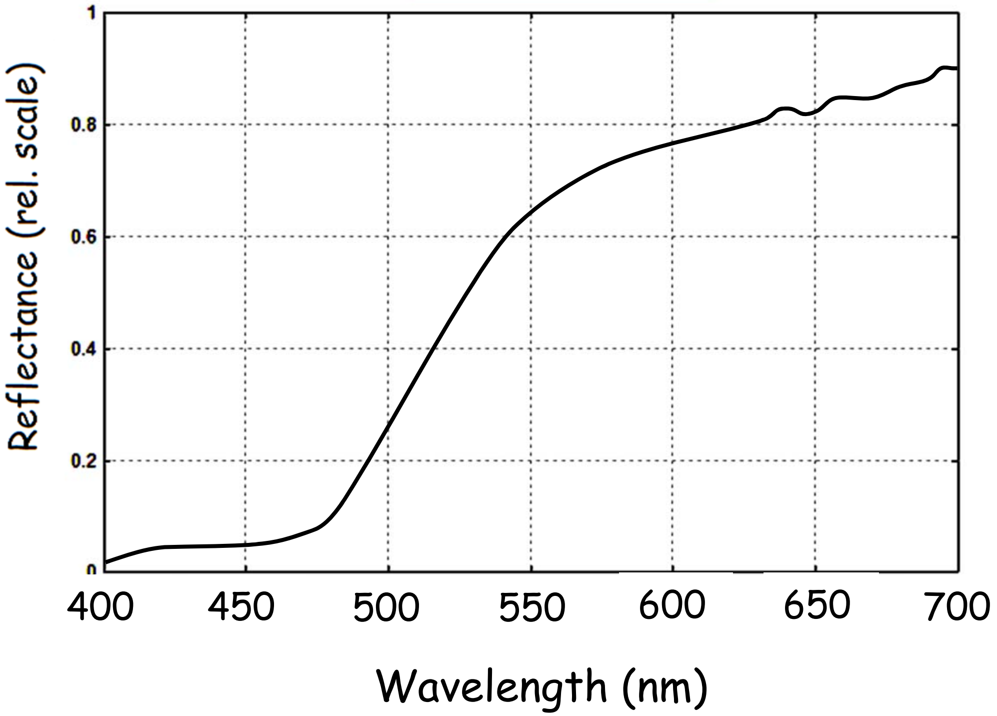
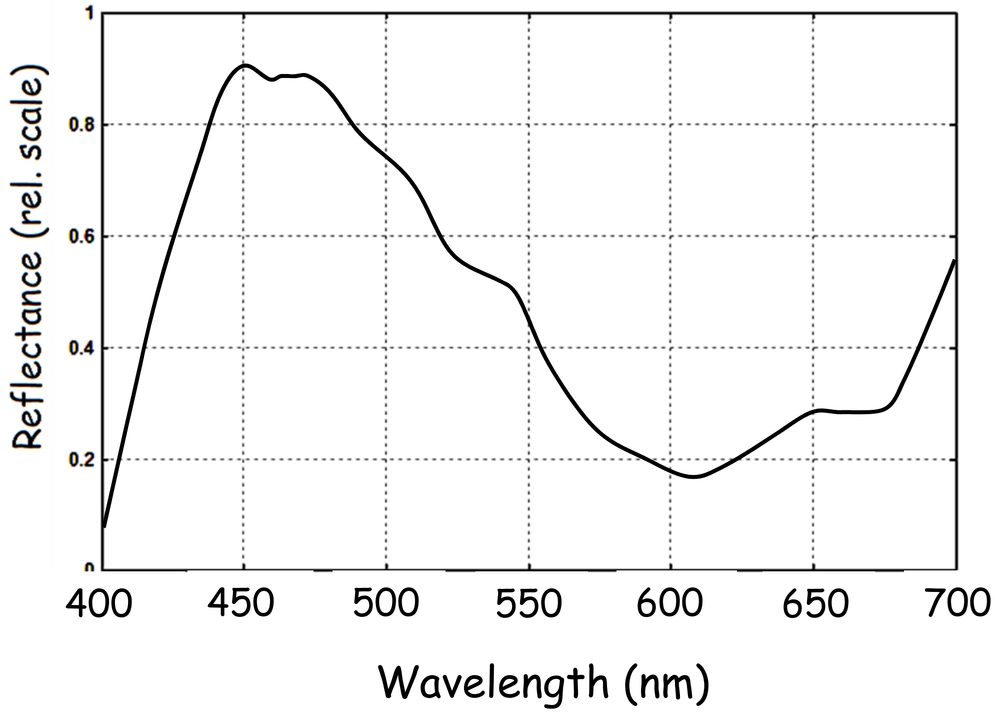
But things are not quite so ideal

(For example inkjet printers)

Yellow ink

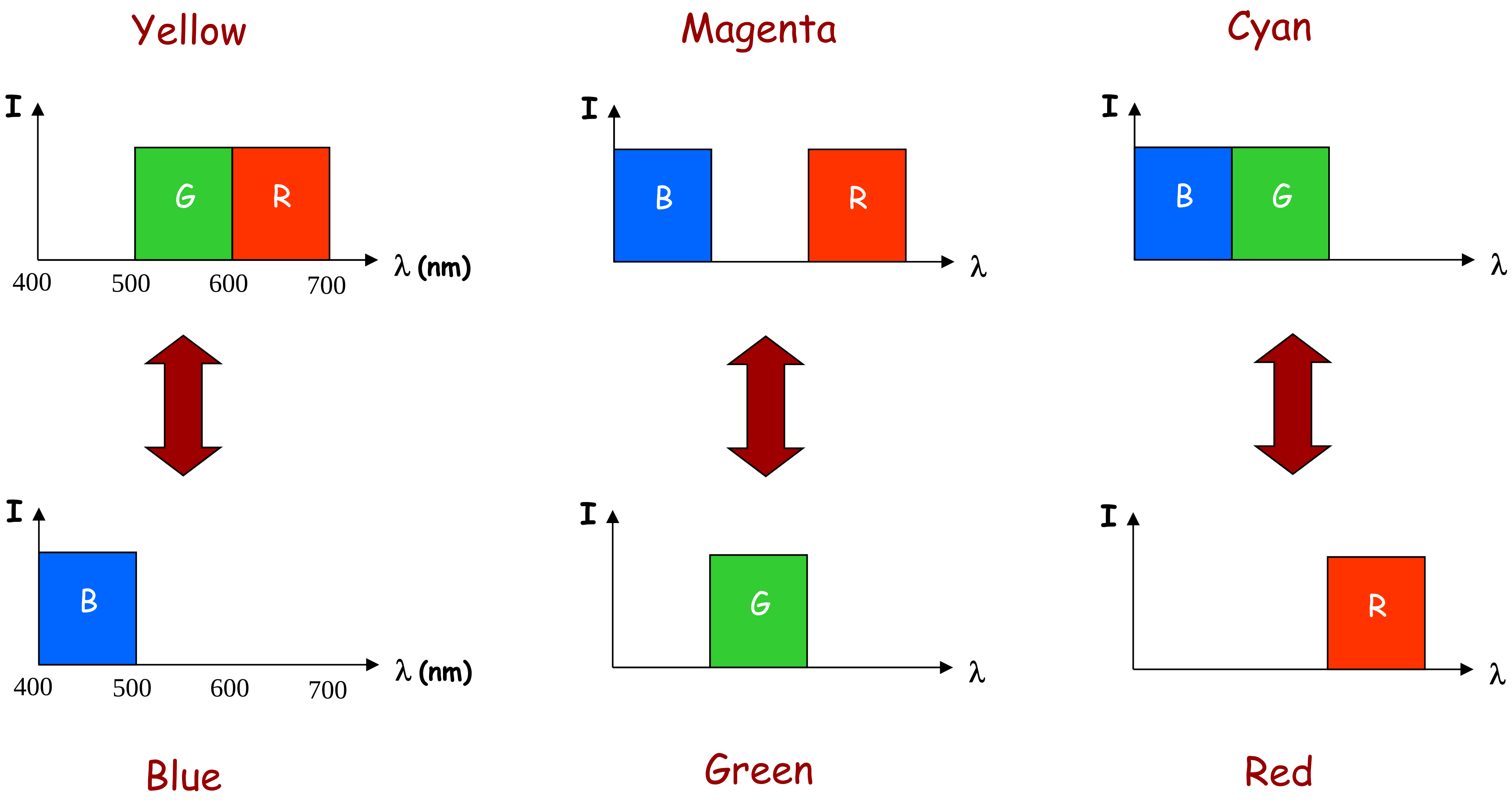


Cyan ink



But it works anyway!

Complementary colors



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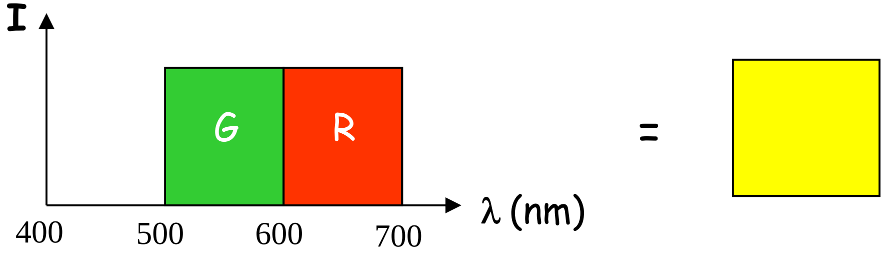
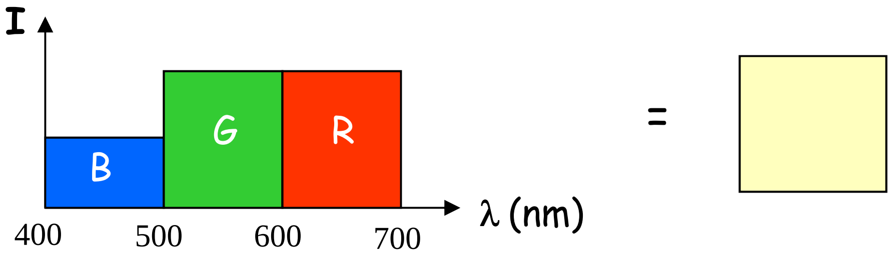
Saturated and unsaturated colors

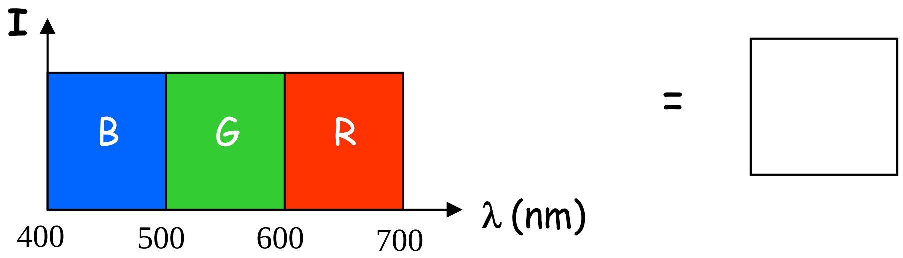
Example:



Saturated yellow
(blue is missing)

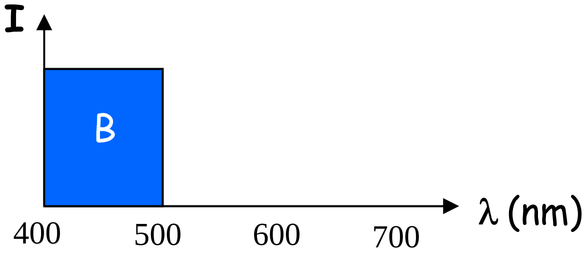


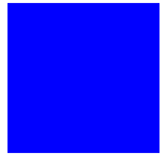
Unsaturated yellow

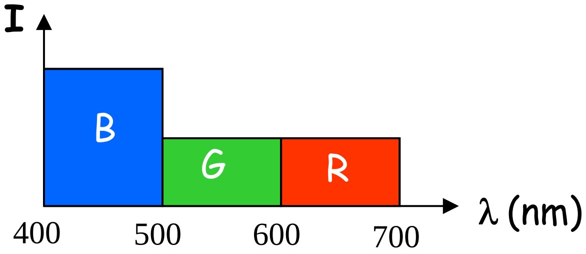


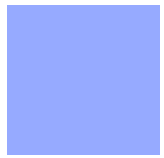
Zero saturation
(white)

Saturated and unsaturated, continued



=  = Saturated blue



=  = Unsaturated blue

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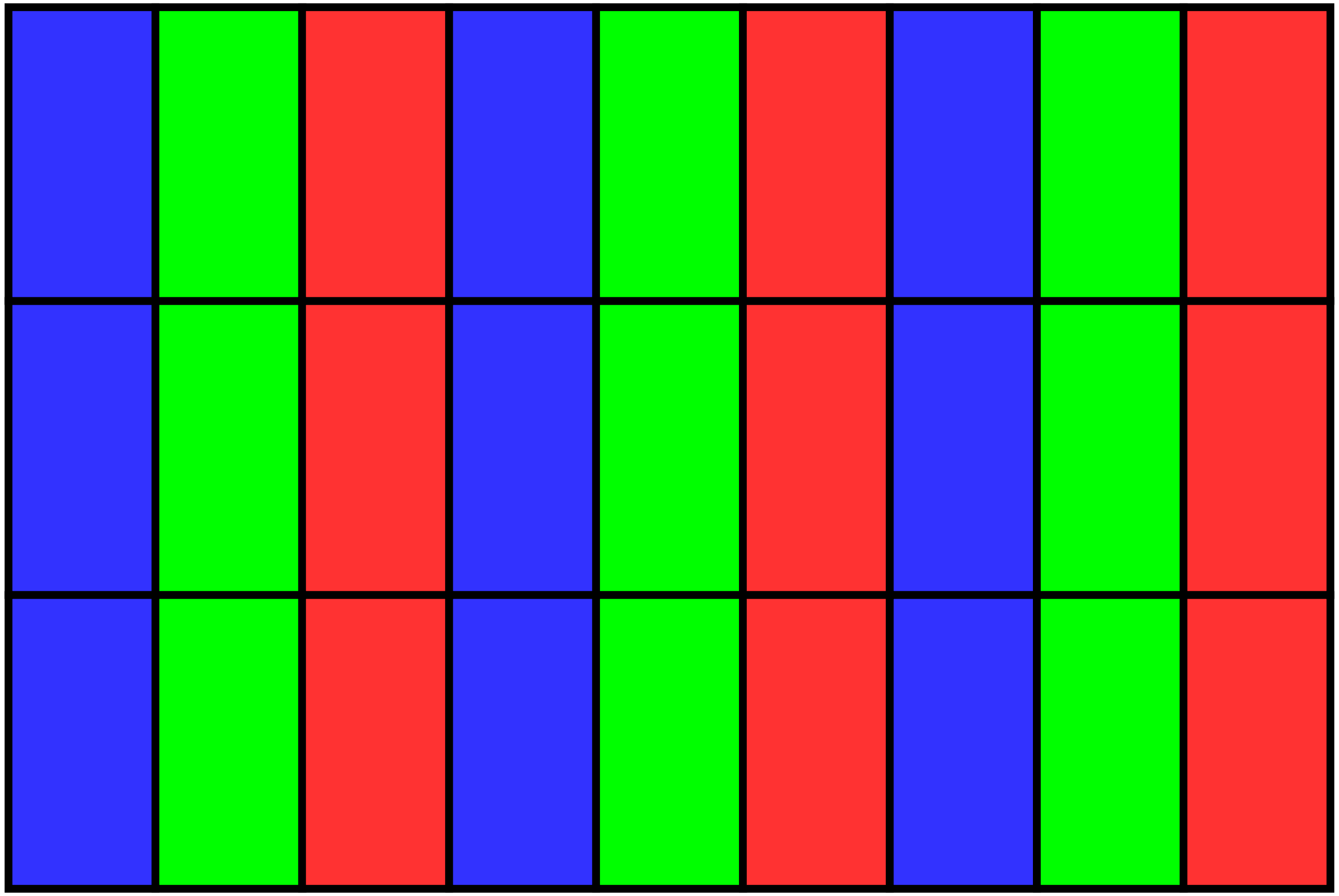
TV/Computer screen mosaic

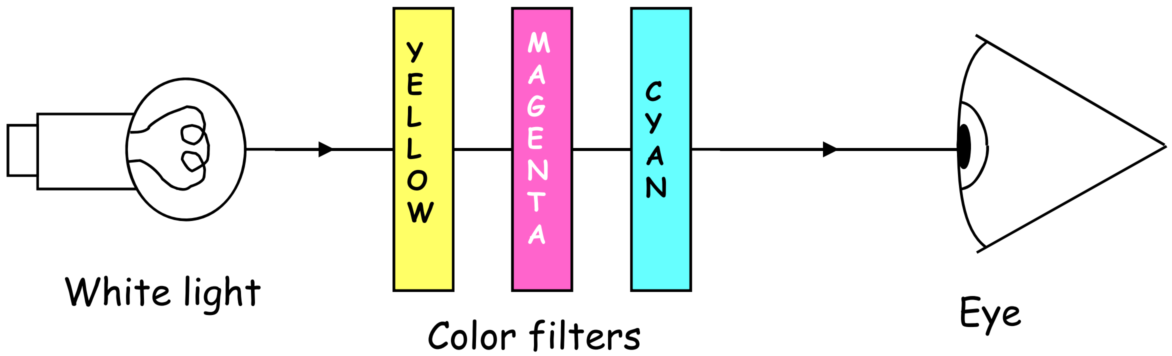


BUT!!

- Color film
- Inkjet printers
- Newspaper/Book printing

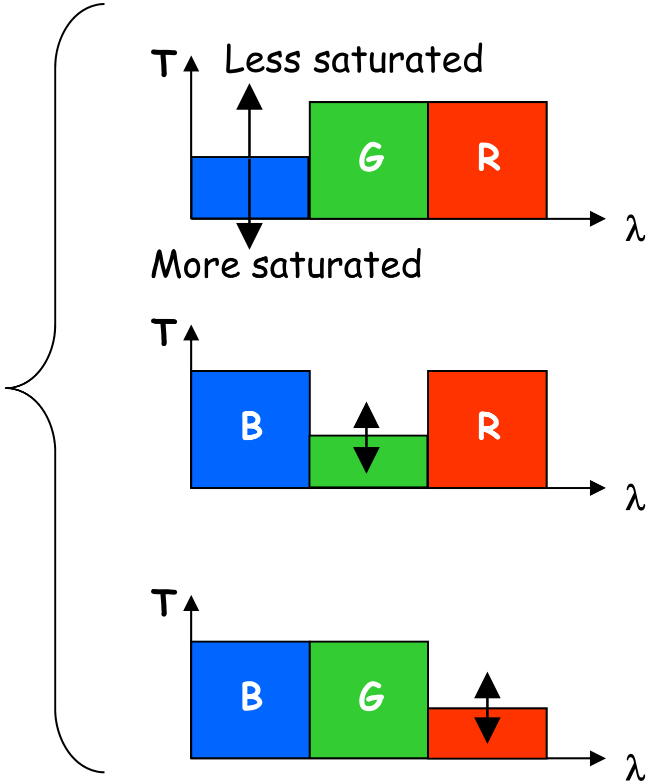
do not work like this!

Subtractive color synthesis



Time for experiments!!

Filter transmission curves

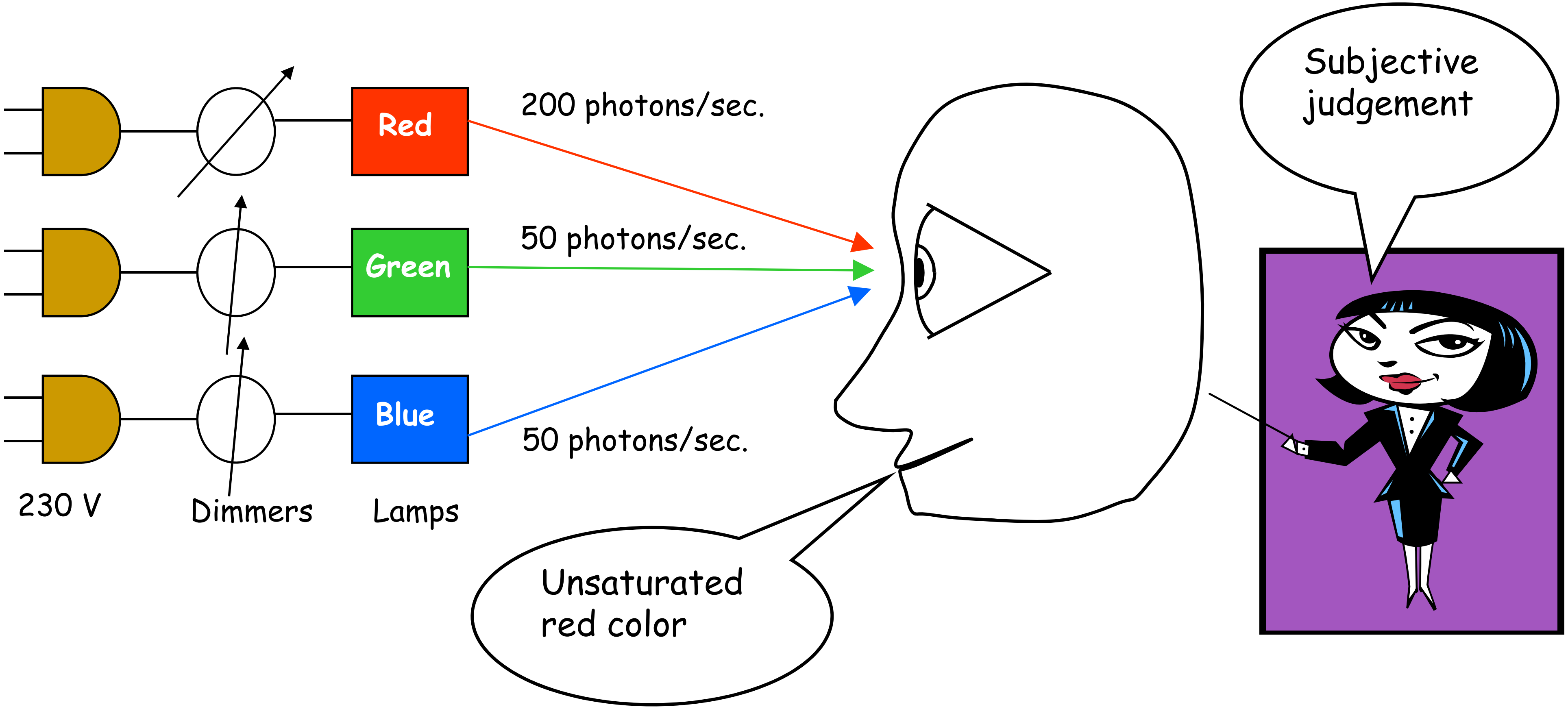


Yellow filter controls the amount of blue

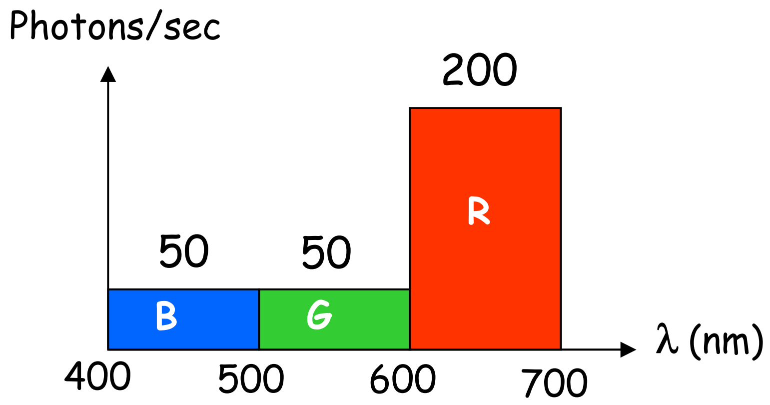
Magenta filter controls the amount of green

Cyan filter controls the amount of red

Color measurement (Lab. 7)



We need to quantify!



(R, G, B) = (200, 50, 50) Photons/sec.

R + G + B = Brightness (uninteresting) → Normalize!

$$r = \frac{R}{R+G+B}; \quad g = \frac{G}{R+G+B}; \quad b = \frac{B}{R+G+B}$$

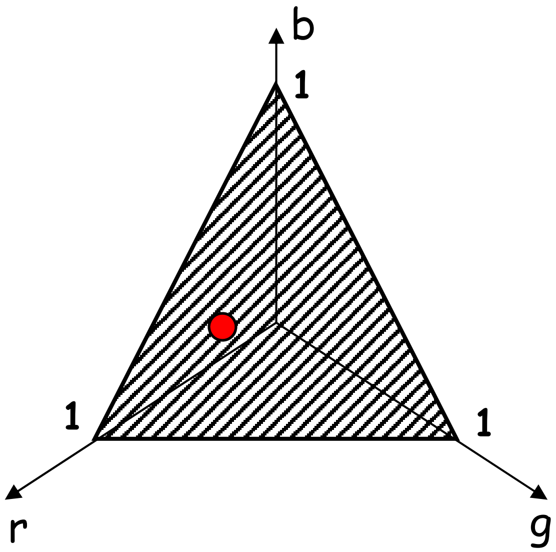
r = 0.67
g = 0.17
b = 0.17

(r, g, b) depend only on the hue and saturation of the color, not the brightness.

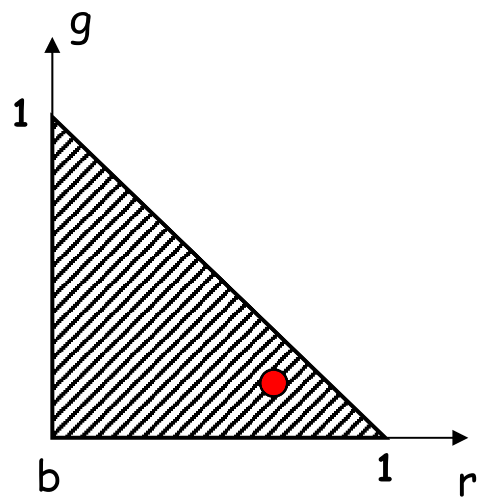
The color triangle

(r, g, b) = (0.67, 0.17, 0.17) represents a point in 3D space

that is always located in the dashed plane (r+g+b = 1)

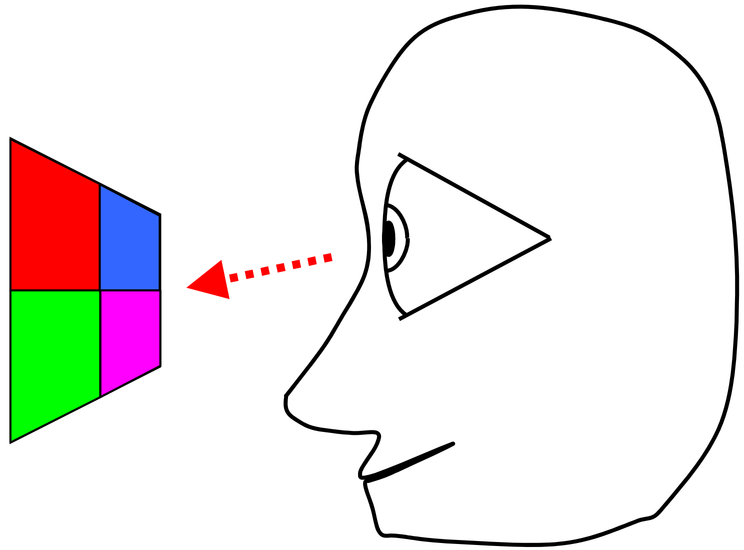


Therefore it is sufficient to look at a projection in the rg-plane.



Fine, but we need to take the human observer into account!

Enter: ”Normal observer”



Then it becomes tricky, see compendium for details

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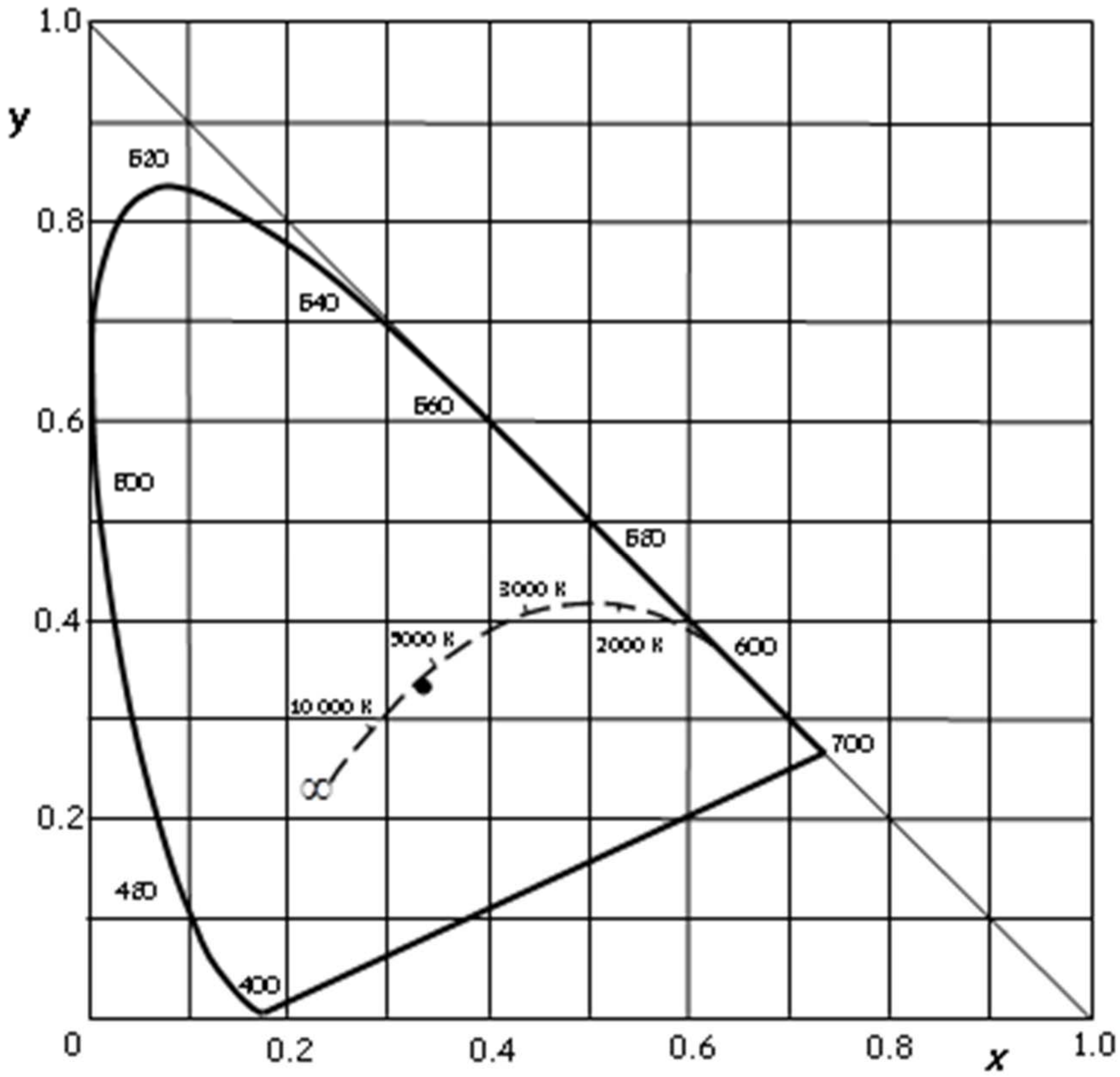
CIE color system



≈ Green

≈ Red

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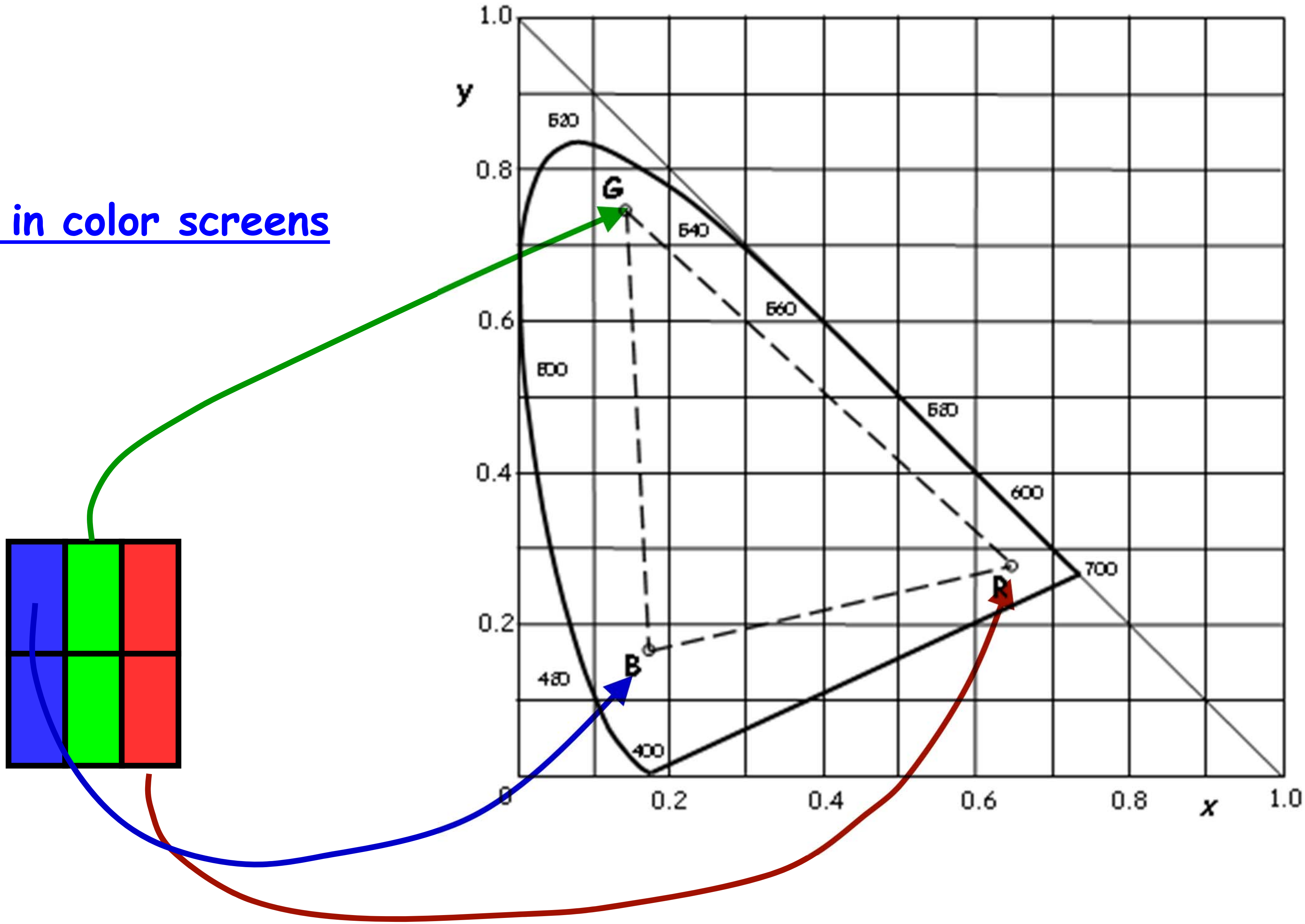
Equipment for measuring CIE color coordinates

Gamut in color screens



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Analog color photography

- Still used by some professional photographers (mostly medium and large format)

- Large film archives exist

- The output medium for digital images is often photographic paper

RGB lasers exposing photographic paper which is then chemically developed

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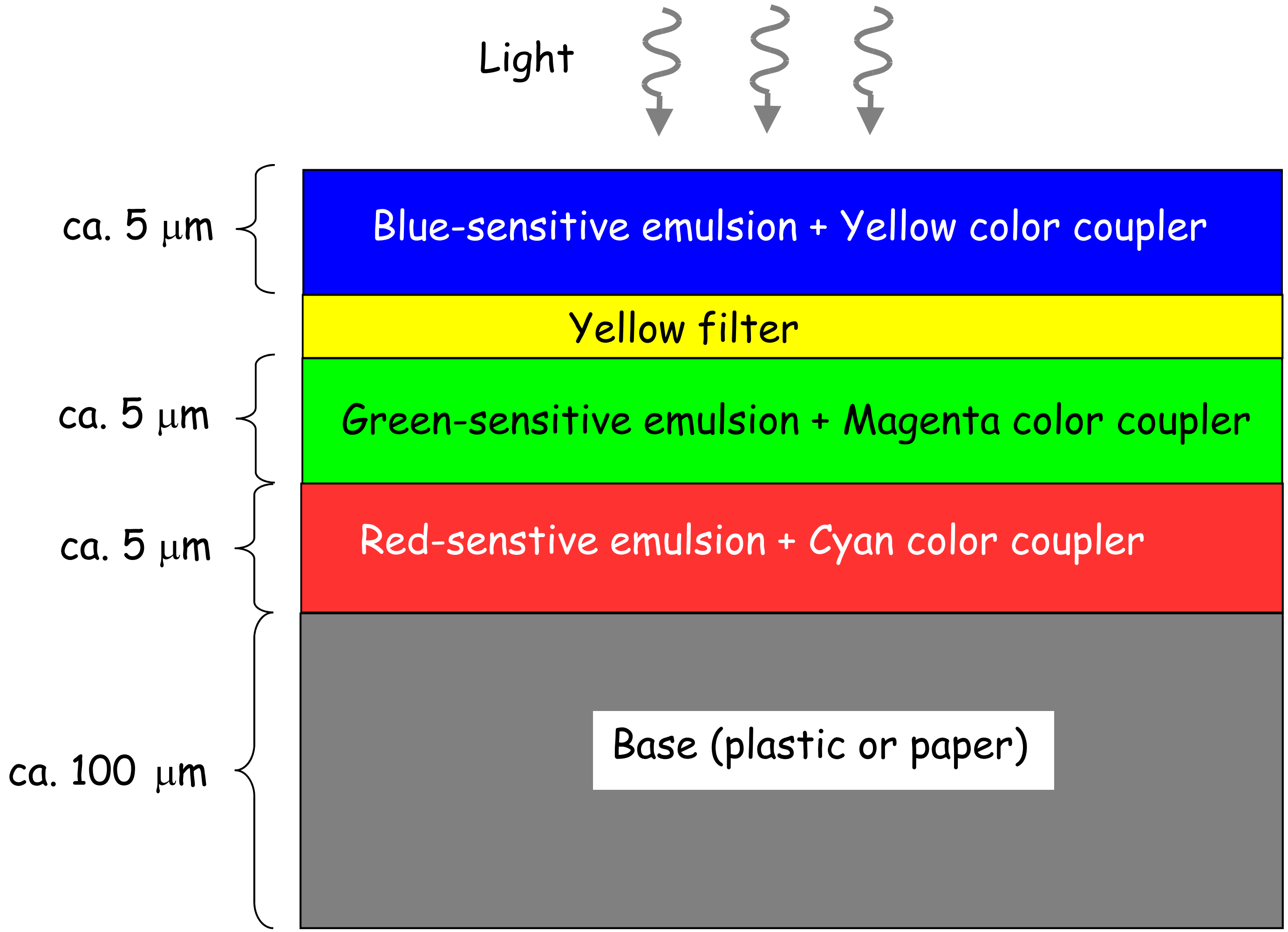
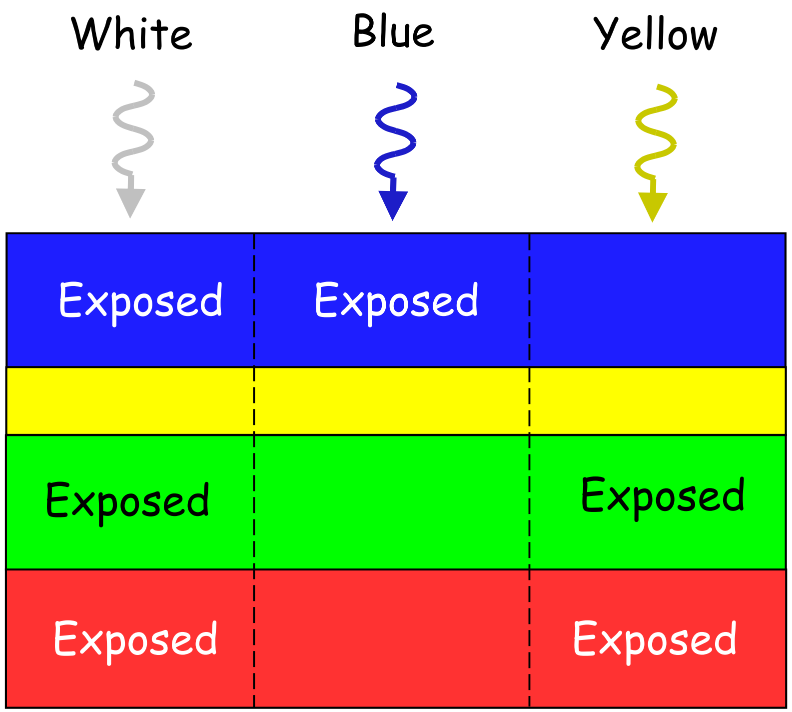
Cross section of photographic film/paper



Exposure & development

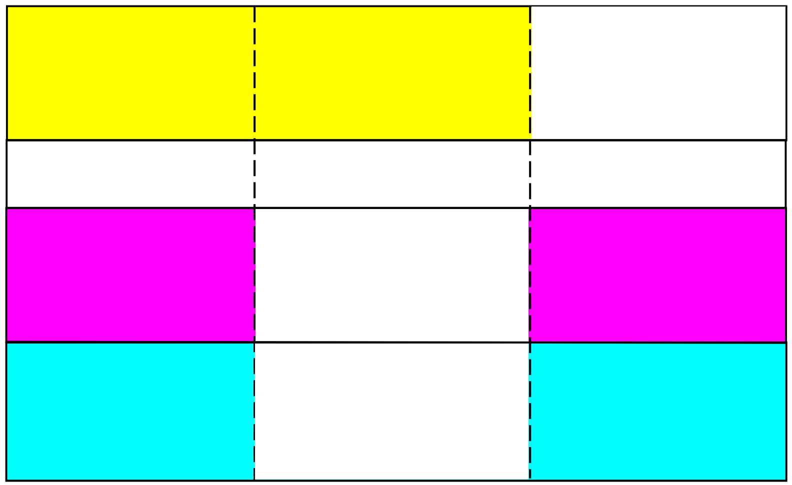
Exposure



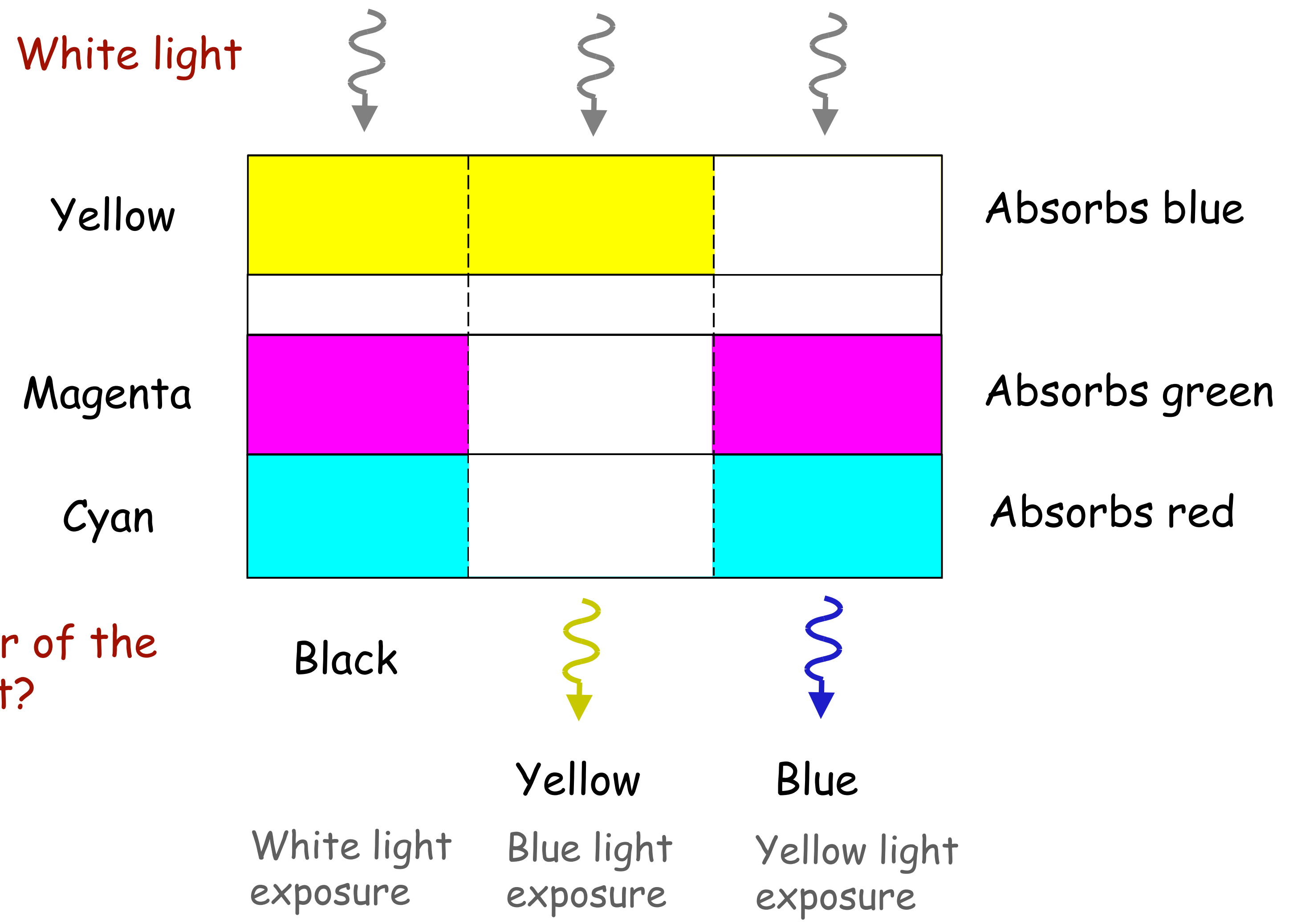
Development

(Details on blackboard)

In exposed areas complementary colors are formed



Viewing



What is the color of the transmitted light?

We get complementary colors – a photographic negative

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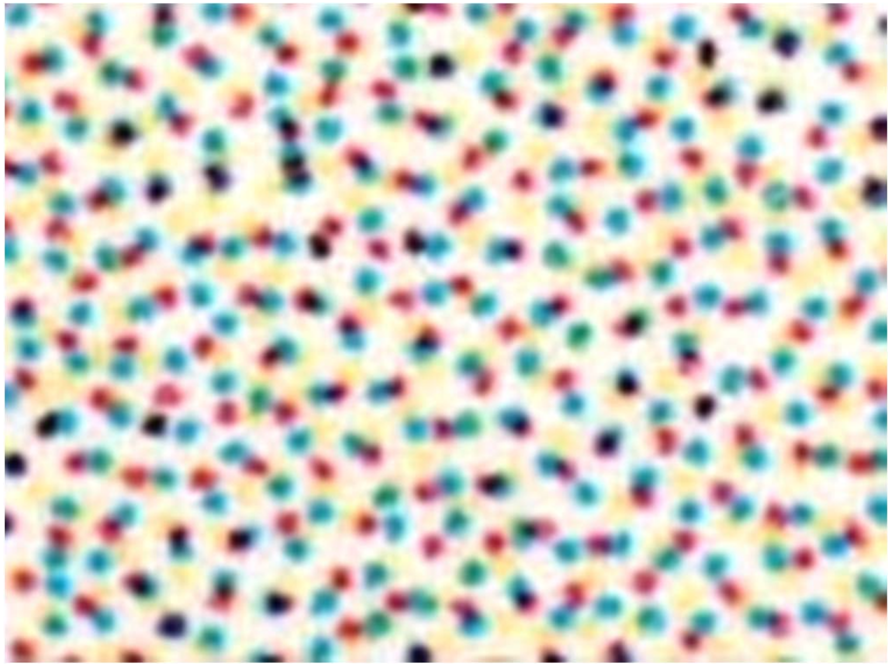
Color negative
is imaged onto
photographic paper.
After paper develop-
ment we get positive
image

Color positive

Photo credit: Kodak

Inkjet printers

Dot size approx. 0.05 mm



Ink colors:

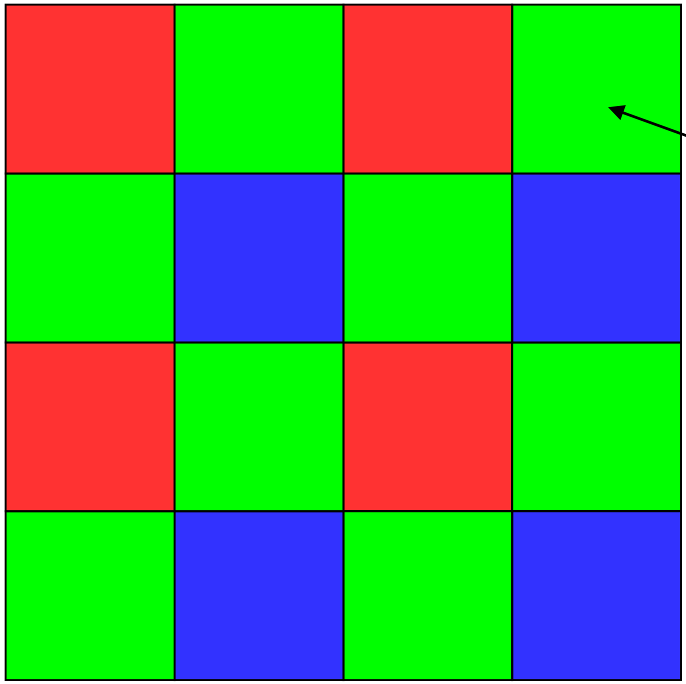
- Yellow
- Magenta
- Cyan
- Black

+ unsaturated colors

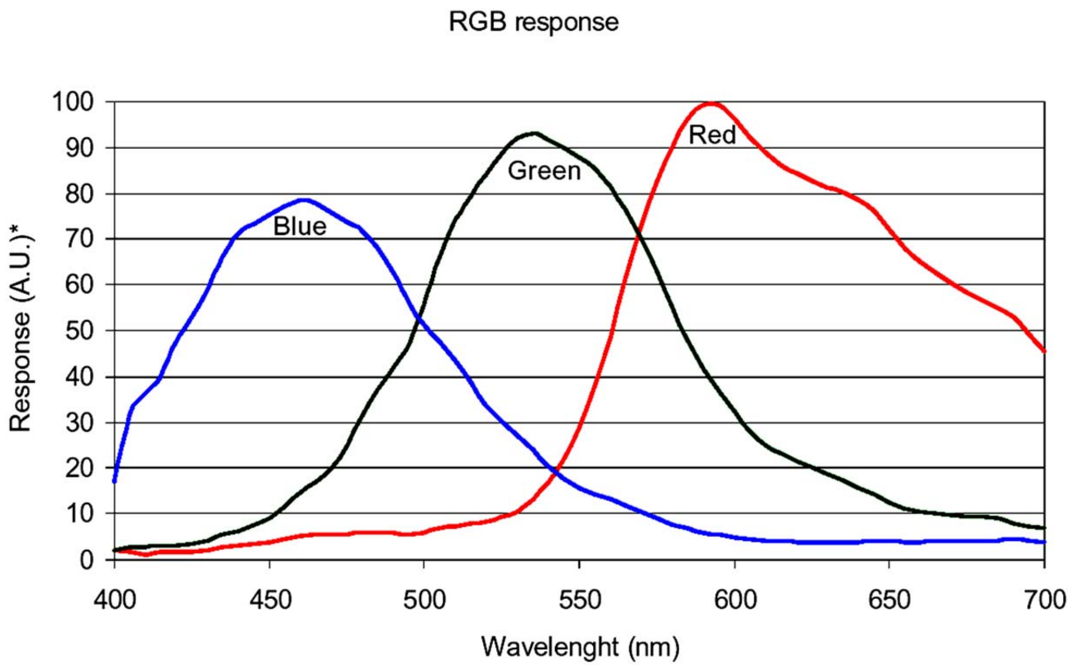
(Details in compendium)

Color detection in electronic sensors

RGB Bayer pattern

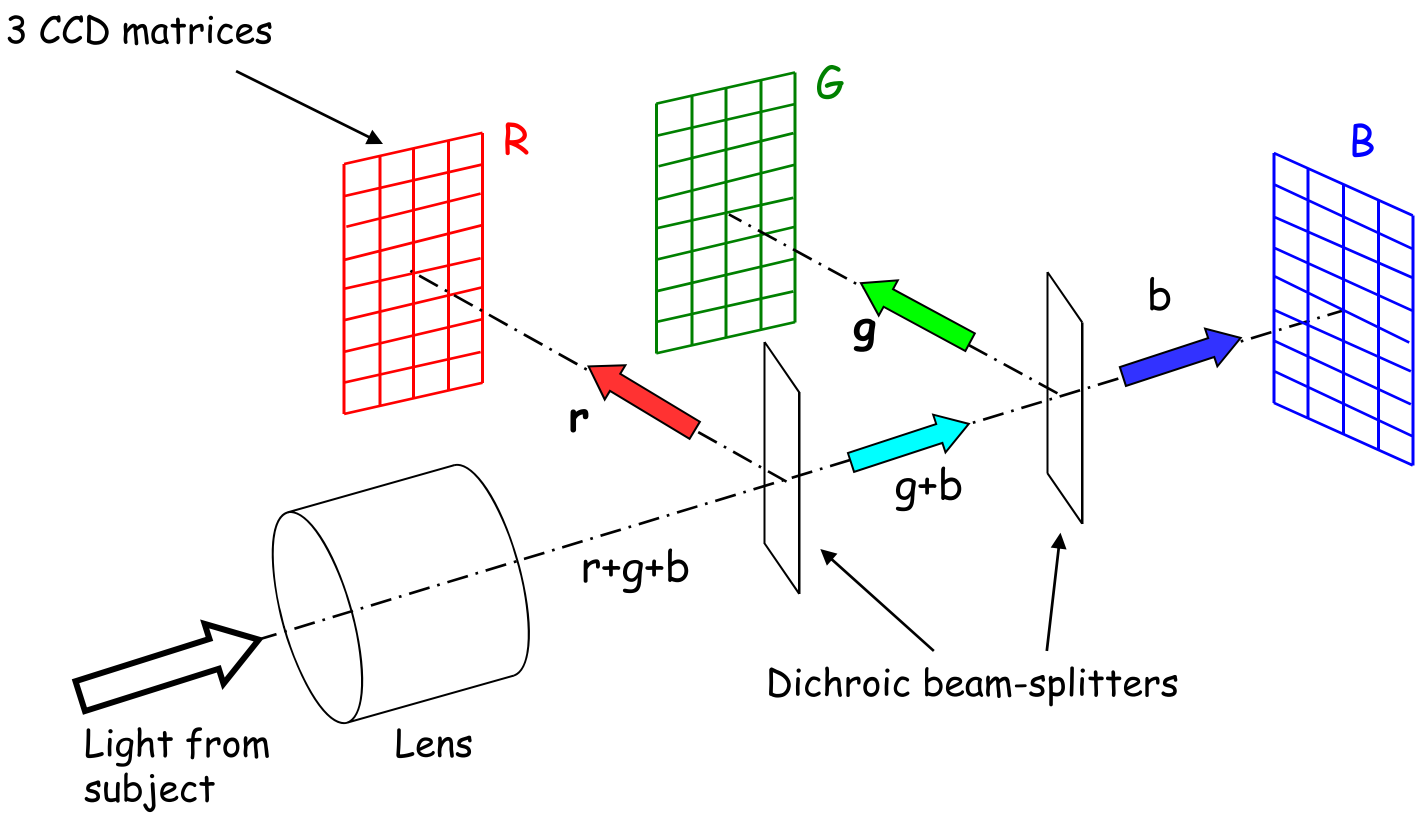


Each pixel only detects one primary color. The other two primaries are obtained through interpolation

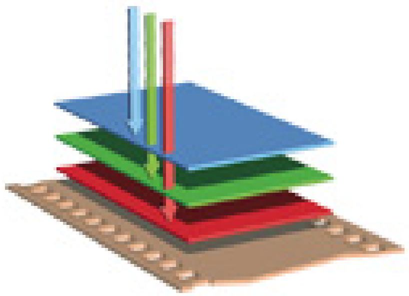


Alternative color detection #1

Camera with 3 CCD:s (mostly video cameras)

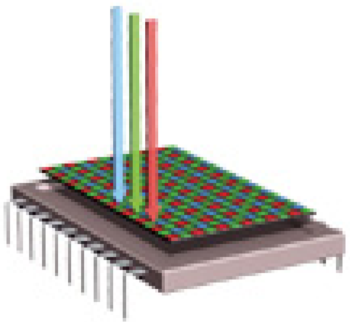


Alternative color detection #2



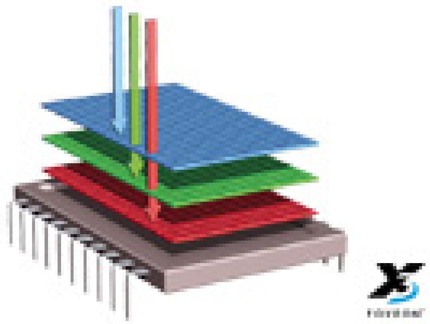
First came film.

COLOR FILM contains three layers of emulsion which directly record red, green, and blue light.



Then came digital.

TYPICAL DIGITAL SENSORS have just one layer of pixels and capture only part of the color.



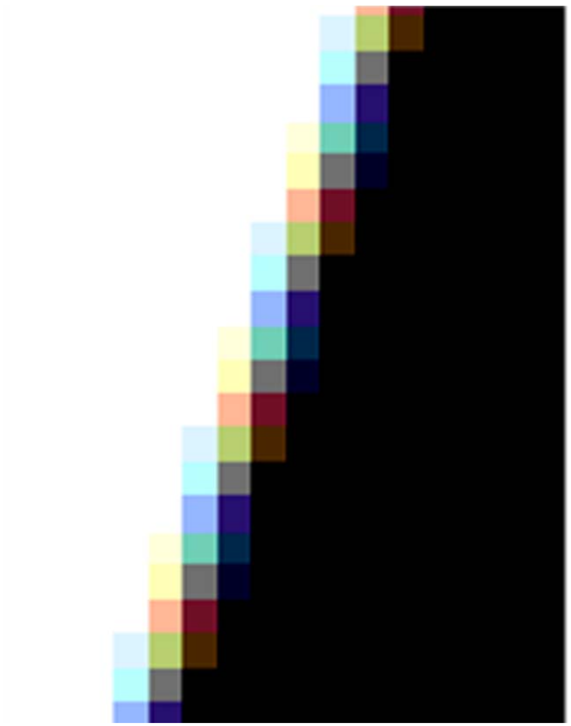
Now there's Foveon X3.

FOVEON X3 direct image sensors have three layers of pixels which directly capture all of the color.

Effects of color interpolation

Slanting black/white edge

Without color interpolation



With color interpolation

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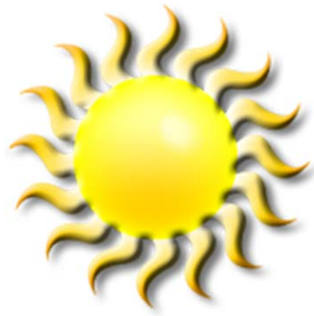
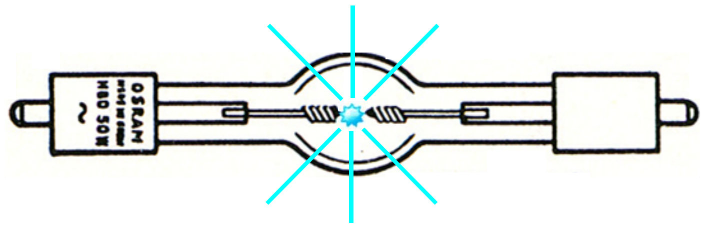
Light sources for photography

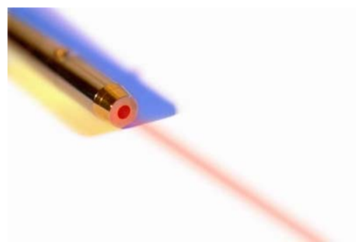
1) ”Warm bodies” (blackbody radiators).



2) Gas discharge lamps

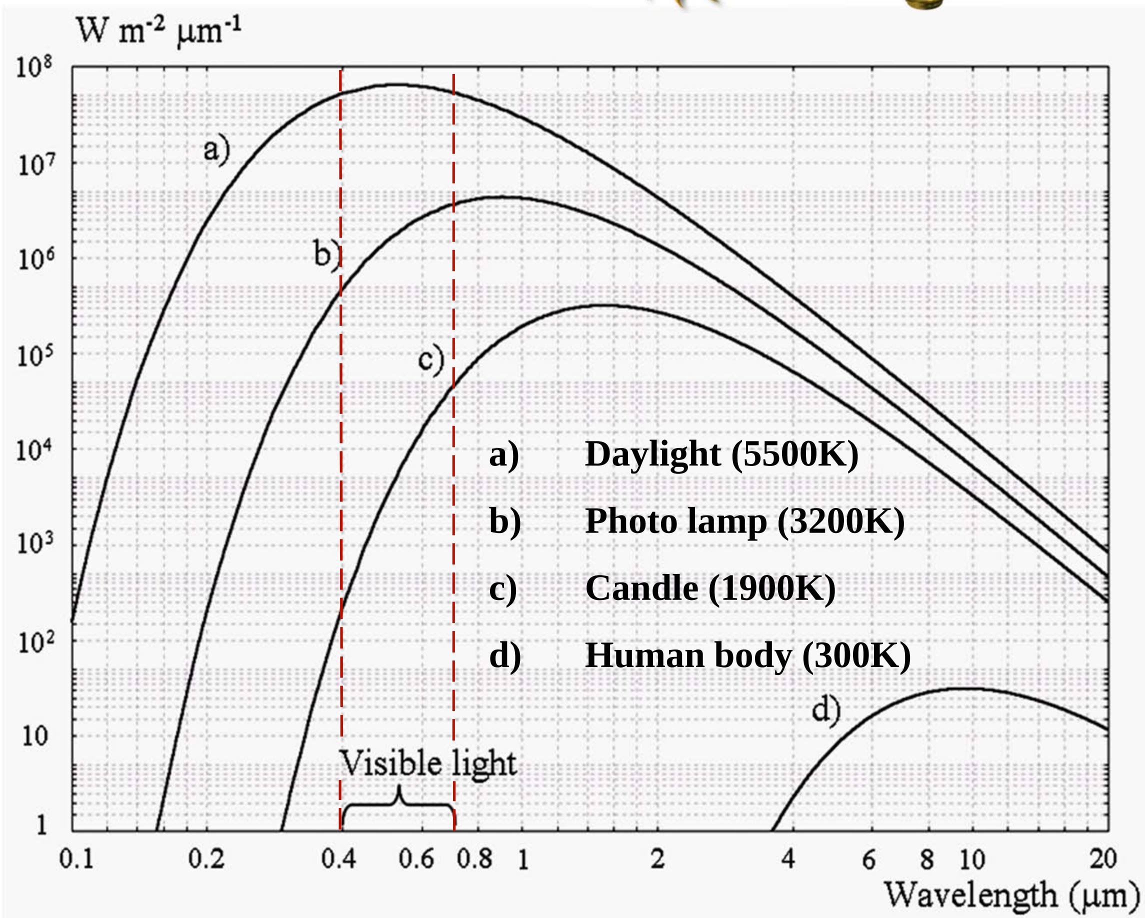


3) ”Other types” (lasers, LEDs etc.)



Blackbody radiators

Examples: Sun, light bulb



Spectral distributions for blackbody radiators

Color temperature, T_c

(White balance)

If, for example, T_c = 5500 K, the spectral distribution of the light source is (approximately) that of a blackbody radiator with T = 5500 K.

Common color temperatures in photography are 5500 (daylight) and 3200 K (photo lamp).

White balance is selected in the camera menu (digital phot.) or through choice of film and filters (analog phot.)

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Incorrect color temperature setting means poor color rendition

Camera white balance setting is correct.

Camera white balance setting is too high.

Camera white balance setting is too low.

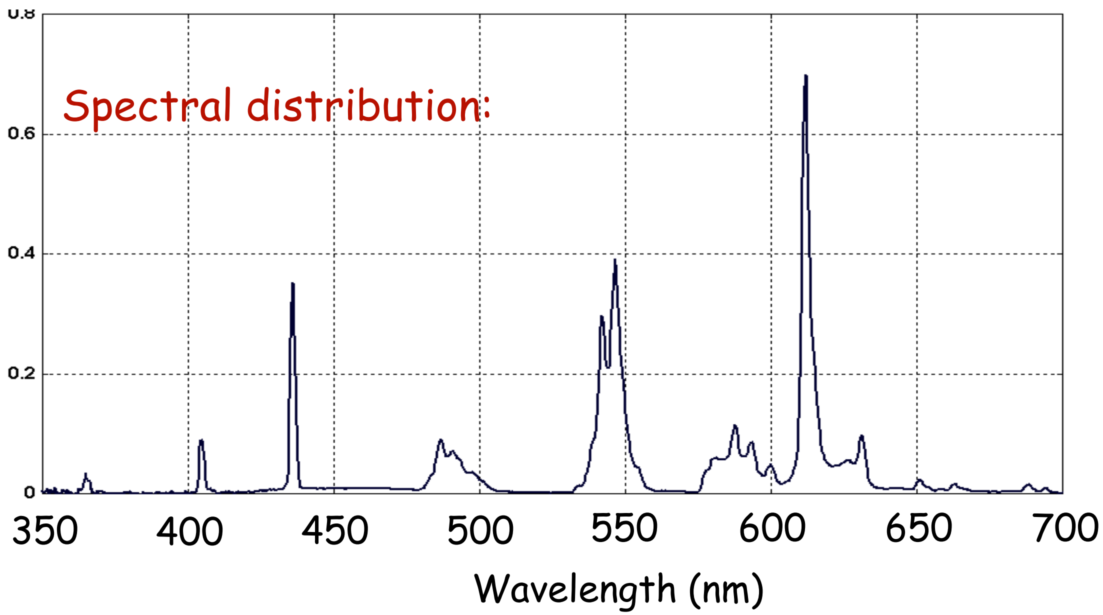
Color corrections can (to some extent) be made by computer processing

Photo credit: Kodak

Gas discharge lamps

Fluorescent lamp (lysrör):

Results difficult to predict. Avoid if possible



Photographic flash:

Daylight characteristics