Light and Colour

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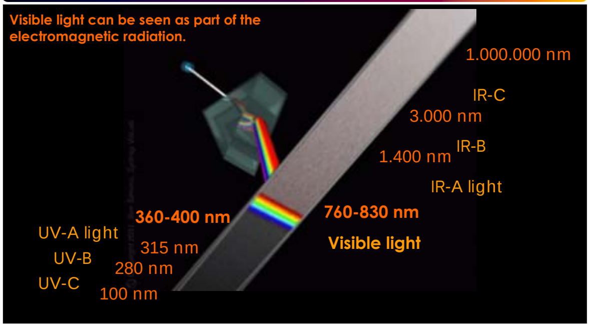
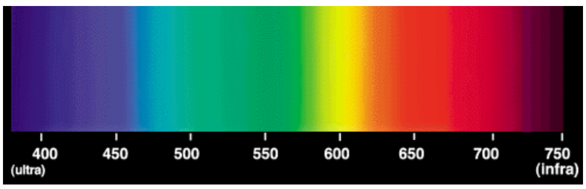
Light as part of the EM spectrum

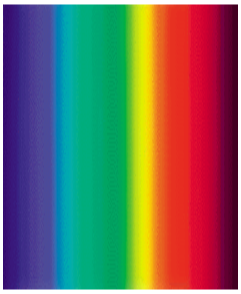


Light as part of the EM spectrum

The human eye perceive visible light of each wavelength as a specific colors.



Light as part of the EM spectrum



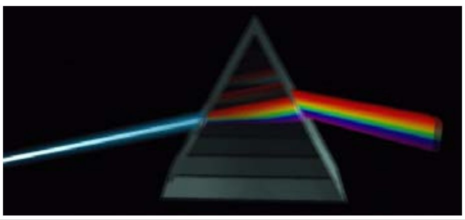
380 - violet -420
420 - indigo -450
450 - blue - 495
495 - green - 566
566 - yellow - 589
589 - orange - 627
627 - red - 780

White light

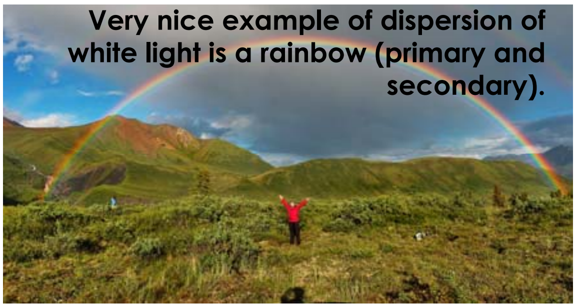
And where is the now the white light from the sun?

White light

All spectral colours together gives us a white light or we can get spectral colours from white light by dispersion.



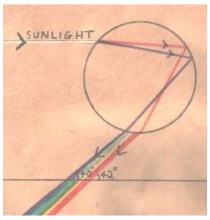
Dispersion of light in nature

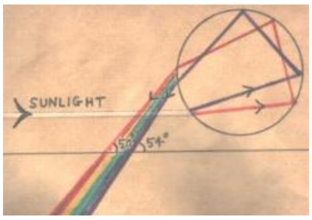


Very nice example of dispersion of white light is a rainbow (primary and secondary).

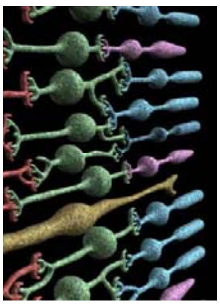
Dispersion of light in nature

The rainbow is formed due to the refraction and reflection of sunlight on water drops.





Light, colour and human eye



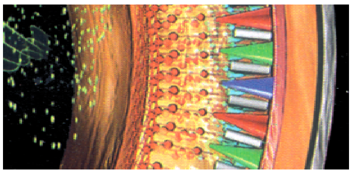
Only the cones distinguish colours

Cones

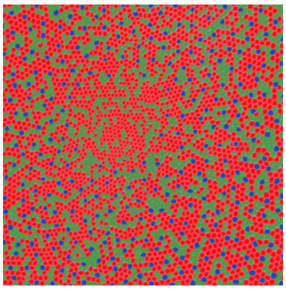
- There are 4.500.000 cones in average eye.
- They are less sensitive to light.
- They distinguish colours.
- They are arranged mostly in fovea and macula.
- They contribute to vision in well lit environment – photopic vision.

Light, colour and human eye

Humans normally have three kinds of cones. The first (L - red) responds most to light of long wavelengths, peaking in the yellow region. The second type (M - green) responds most to light of medium-wavelength, peaking at green. The third type (S - blue) responds most to short-wavelength light, of a violet color.

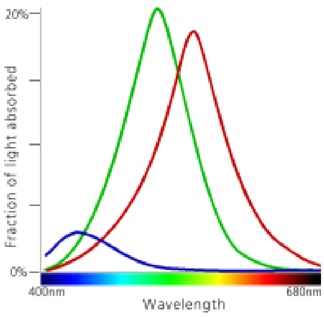


Light, colour and human eye



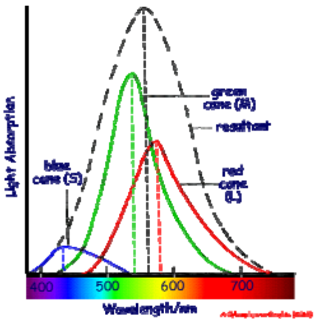
The number of individual types of cones in the retina is different. There is only 7 % of "blue" ones in the central part and "green" and "red" are in the ratio 1:1,5. There is no "blue" right in the middle and there is only 1 % of them on the whole retina.

Light, colour and human eye



Responsivities of different kinds of cones are different having peeks at around 420 nm, 534nm and 564 nm.

Light, colour and human eye



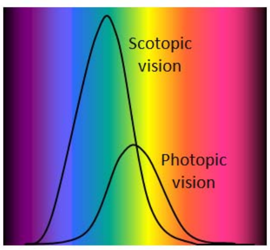
All three together give us a spectral responsivity of a human eye V(λ) with peek at 555 nm.

Light, colour and human eye

That is why we see better when light is yellow as when it is red or blue and why we can not see if light is in IR or UV range.

Light, colour and human eye

The spectral response of rods is similar to the one of cons.

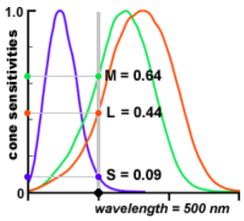


The responsivity function of rods has peek at 507 nm

K=683 lm/W,
K'=1700 lm/W

Light, colour and human eye

The percepted colour depends on response of different type of cons.

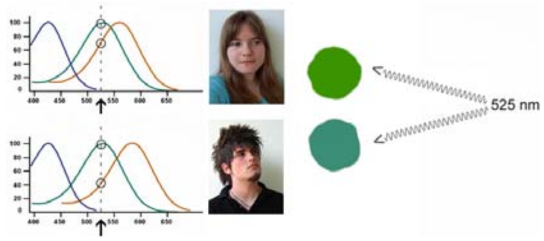


On light with 500 nm
"blue" cons response with 0,09;
"green" cons response with 0,64;
"red" cons response with 0,44.

The light would be perceived as green.

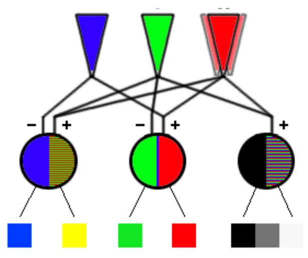
Light, colour and human eye

But perceived colour depends also on each individual and his/hers nervous system.



Light, colour and human eye

How the information about a colour come to the brains?



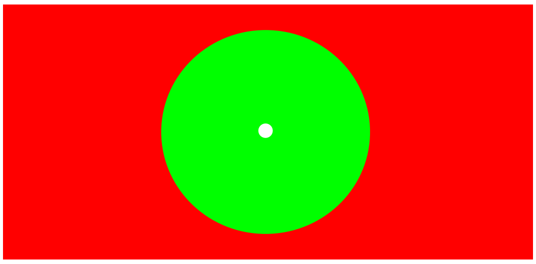
Most likely the opponent process theory is the right one: the visual system interprets color in an antagonistic way: red vs. green,

blue vs. yellow,

black vs. white.

Light, colour and human eye

This theory can be "supported" by afterimage.

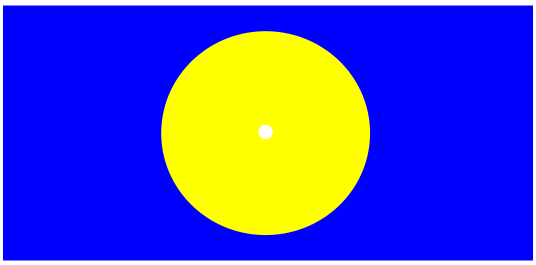


Light, colour and human eye

... what do you see?

Light, colour and human eye

This theory can be "supported" by afterimage.



Light, colour and human eye

... what do you see?

Colour vision deficiency

Normal vision is trichromatic but it can also be dichromatic or monochromatic. This condition is in most cases inharited geneticaly but it can also be result of brain or retinal damage.

Colour vision deficiency

About 8 % of males and 0,5 % of females, are color blind in some way:

- monocromacy (0,00001%): rod or cone
- dichromacy: protanopia (1,3%/0,02%), deuteranopia (1,2%/0,01%) , tritanopia (0,001%/0,03%)
- abnomalous trichromacy: protanomaly (1,3%/0,02%), deuteranomaly (5,0%/0,35%), tritanomaly(0,01%/=,01%).

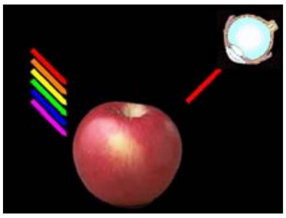
Be careful with colour design!

Colour of objects

what determines the color of objects that we see.

Colour of objects

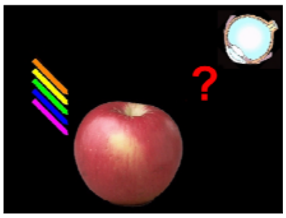
- spectrum of the light
- reflection properties of object
- responsivity of our visual system



Colour of objects

- If the spectrum does not contain the right colour or
- if the object does not reflect colours in a spectrum or
- if our visual system does not respond to the reflected color

we can not see the (colour of) object.



Colour of objects

That is why the frequency spectrum of the light source influences the perception of colours.

But due to the perceptual (colour) constancy the difference is not always percepted.

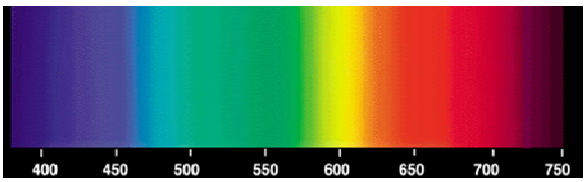
Colour of objects

Why:

- sky is blue?
- sun is red?
- clouds are white?

How to describe colour?

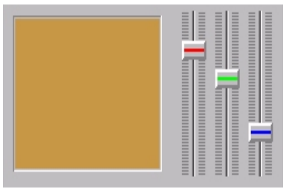
Colour can be described by the appropriate wavelength of light – but not all light is monochromatic.



How to describe colour?

Colour can be described using combination of three primary colours.

Primary colours should be selected so that the third can not be obtained by mixing two of them



Typically, the selected three colours are red, green and blue to which the cons in human eye are sensitive.

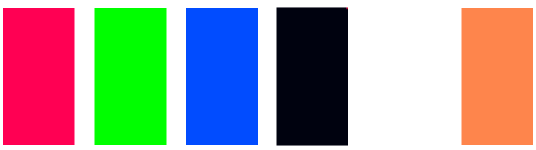
How to describe colour?

This principle is used in CIE XYZ colour system where tristimulus values (shares) of the primary colours are denoted with X for red (R), Y for green (G) and Z for blue (B).

$$C = X \cdot R + Y \cdot G + Z \cdot B$$

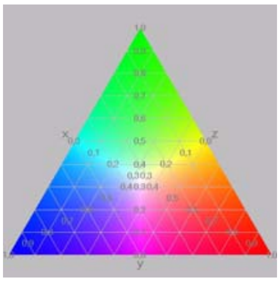
How to describe colour?

Colours can so be represented by a combination of three numbers (X; Y; Z)



(1;0;0) (0;1;0) (0;0;1) (0;0;0) (1;1;1) (0,6;0,4;0,1)

How to describe colour?



One of the first using three primary colours and representing colours in a colour triangle was J. C. Maxwell

vermilion

emerald

ultramarine

How to describe colour?

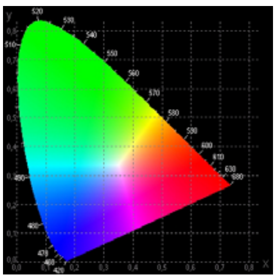
Tristimulus values can be normalized in which case their sum is always 1.

$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

So it is possible to define a colour only with two coordinates x and y:

X=0,10 Y=0,80 Z=0,60 oziroma x=0,0667 y=0,5333

How to describe colour?

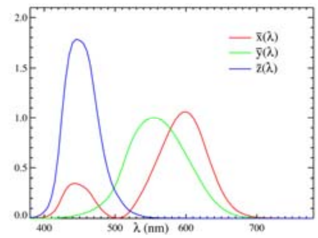


The CIE color space chromaticity diagram uses coordinates x and y.

It is part of the CIE xyY colour space where Y parameter is (also) a measure of the brightness or luminance of a color.

How to describe colour?

Part of the CIEXYZ are also three color-matching functions, which can be thought of as the spectral sensitivity curves of three linear light detectors that yield the CIE XYZ tristimulus values X, Y, and Z.



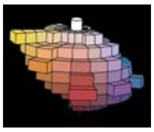
$$X = \int_0^\infty I(\lambda)\,\overline{x}(\lambda)\,d\lambda$$

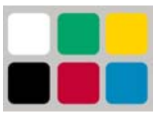
$$Y = \int_0^\infty I(\lambda)\,\overline{y}(\lambda)\,d\lambda$$

$$Z = \int_0^\infty I(\lambda)\,\overline{z}(\lambda)\,d\lambda$$

How to describe colour?

The colours can be described also by other colour system :

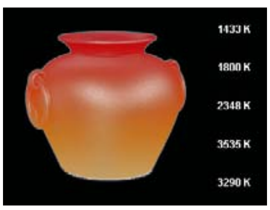




- Munsell colour system
  (hue, value, chroma) 5P 5/10
- NCS colour system
  (darkness, saturation, hue) 4055-R95B ,
- Pantone
  PMS 130,
- RAL
  RAL 1034 Pastel Yellow,
- ……

Colour temperature

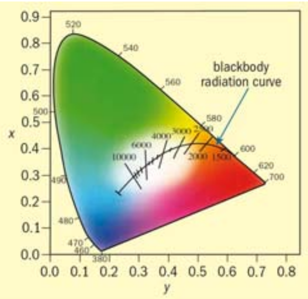
Colour of light of thermal light sources can be described with their temperature.



If the (metal) object is heated it starts to emit energy in the form of visible light. First dark red, then its color passes through orange and yellow to white and finally blue.

So some of the colours can be described with the temperature of an ideal black-body radiator that radiates light of comparable hue to that light colour.

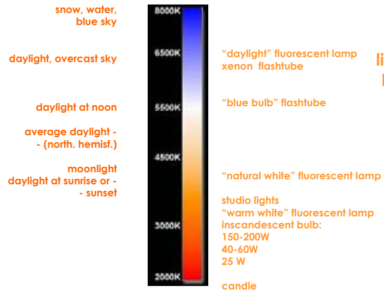
Colour temperature



Only colours on a "Planckian locus" (colours of thermal light sources) can be described with the colour temperature.

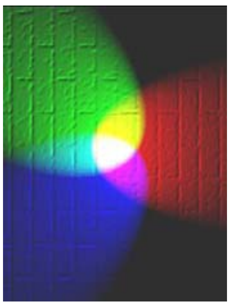
For other (non thermal) lighting sources a Correlated Colour Temperature (CCT) is used, which is the temperature of the Planckian radiator whose perceived colour most closely resembles that of a given light source.

Colour temperature



Light colour of light sources used in lighting is close to the light colour of black-body radiator so in lighting the light colour is normaly described with Colour Temperature or Corelated Colour Temperature.

Additive colour mixing



Light of different (primary) colours can be mixed together to obtain different (secondary) light colours.

red+blue=magenta

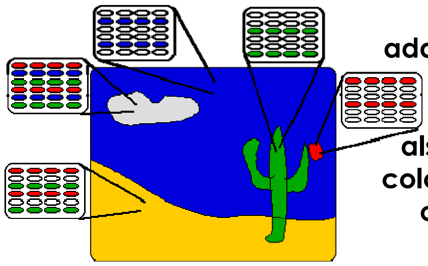
blue+green=cyan

red+green=yellow

red+green+blue=white

Mixing of light is called additive mixing, the mixture is always "brighter" as the components because we add light.

Additive colour mixing



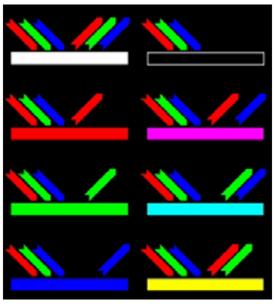
"A kind of" additive colour mixing is used also to create colours on a TV or computer screens.

Additive colour mixing

Paints, Dyes, Inks

A pigment is a material that changes the color of reflected or transmitted light as the result of wavelength-selective absorption.

Subtractive colour mixing

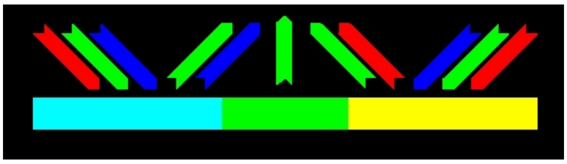


Reflected light determines the percepted colour.

Red pigment reflects only red light but magenta pigment reflects red and blue. Seen together they are percepted as magenta.

Subtractive colour mixing

Cyan pigment reflect green and blue light and yellow reflect green and red. Mixed together they reflect only green light.



Subtractive colour mixing

Subtractive colour mixing is mixing of pigments and so subtracting colour (of light).

yellow+cyan=green
cyan+magenta=blue
magenta+yellow=red
yellow+cyan+magenta= black

The mixture is always “darker” as the components because we “subtract” light

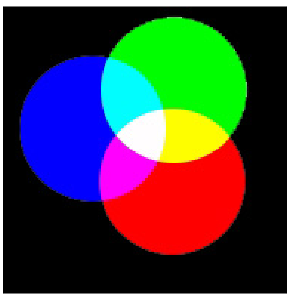
Subtractive colour mixing

Colour printing process is using subtractive colour mixing.

At least three primary colours need to be used: cyan, yellow and magenta. In most cases fourth is added – black: CYMK

Subtractive colour mixing

Frequency spectrum of light



Three primary colors give the impression of white light. However, white light may be more or less "white", depending on the ratio of different primary colors.

Frequency spectrum of light

We can increase or decrease the share of one on the primary colour. The result is still a white colour.

245 255 255	255 245 245
255 245 255	245 255 245
255 255 245	245 245 255

Frequency spectrum of light

The differences are better seen on a 1:1:1 white background.

255 255 255

245 255 255	255 245 245
255 245 255	245 255 245
255 255 245	245 245 255

Frequency spectrum of light

And without outlines.

255 255 255

245 255 255	255 245 245
255 245 255	245 255 245
255 255 245	245 245 255

Frequency spectrum of light

The difference between “white” and “white” light is in its frequency spectrum, which shows which frequencies (wave-lengths) are included in a light.


white sunlight

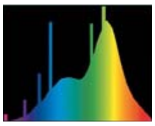

white “RGB” light

Frequency spectrum of light

Different “white light” sources have different frequency spectra.


White sunlight on a north sky.

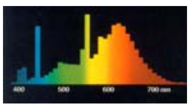

White light of an incendesent lamp.


White light of a fluorescent lamp.

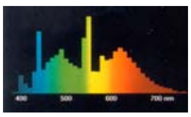
Colour Rendering Index

The perception of the (objects) colour depends also on a frequency spectrum of the light source.

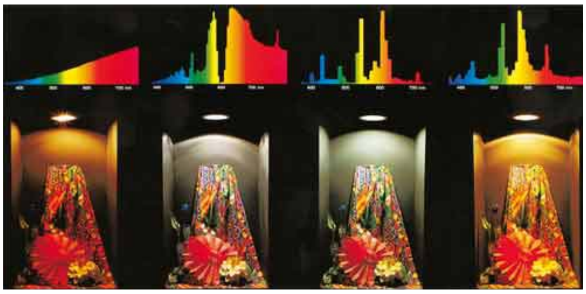
Under the light source with emphasized red spectrum red colour looks more saturated.



If frequency spectrum of light source is different (less red, more green), the red object look different.

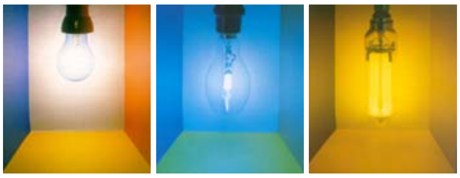


Colour Rendering Index



Colour Rendering Index

As perception of the object (colour) depends on the light source we need a kind of measure for that (light source) property.



Colour Rendering Index

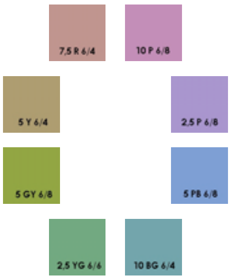
English: Color Rendering Index (CRI)

German: Farbwiedergabeindex (Ra)

a quantitative measure of the ability of a light source to reproduce the colours of various objects faithfully in comparison with an ideal or natural light source.

Under a light source with an Ra = 100 rating, all the colours have the same – optimal – appearance as under the reference light source. The lower the Ra index, the poorer the rendering of the surface colours of the illuminated objects.

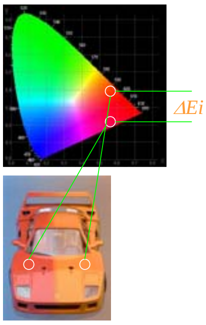
Colour Rendering Index



To determine the Ra values of light sources, eight defined test colours commonly found in the environment are each illuminated under the reference light source (Ra = 100) and then under the source being evaluated.

The greater the difference in the appearance of the test colours rendered, the poorer the colour rendering properties of the light source under examination.

Colour Rendering Index



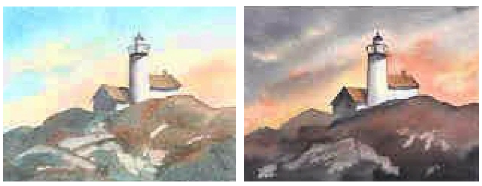
$$Ri = 100 - 4.6\Delta Ei$$

$$Ra = \frac{1}{8}\sum_{i=1}^{8} Ri$$

The reference light source has the same CCT as the test source. Up to 5000 K a black-body radiant source is used and for higher CCT a D source (daylight) is used.

Colours and emotions

Colors (like light) affect human welfare. We feel better in environment with bright, vivid colours as in environment with a dark, dull colours.



Colours and emotions

Warm colours: yellow, orange, red, brown, black, ...

They are called warm because they remind us of warm things like the sun or fire. They tend to be more exiting and to optically advance in space..

Colours and emotions

Cold colors: green, blue, white, ...

They are called cold because they remind us of cold things like a cool forest, a cold lake or sky. They tend to be psychologically soothing and have a tendency to feel like they are receding (or backing away from you).

Colours and emotions

Meanings generally associated with the most common colors:

Red symbolizes energy, passion, strength, courage, physical activity, creativity, warmth, and security. It is also associated with aggression.

Orange symbolizes the individual's relationship to the external world, the needs and wants of the physical body and the ways in which these are satisfied, the world of work.

Yellow symbolizes intellect, creativity, happiness and the power of persuasion. It is also associated with cowardice.

Green symbolizes money, luck, prosperity, vitality and fertility. It is also associated with envy.

Blue is the color of spirituality, intuition, inspiration and inner peace. It is also associated with sadness and depression (the "blues").

Pink represents unconditional love, love requiring nothing in return. It is also the color of friendship and conviviality.

At the end

- There is a lot of different “white” lights.
- There are three types of cones in human eye.
- Colour can be described in different way, for colour of white light (Correlated) Colour Temperature is mostly used.
- Perception of (objects) colour is influenced by frequency spectrum of the source, reflective properties of the (objects) surface and our visual system.

… and now:

Questions?