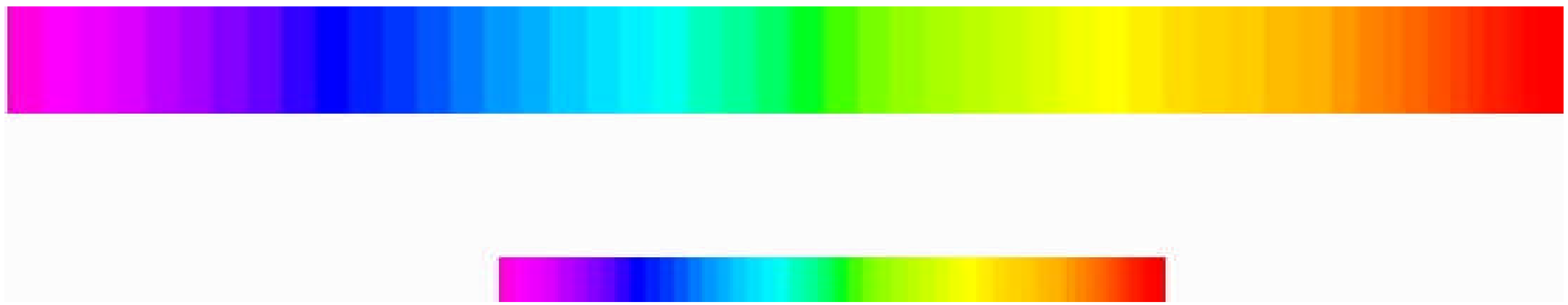
Colour
Basics

Here some naïve questions:

- How do we see the rainbow? How many colours? Do we see a continuous or a discrete spectrum?

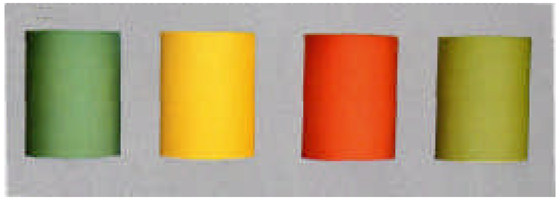


Further questions: light waves and colour awareness

- What is the relation between certain bundles of light waves that affect a certain region of the retina and colour perception?
  How many photons are necessary to elicit colour awareness?

- Which parts of our body are responsible for colour awareness? (which parts of the eye and the brain?)

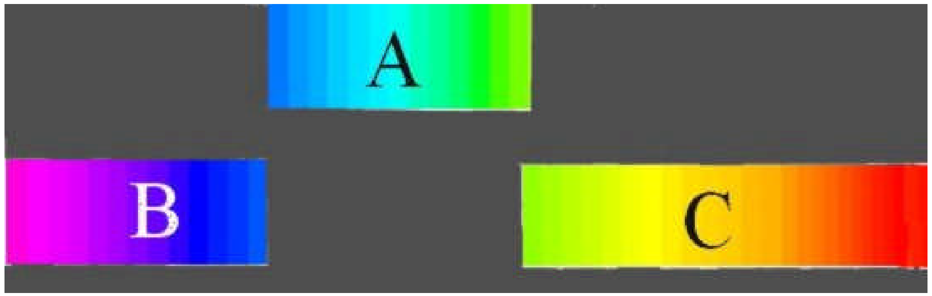
- How can we explain the phenomenon of colour constancy?



Further questions: language and colour

- Does the number of the basic colour words of our language influence how we see the rainbow?

- Is for each tessellation of the spectrum of the rainbow a natural system of colour words possible that designates the corresponding categories?



Why colour matters to philosophy

- The problem of *colour realism*: It concerns the relation between appearance and reality—whether, or to what extent, the world is as it appears? (Galileo, for example, thought that physical science had shown that objects are not really coloured, but colours instead are "in the mind". This conflicts with the naïve view that many things **are** coloured.

- The problem of our *knowledge of others' minds*: the famous "inverted spectrum" thought experiment, which supposes (waiving some qualifications) that objects that look green to me look red to you, and vice versa.

- The problem of *Qualia*: It concerns the *phenomenal character* of an experience (i.e. a *private property* of our experience). The experience of seeing a red circle differs in phenomenal character from the experience of seeing a blue circle. The experiences are different in character! Is the material (neuronal) basis of our colour system sufficient to account for the phenomenal character of an experience?

The physical description of colour

The physical description of colour is as a *spectrum*: the intensity of light at each wavelength.
A prism can be used in order to make the spectrum visible.

The spectrum of sunlight

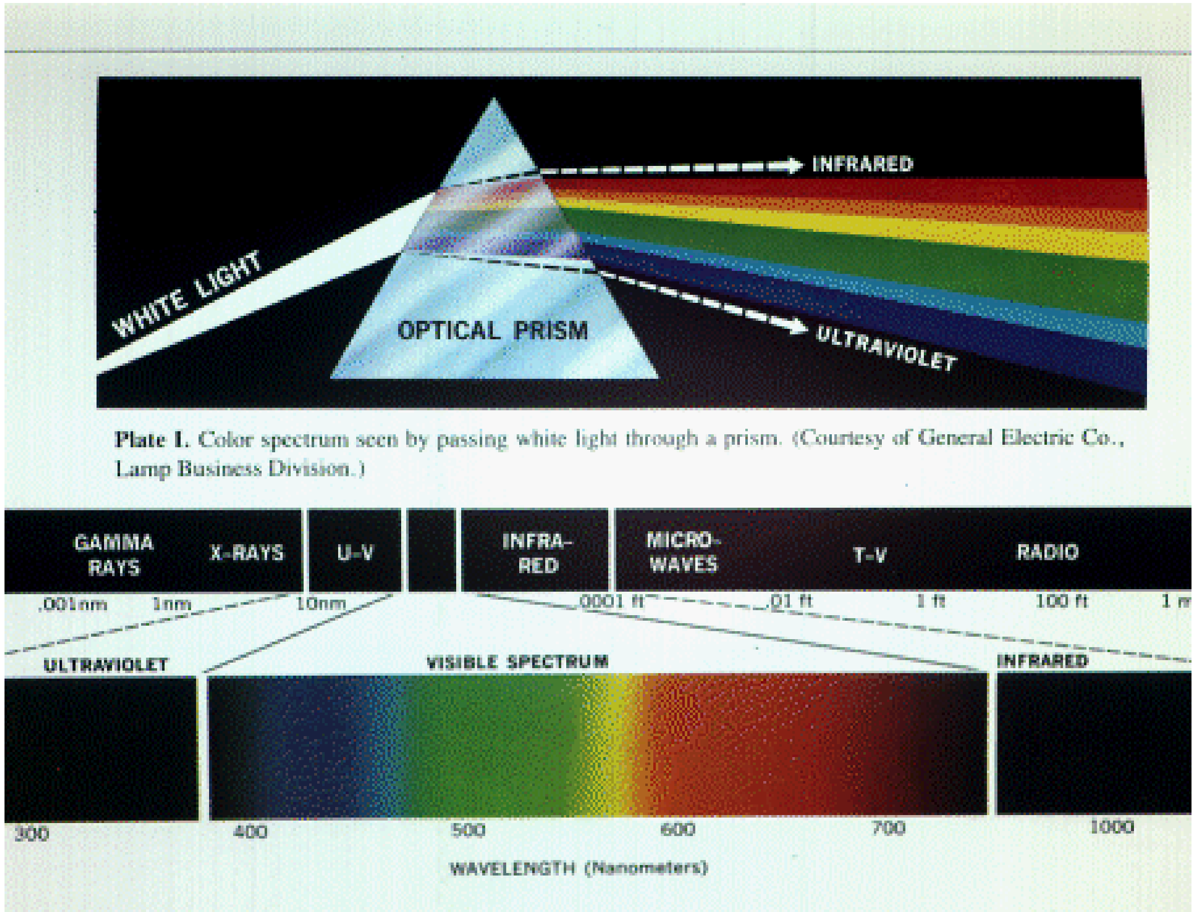


Plate I. Color spectrum seen by passing white light through a prism. (Courtesy of General Electric Co., Lamp Business Division.)

The wavelength distribution of sunlight is relatively flat, indicating that sunlight contains an approximate equal intensity of each wavelength across the spectrum. Such a light is called white light.

White: $f(\lambda)$ = constant

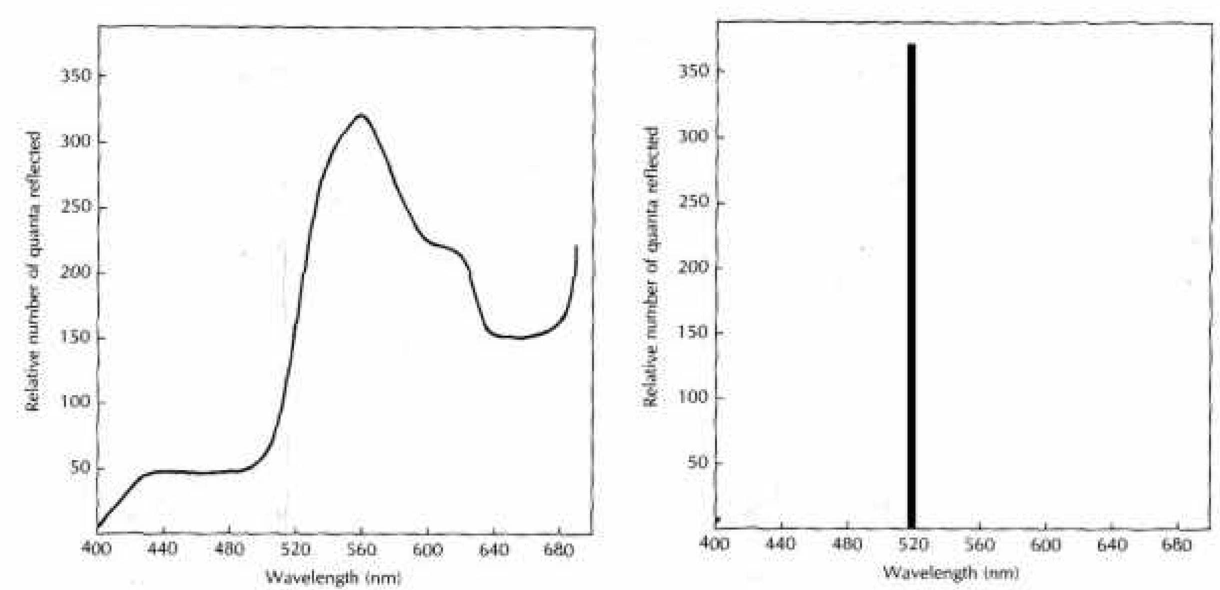
Monochromatic light:

Red: $f(\lambda) = \delta(\lambda{=}650\text{nm})$

Green: $f(\lambda) = \delta(\lambda{=}520\text{nm})$

Blue: $f(\lambda) = \delta(\lambda{=}450\text{nm})$

Can our eye always discriminate different spectra?



The spectral reflectance of green grass in sunlight and monochromatic Green. The eye cannot discriminate the two spectra!

Colour space

- Experiments show that humans can match all colours by combining three primary colours.

- The *principle of trichromacy* means that the colours displayable are all the linear combination of three primaries. The most common computer graphics primaries are Red (645.16nm), Green (526.32nm) and Blue (444.44nm).

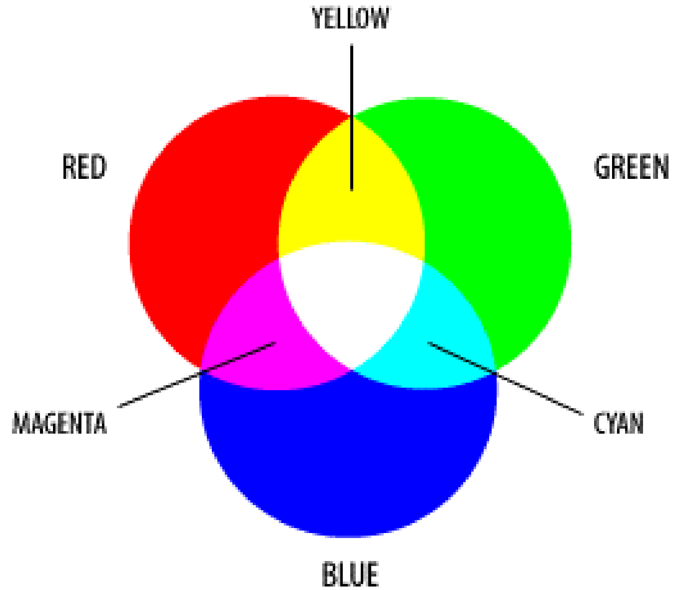
- Particular output devices, such as a monitor, colour printer, photographic film or printing press are able to produce colours. *A colour space* represents all the possible colours that can be produced by such a device. The colour space is device-dependent. There are transformations between the different colour spaces.

- The definition of various colour spaces arose from a need to standardize colour descriptions.

The RGB model (additive colour space)

- In 1931, the Vienna-based Commission Internationale de l'Eclairage (CIE) developed the RGB model, which uses the three primary colours of transmitted light: Red (645.16nm), Green (526.32nm) and Blue (444.44nm).

- The RGB standard is an *additive colour model* - that is, if you add red, green and blue light and you get white.



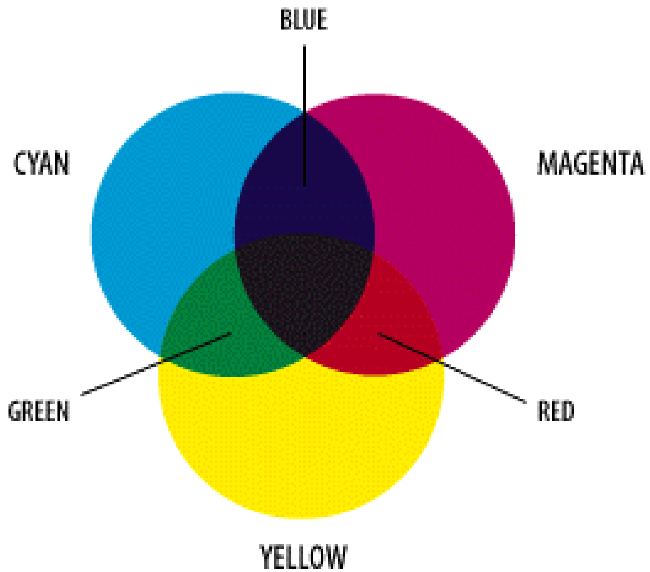
The rotating colour disc

The CMY model (subtractive colour space)

- Whereas monitors emit light, inked paper absorbs or reflects specific wavelengths.

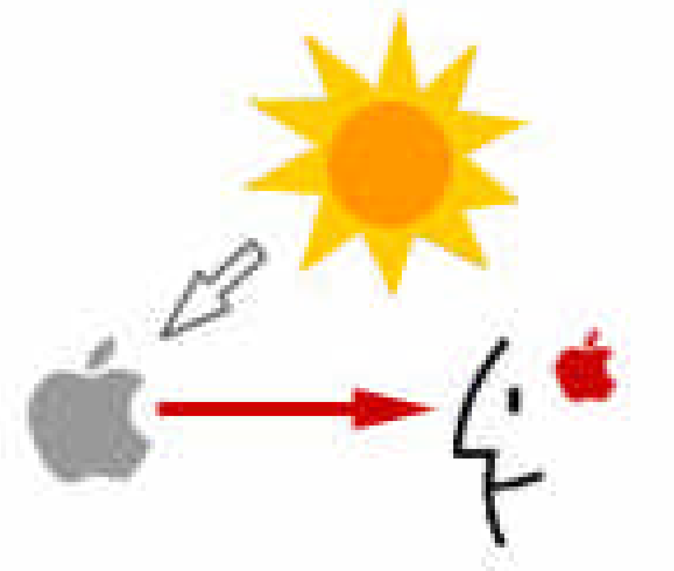
- **C**yan, **M**agenta and **Y**ellow pigments serve as filters, subtracting varying degrees of **R**ed, **G**reen and **B**lue from white light to produce a selective gamut of spectral colours.

- Like monitors, printing inks also produce a colour gamut that is only a subset of the visible spectrum, although the range is not exactly the same for both.



What colour is a red apple?

A red apple is a good example of subtractive colour. **The apple really has no colour**; it has no light energy of its own, it merely reflects the wavelengths of white light that cause us to see red and absorbs most of the other wavelengths which evokes the sensation of red.



The subtractive colour system involves colorants and reflected light. Subtractive colour starts with an object (often a substrate such as paper or canvas) that reflects light and uses colorants (such as pigments or dyes) to subtract portions of the white light illuminating an object to produce other colours. If an object reflects all the white light back to the viewer, it appears white. If an object absorbs (subtracts) all the light illuminating it, no light is reflected back to the viewer and it appears black. It is the subtractive process that allows everyday objects around us to show colour!

Conversions between RGB and CMY

RGB ® CMY

C = 1-R
M=1-G
Y=1-B

CMY ® RGB

R=1-C
G=1-M
B=1-Y

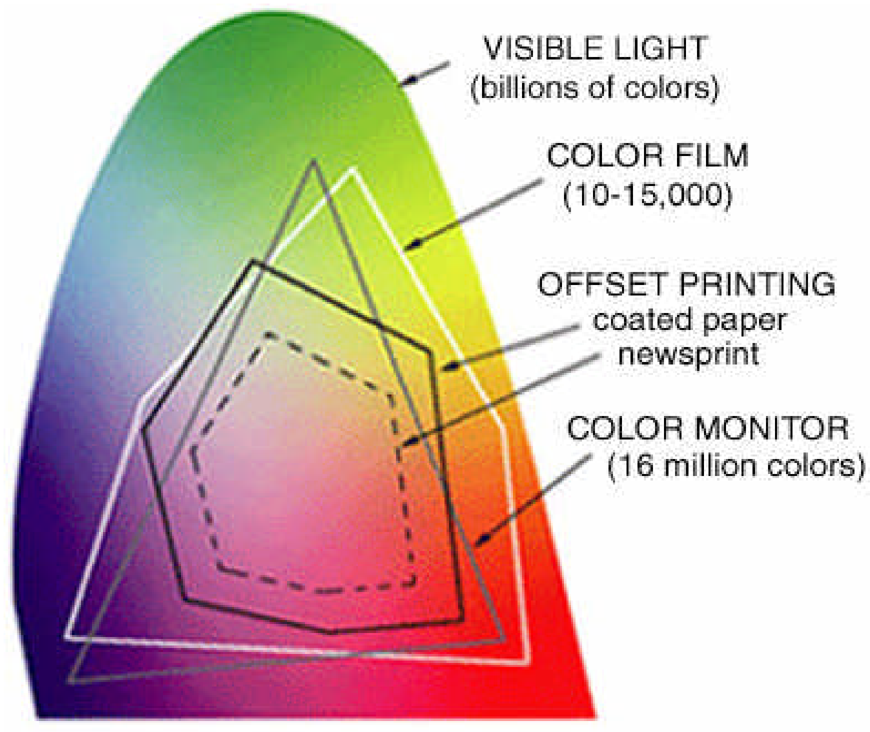
In general

$$\begin{pmatrix} c \\ m \\ y \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} r \\ g \\ b \end{pmatrix}$$

$$\begin{pmatrix} r \\ g \\ b \end{pmatrix} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} - \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} c \\ m \\ v \end{pmatrix}$$

RGB				CMY		
0	0	0		255	255	255
255	0	0		0	255	255
0	255	0		255	0	255
0	0	255		255	255	0
255	255	0		0	0	255
0	255	255		255	0	0
255	0	255		0	255	0
255	255	255		0	0	0
153	102	51		102	153	204
204	153	51		51	102	204

Problems with RGB and CMY

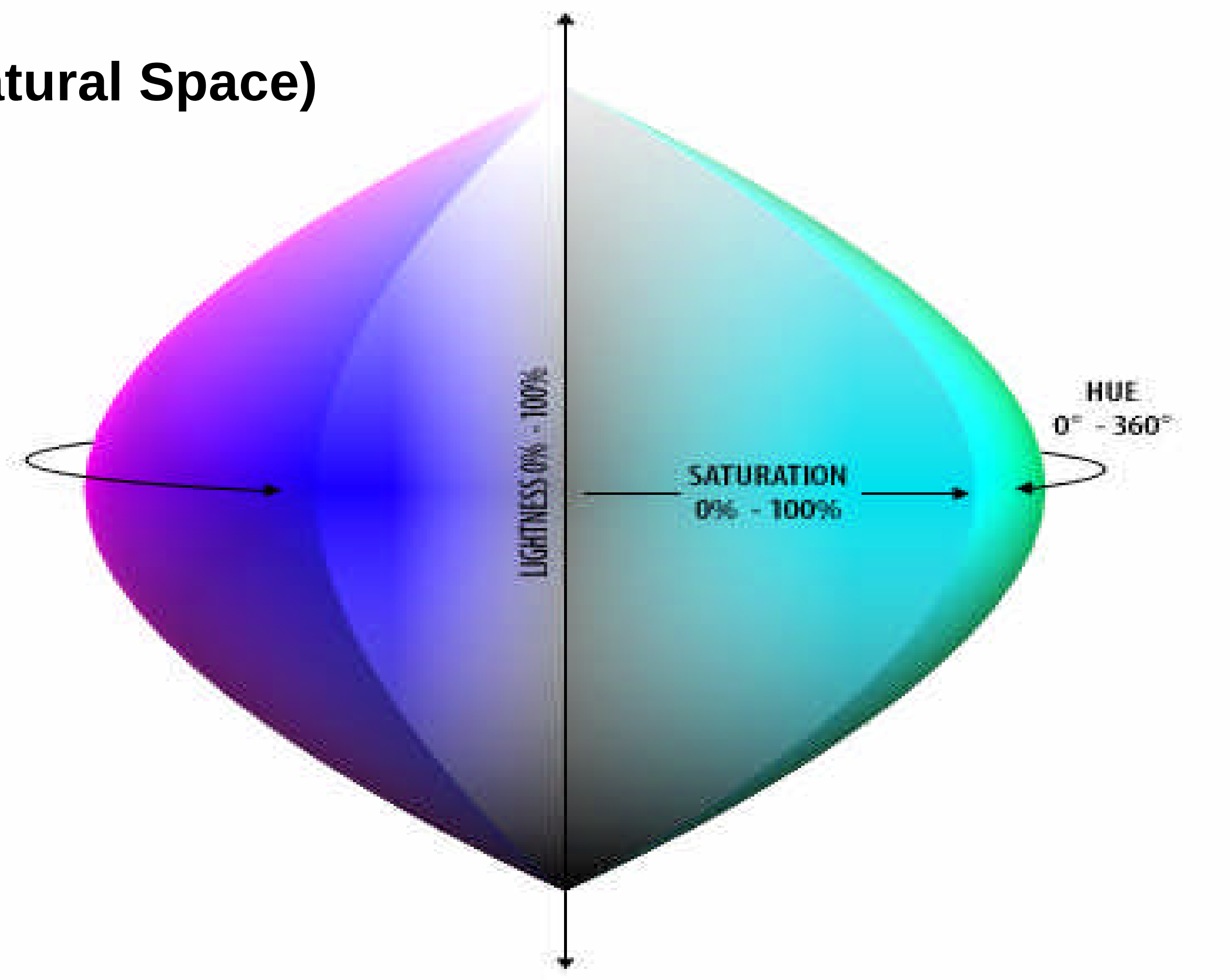


- Represents only a small range of all the colours humans are capable of perceiving (particularly for monitor RGB)
- It isn't easy for humans to say how much of RGB to use to make a given colour. How much R, G and B is there in "brown"? (Answer: .64,.16, .16)
- Perceptually non-linear: Two points a certain distance apart in one part of the space may be perceptually different; two other points, the same distance apart in another part of the space, may be perceptually the same.

Colour space again

- In general terms, a *colour space* is a method by which we can specify, create and visualise colour.
- A computer will define a colour in terms of the excitations of red, green and blue phosphors on the CRT faceplate.
- A printing press defines a colour in terms of the reflectance and absorbance of cyan, magenta, yellow (and black) inks on the paper.
- As human's, we may define a colour by its attributes of brightness, hue and colourfulness

The HSL colour space (Natural Space)



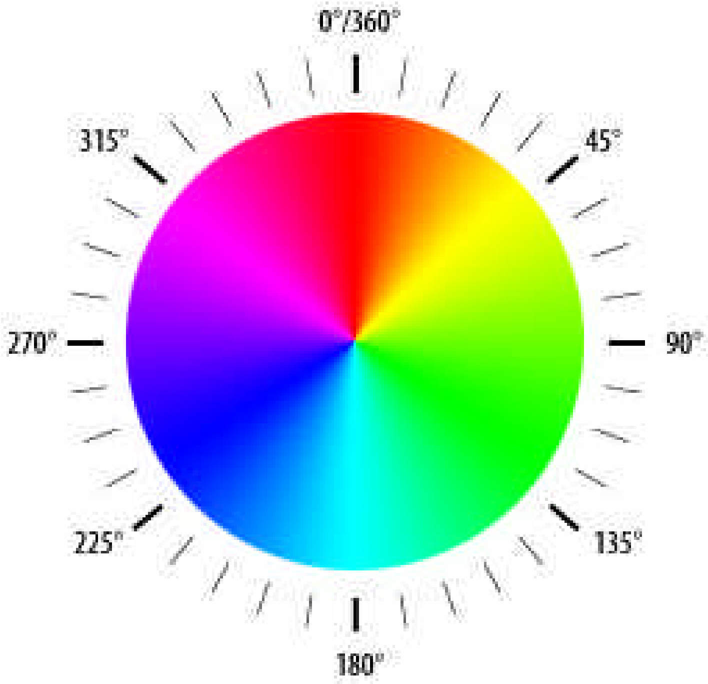
H = Hue,

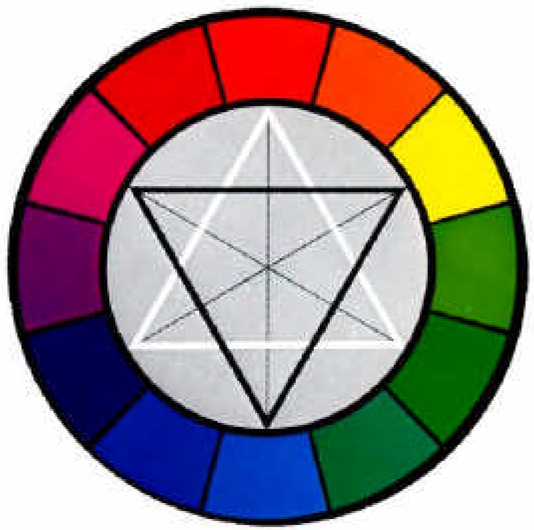
S = Saturation

L = Luminance

Hue

The hue determines which basic colour it is: red, green, blue, yellow, orange, etc. A hue is referenced by an angle on a colour wheel. For a certain hue, the ratio of each primary (RGB) colour to the other is fixed





Saturation

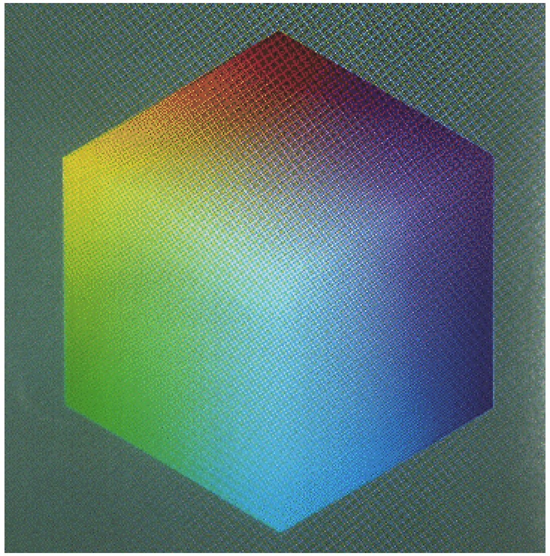
This parameter controls how intense or gray the colour becomes. Lowering saturation, equalizes the ratio between each of the primary (RGB) colours resulting in lower contrast and at its extreme a grey screen. Increasing saturation increases the ratio between the predominant primary colour and the subordinate primary colour resulting in increased contrast.

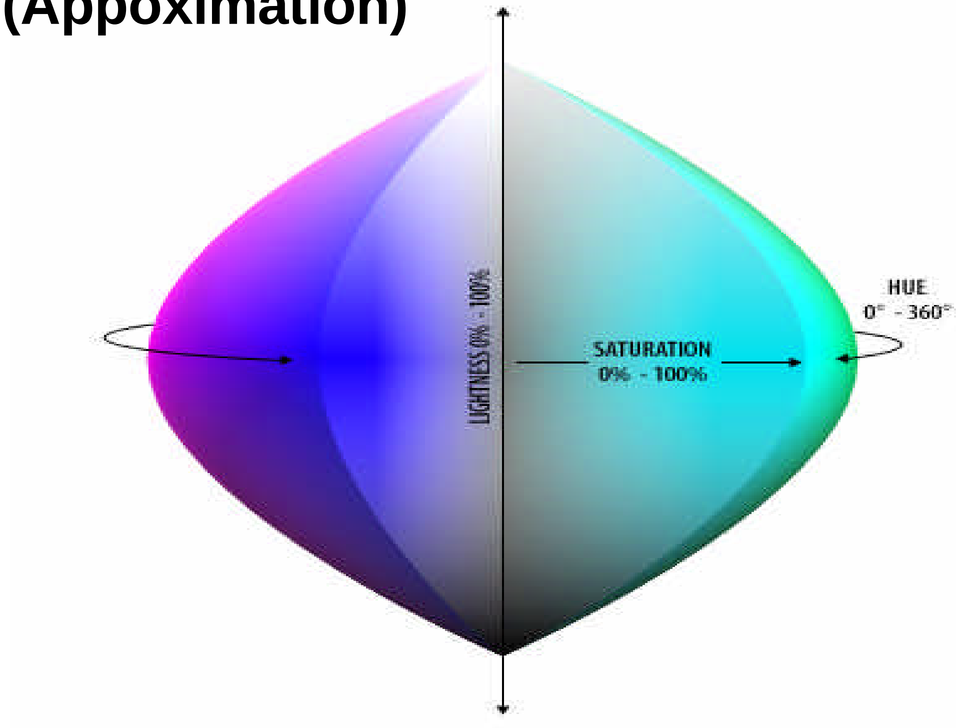
Luminance

It increases the "brightness" of the particular hue. Lowering Luminance has the characteristic of reducing the numerical value of the primary colours while keeping the ratios the same.

Increasing the luminance in turn increases the numerical value of the primary colours while keeping the ratio the same until one primary colour reaches its maximum, then the hue becomes pastel as the other two primary colour values continue to increase until the image finally becomes pure white at maximum luminance. This mimics the eye response in nature since as things become brighter they look more pastel until they become washed out.

Conversion between RGB and HSL (Appoximation)





H = arctan2(x,y)/(2 π) ; S = $\sqrt{}$(x^2+y^2); L = (R+G+B)/3;
where x = R–(G+B)/2; y = 0.866(G–B)

Device-Independent Colour Spaces (CIE)

- RGB colours vary with display and scanner characteristics
- CMYK colours vary with printer, ink, and paper characteristics
- *Device-independent colours* are meant to be true representations of colours as perceived by the human eye. These colour representations, called **device-independent colour spaces,** result from work carried out in 1931 by the Commission Internationale d'Eclairage (CIE) and for that reason are also called **CIE-based colour spaces.**

Colour matching

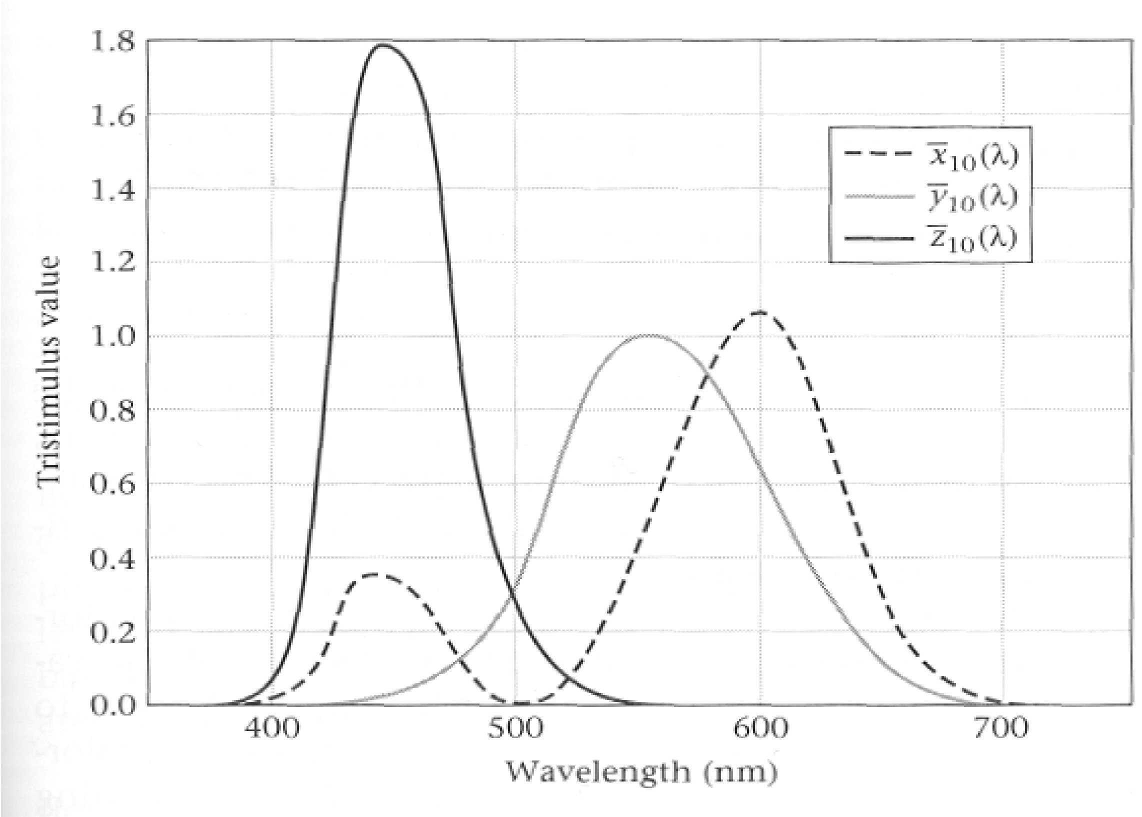
- Given a spectrum, how do we determine how much each of R, G and B to use to match it?

- First step: For a light of unit intensity at each wavelength, ask people to match it with R, G and B primaries (e.g., R= 645nm, G=523nm, B=444nm). This results in three functions, r(l), g(l) and b(l), the RGB *color matching functions*.

- Next step: Averaging over a set of such functions. The result is the XYZ space.

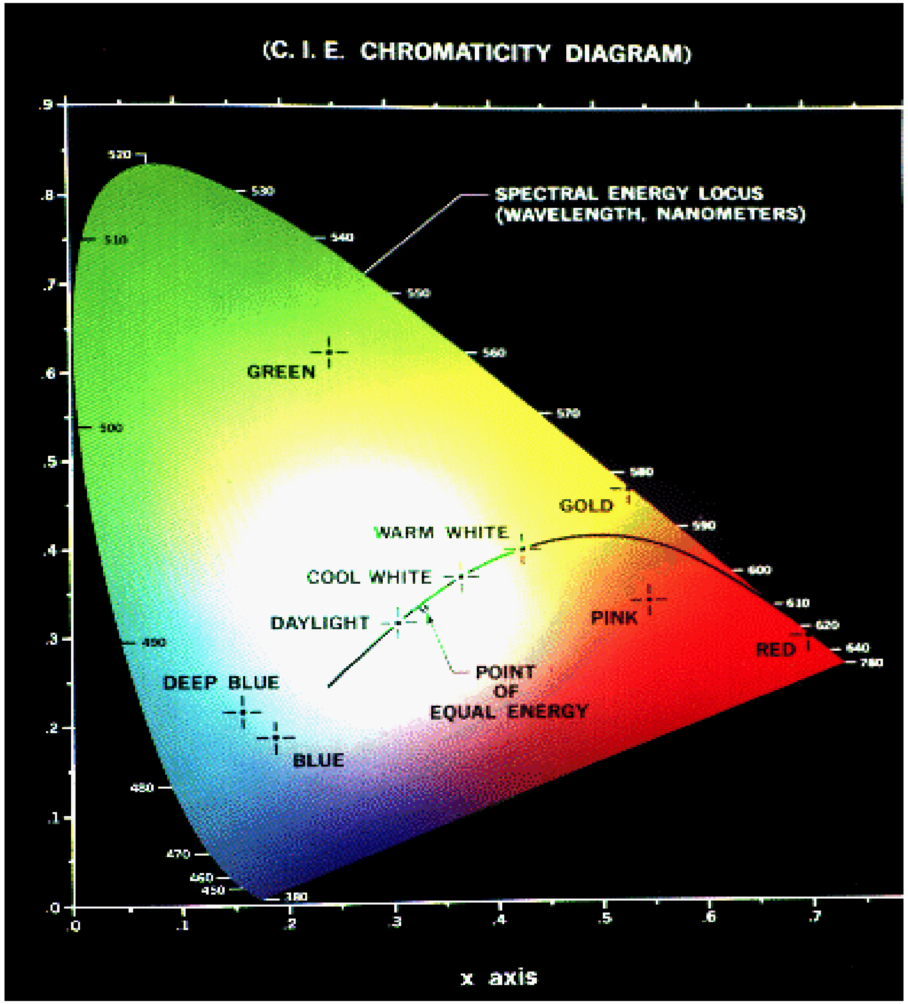
XYZ Space

After experimentation, the CIE set up a hypothetical set of primaries, XYZ, that correspond to the way the eye's retina behaves.



4.14 THE XYZ STANDARD COLOR-MATCHING FUNCTIONS. In 1931 the CIE standardized a set of color-matching functions for image interchange. These color-matching functions are called $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$. Industrial applications commonly describe the color properties of a light source using the three primary intensities needed to match the light source that can be computed from the XYZ color-matching functions.

Chromaticity coordinates



Chromatic values are derived from tristimulus values (the amounts of the primaries) by normalising, thus:

$$x = X/(X+Y+Z)$$
$$y = Y/(X+Y+Z)$$
$$z = Z/(X+Y+Z) = 1-x-y \quad \text{(redundant)}$$

x and y are chromaticity coordinates, somewhat analogous to the hue and saturation coordinates of HSV space. As a third value Y can be taken in order to represent brightness

Munsell colour space

This colour system is approximating a colour space in which distance in the space corresponds to perceptual “distance”. This works only for local distances!

The attributes of this system are
Munsell Hue (H),
Munsell Chroma(C) [Saturation]
and *Munsell Value*(V). [Luminance/Brightness]

Because of its perceptually uniform property, it is recognized as a standard system of colour specification and has been widely used in many fields of colour science.

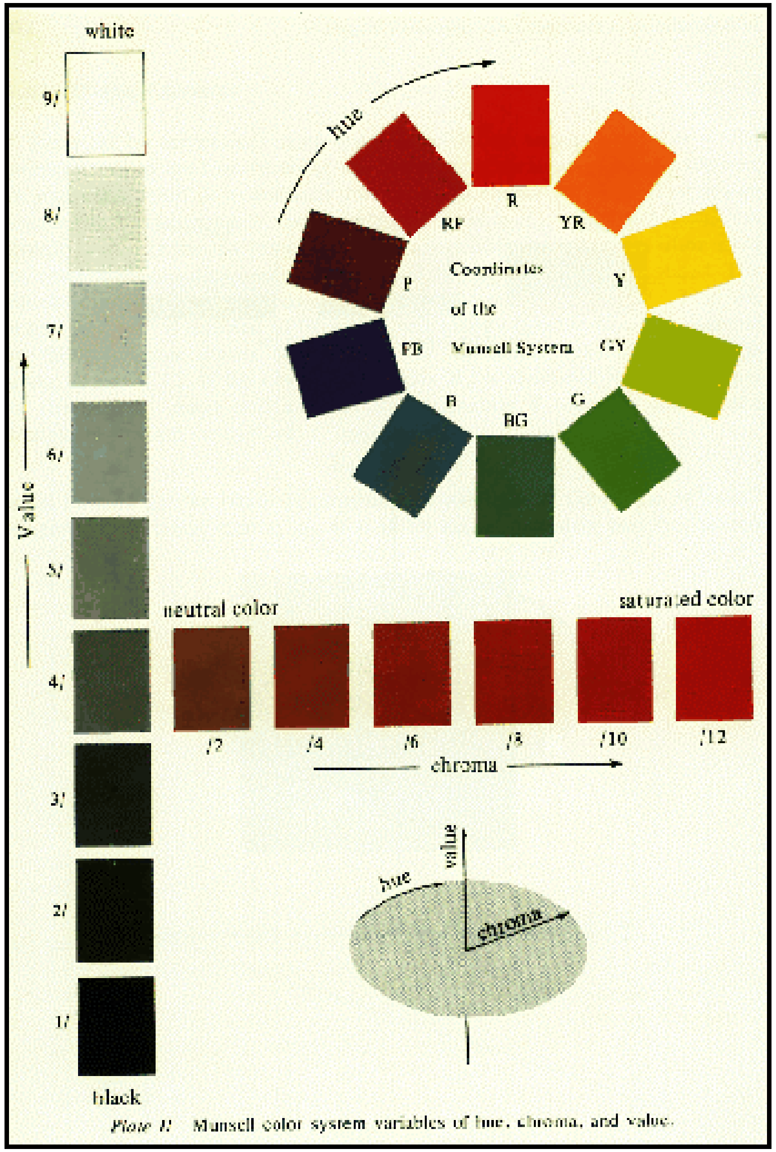


Plate II Munsell color system variables of hue, chroma, and value.

Munsell colour tree illustrating colour solid