Colour tests for qualification of irradiated materials

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Introduction

- Ionizing radiation is known to cause damage in materials.
- The extent of material degradation depends not only on the irradiation parameters (absorbed dose, dose rate, atmosphere, etc.), but also on the chemical structure of the material.
- Methods to evaluate the extent of radiation-induced changes: mechanical testing and physicochemical testing (thermal testing, colorimetry, FTIR spectroscopy, GC/MS, LC/MS spectroscopy, ESR spectroscopy, rheological testing).
- Colorimetry: technique by which a colour is evaluated in terms of standard colours (numbers or a physical colour match). The technique may be visual, photoelectric or indirect by means of reflectance/transmittance spectroscopy.

Standards

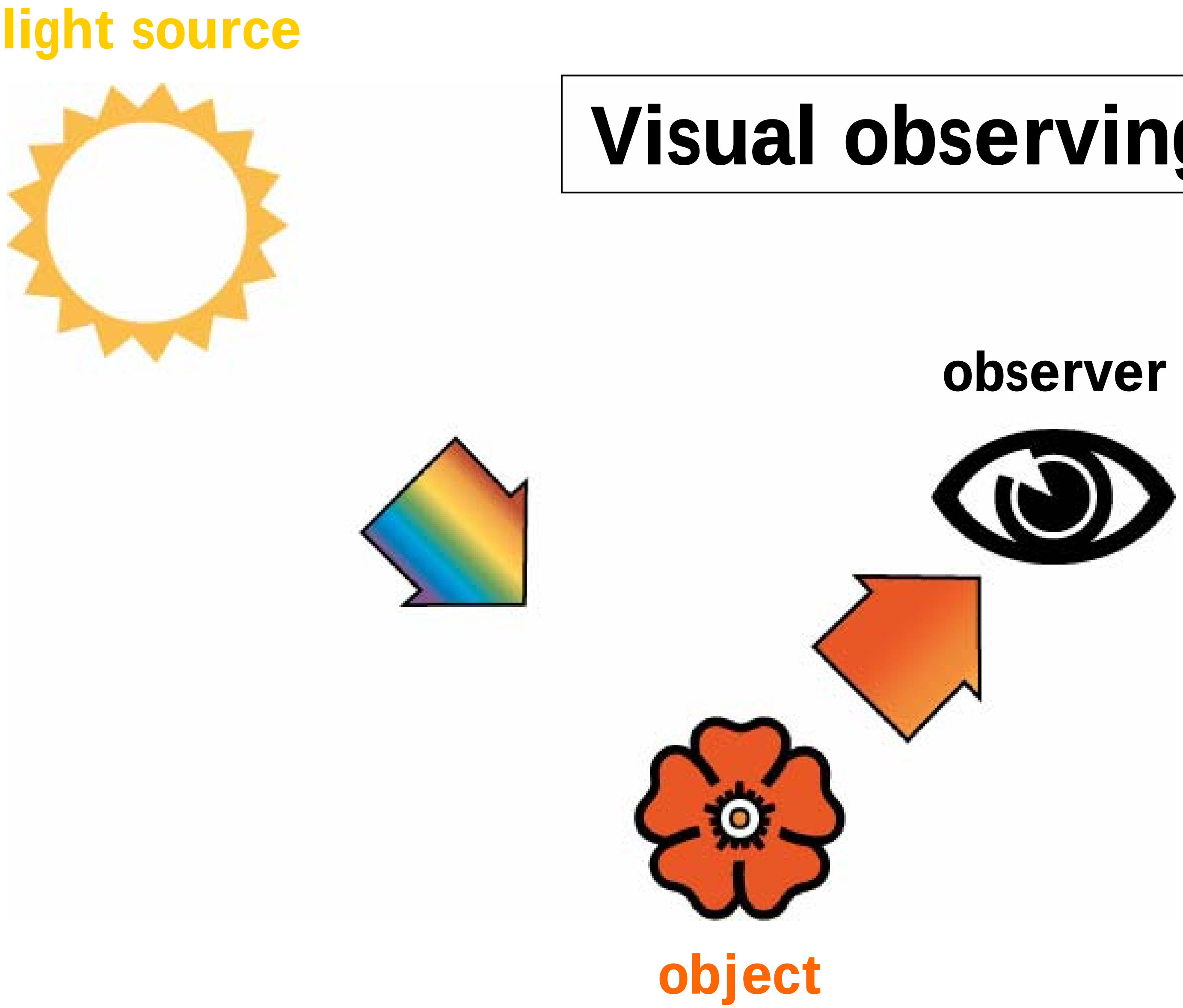
- **AATCC Test Method 173-2005** *CMC: Calculation of Small Color Differences for Acceptability*
- **ASTM D6290-05** *Standard Test Method for Color Determination of Plastic Pellets*
- **ISO 105-J03:1995** *Textiles* - *Tests for colour fastness* - *Part J03: Calculation of colour differences*
- **ISO 5631:2000** *Paper and board* - *Determination of colour (C/2 degrees)* - *Diffuse reflectance method*

Colour

- Colour is a complex phenomenon, governed by the interplay of physics, physiology, individual experience, and memory.

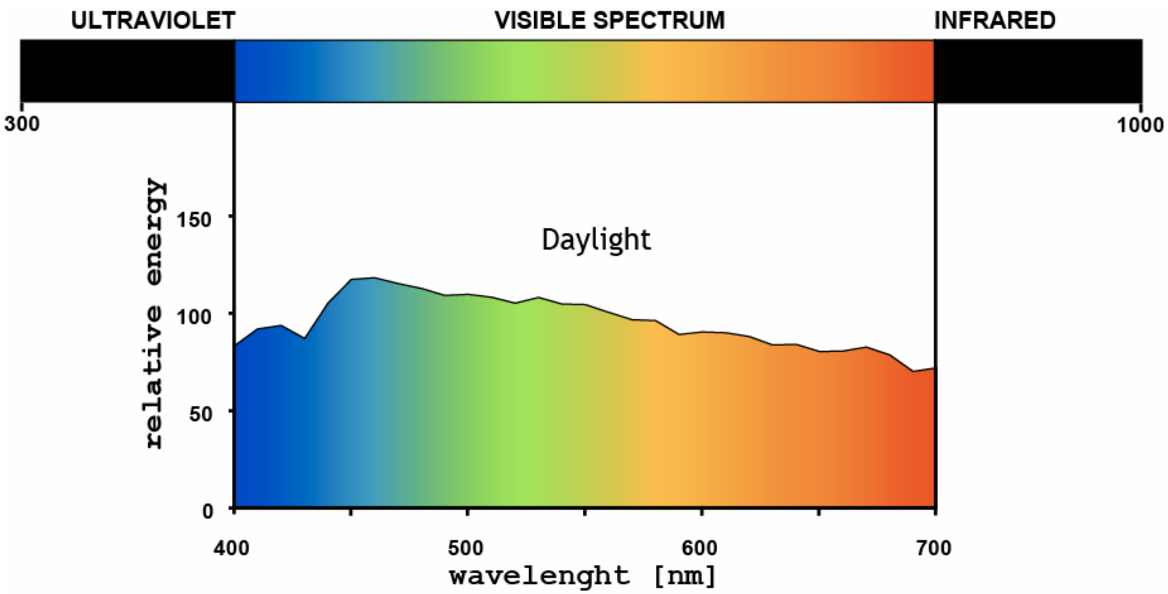
- In the simplest terms, colour is the result of the interaction between light, an object and an observer. The specific manner in which an object modifies light determines the viewer's perception of its colour.

Visual observing model



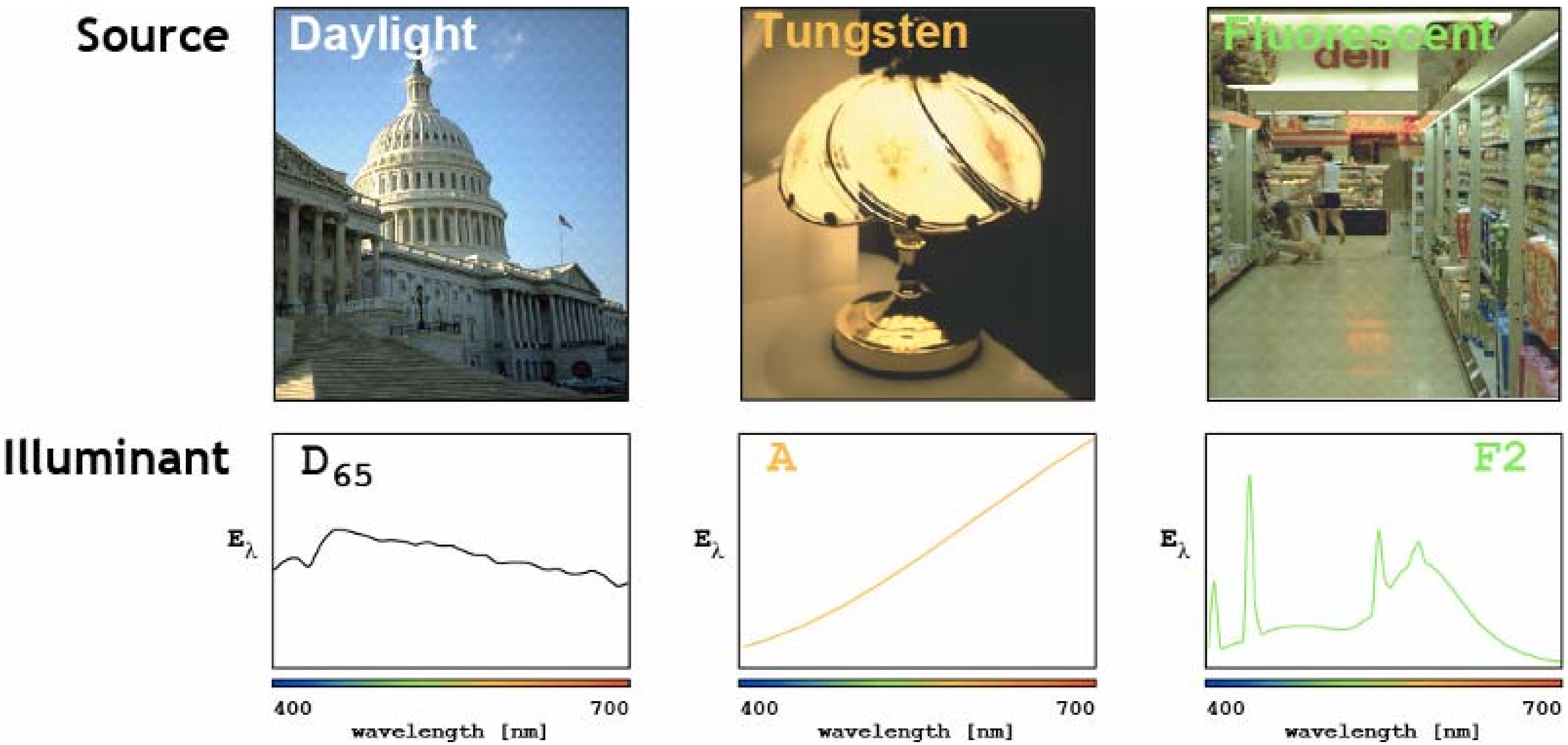
Light source

- a light source normally emits light that appears to be white
- when the light is dispersed by a prism it is seen to be made up of all visible wavelengths
- the wavelength range of visible spectrum: **`400 – 700 nm`**
- a plot of the relative energy of light at each wavelength creates a power distribution curve quantifying the spectral characteristics of the light source



Light source vs. Illuminant

- a **light source** is a real physical source of light
- an **Illuminant** is a plot, or table, of relative energy versus wavelength that represents the spectral characteristics of different types of light sources



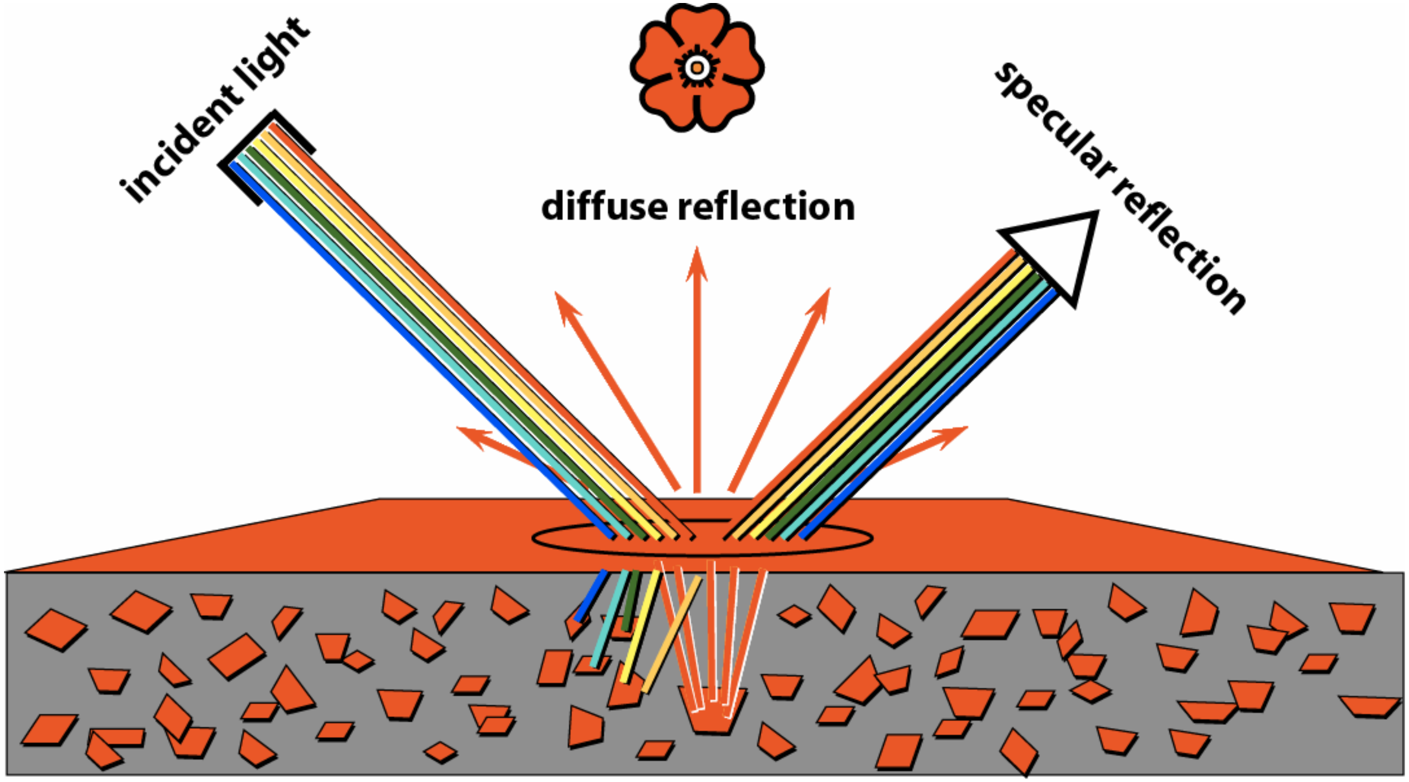
Illuminant

- **some common Illuminants:**
  - **A** Incandescent
  - **C** Average daylight
  - $\mathbf{D_{65}}$ Noon daylight
  - **F2** Cool white fluorescent
  - **U30** Ultralume

❖ **By representing a <u>light source</u> as an Illuminant, the spectral characteristics of the first element of the Visual Observing Model have been quantified and standardized.**

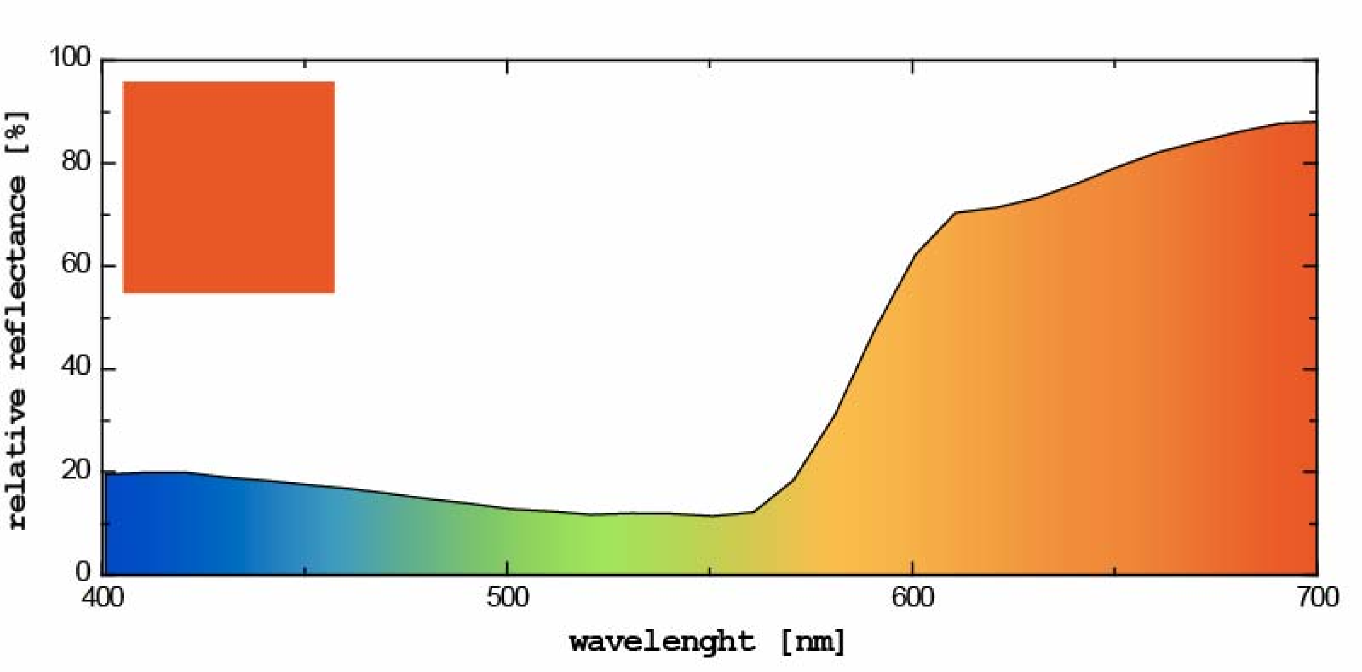
Object

❑ Objects modify light. Colorants such as pigments or dyes, in the object, selectively absorb some wavelengths of the incident light while reflecting or transmitting others.



Object

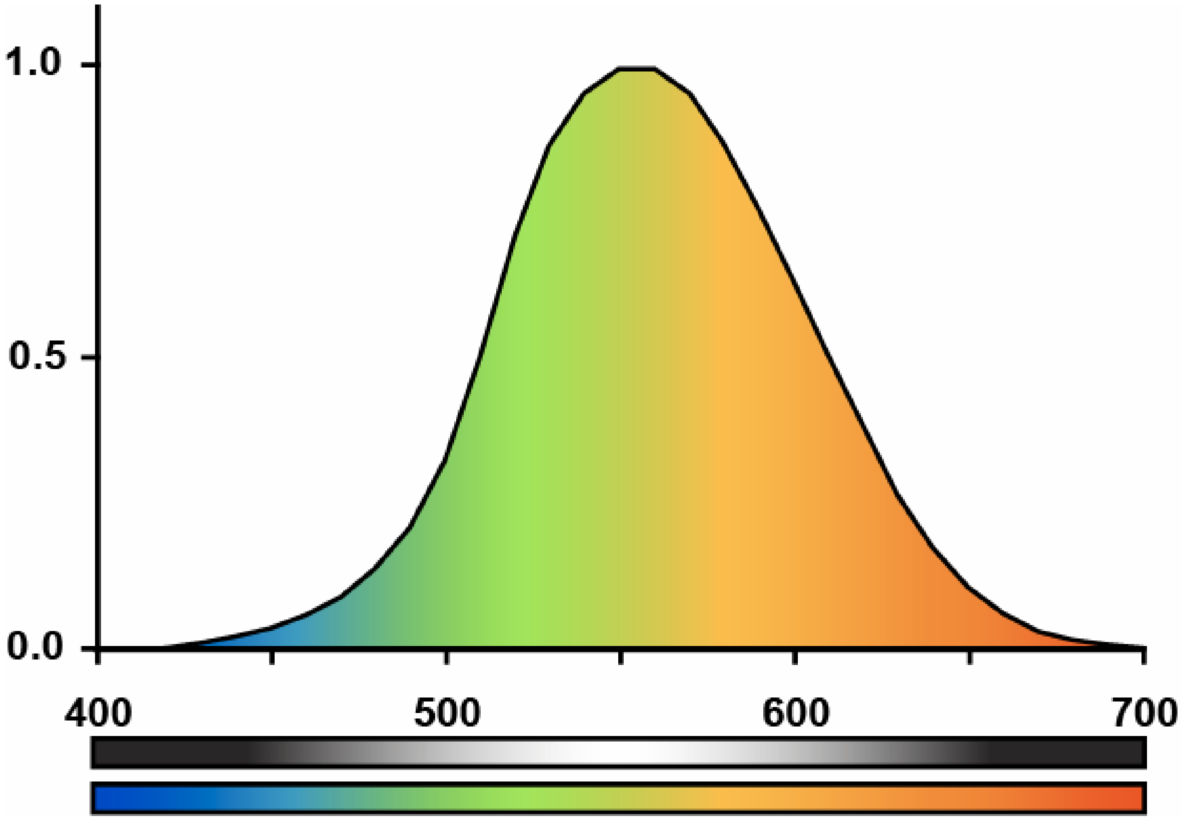
❑ The amount of reflected or transmitted light at each wavelength can be quantified. This is a spectral curve of the colour characteristics of object.



❖ **By measuring the relative reflectance or transmission characteristics of an <u>object</u>, the second element of the Visual Observing Model has been quantified.**

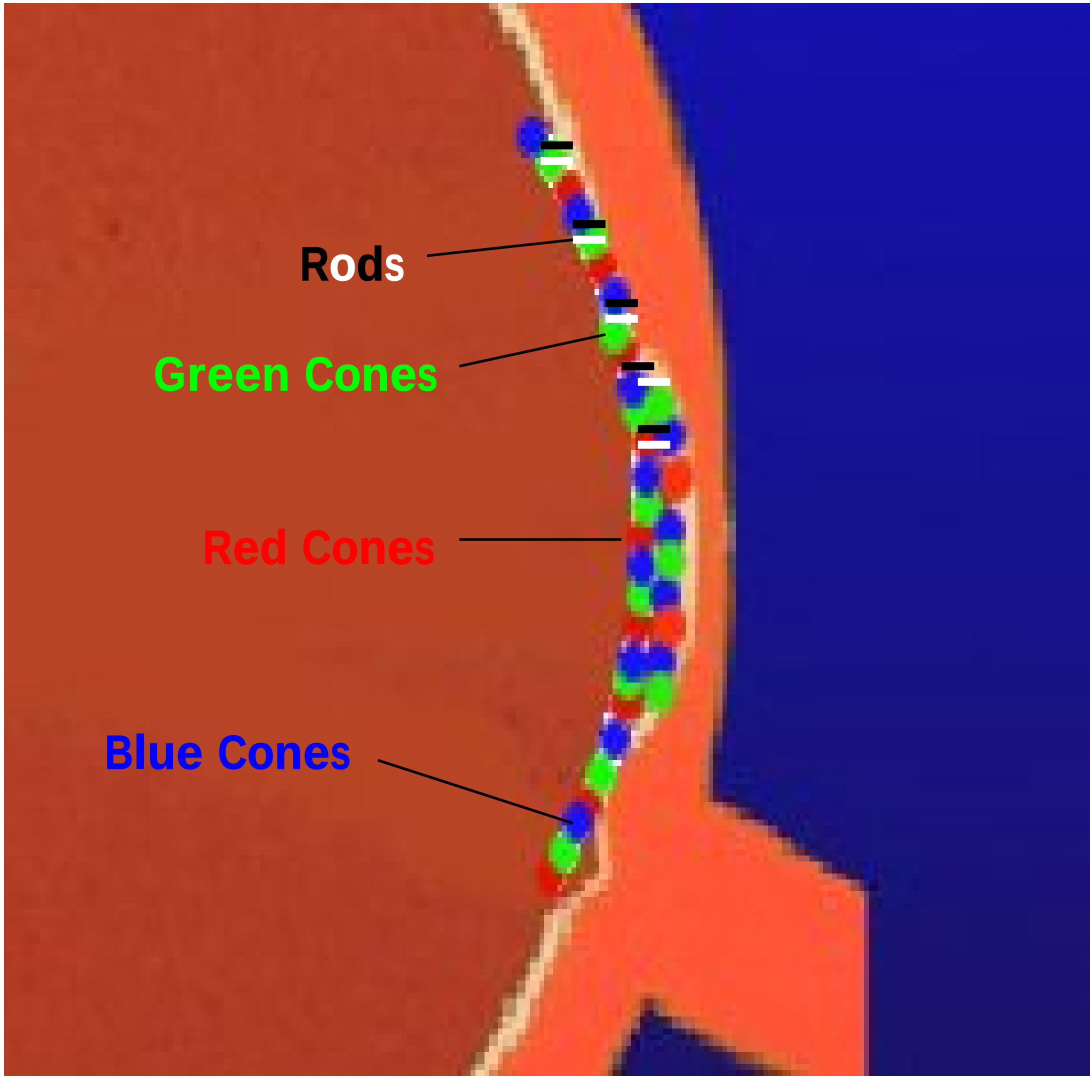
Observer

❑ Luminosity is the relative sensitivity of the human eye to various wavelengths of light.

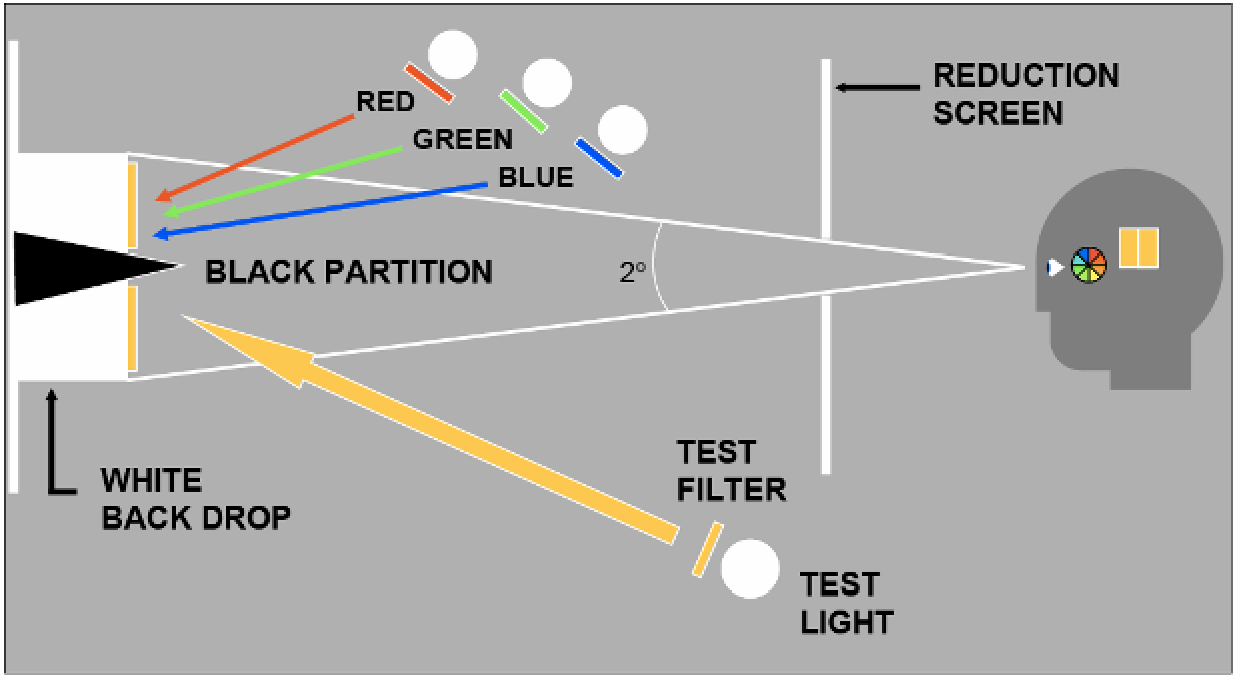


Observer – the human eye

- ❑ Rod shaped receptors are responsible for night vision.
- ❑ Cone shaped receptors are responsible for daylight and colour vision.
- ❑ There are three type of cone shaped receptors sensitive to **red**, **green**, and **blue**.



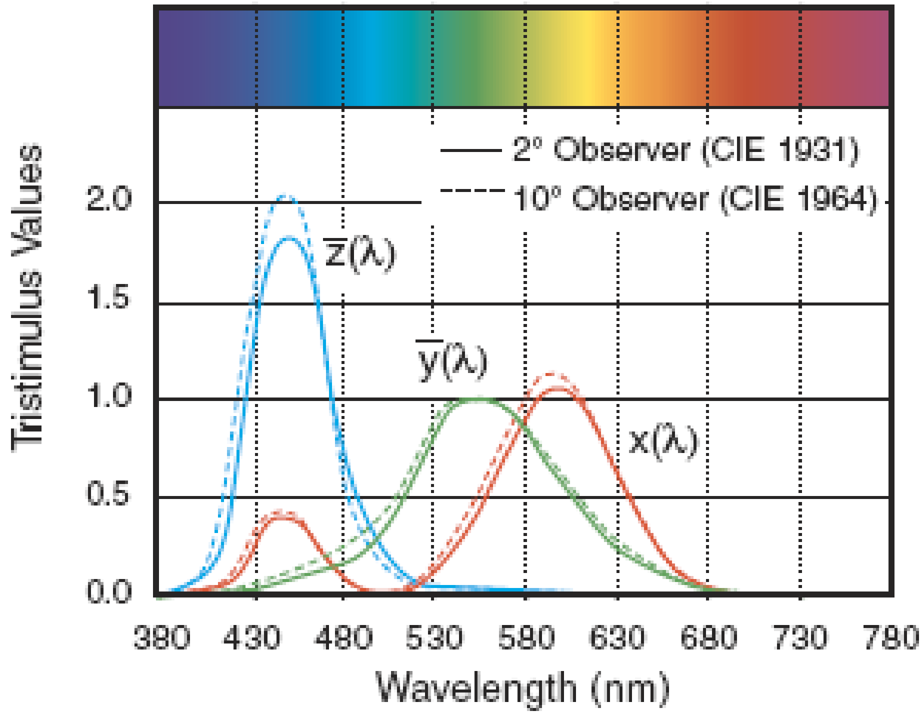
Determination of standard colorimetric observer



Experiments were conducted to quantify the ability of the human eye to perceive colour. An observer looked at a white screen through an aperture having a 2 degree field of view. Half of a screen was illuminated by a test light. The observer adjusted the intensity of three primary coloured lights that mixed together on the other half of the screen until they matched the colour of the test light.

This process was repeated for test colours covering the entire visible spectrum.

CIE Standard Observer



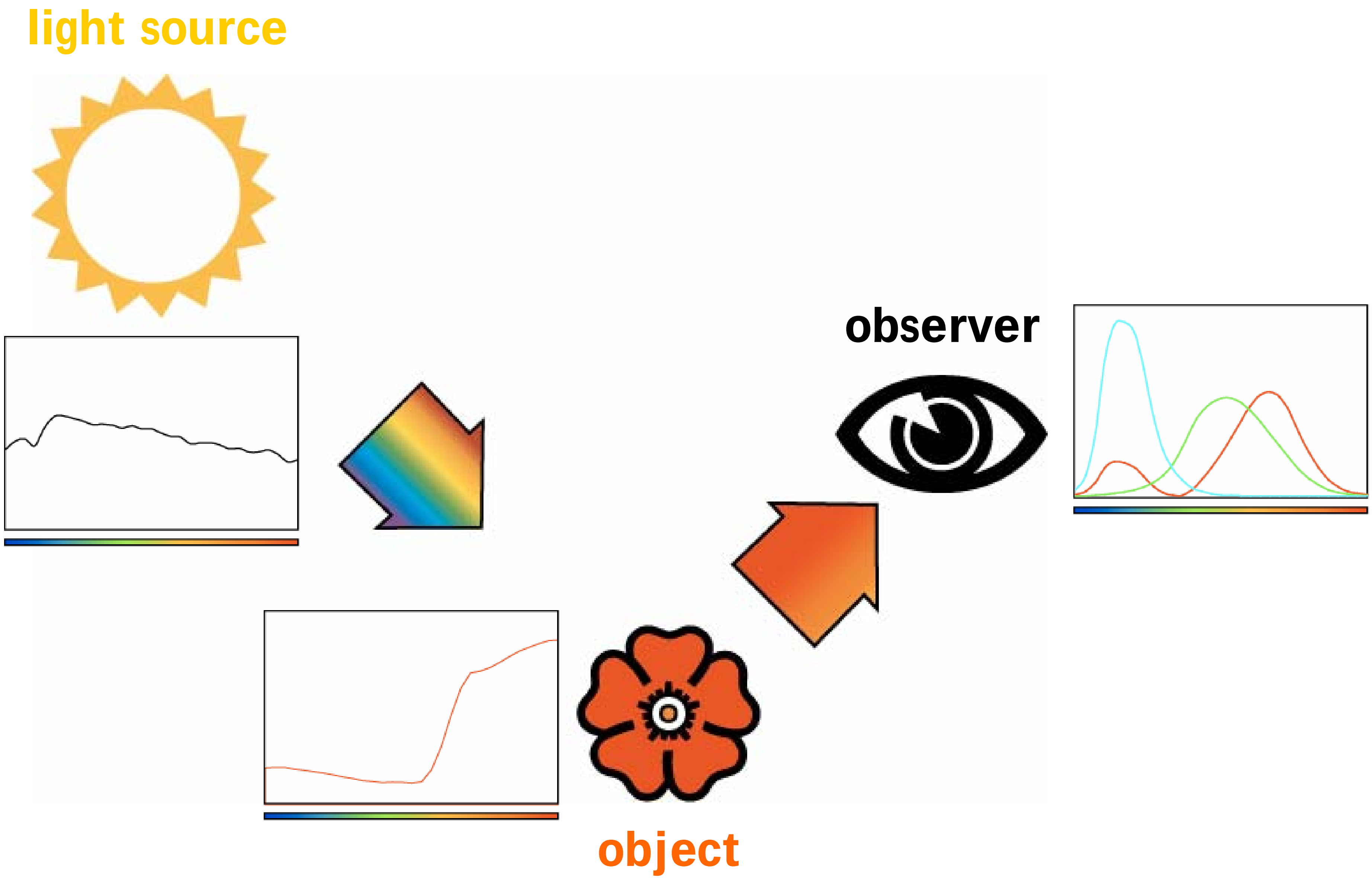
❑ The experimentally derived x, y, and z functions became the CIE 1931 2º Standard Observer. These functions quantify the red, green and blue cone sensitivity of the average human observer.

❑ At the time the 1931 2º Standard Observer experiments were conducted it was thought that the cone concentration was in the fovea region. Later it was determined that the cones were spread beyond the fovea. The experiments were re-done in 1964, resulting in the 1964 10º Standard Observer.

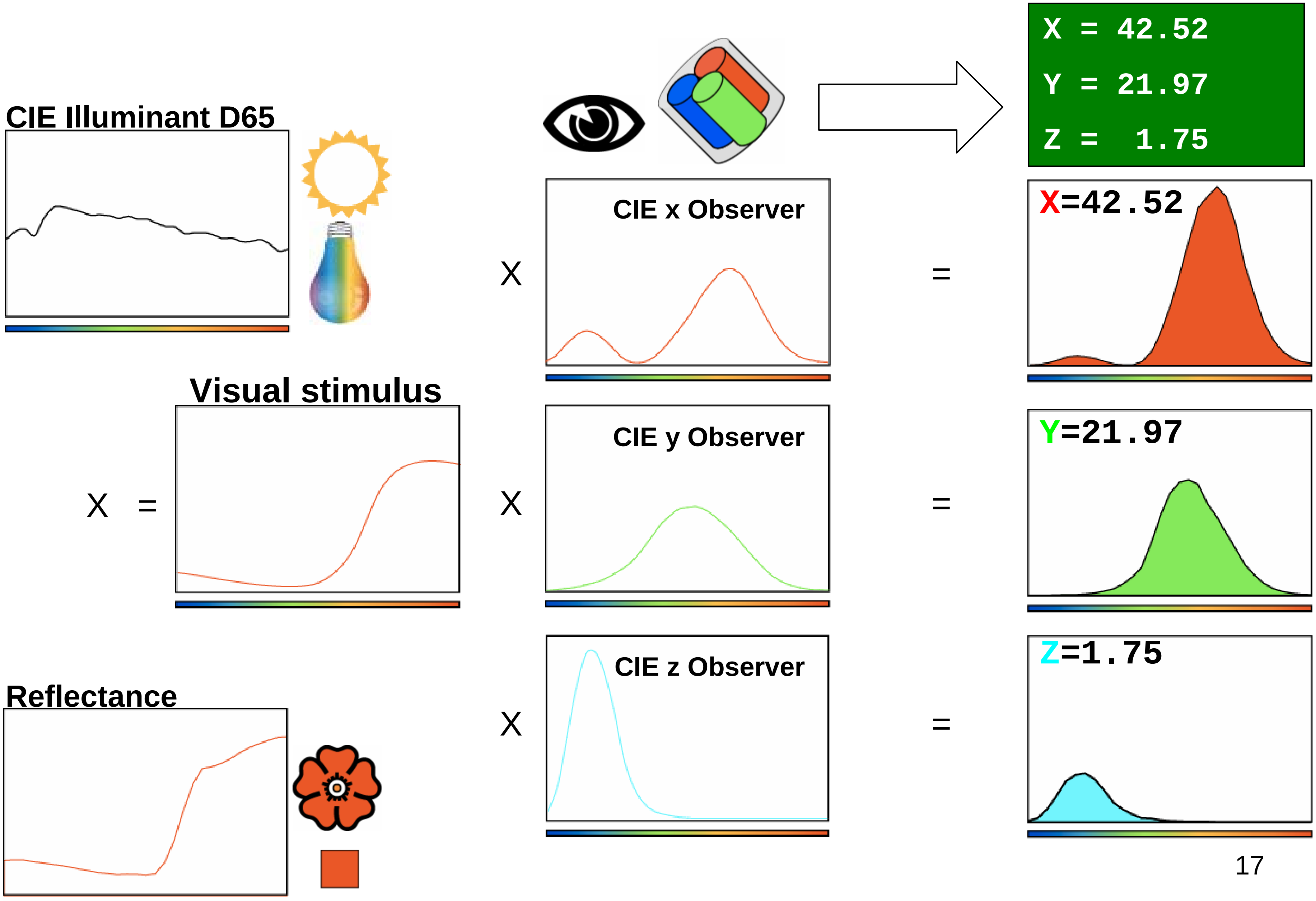
Observer

- Of the two sets of observer functions, the 10º Standard Observer is recommended for better correlation with average visual assessments made with large fields of view that is typical of most commercial applications.

  - **The third element of the Visual Observing Model is quantified by the selected CIE Standard <u>Observer</u> Functions.**


light source
observer
object

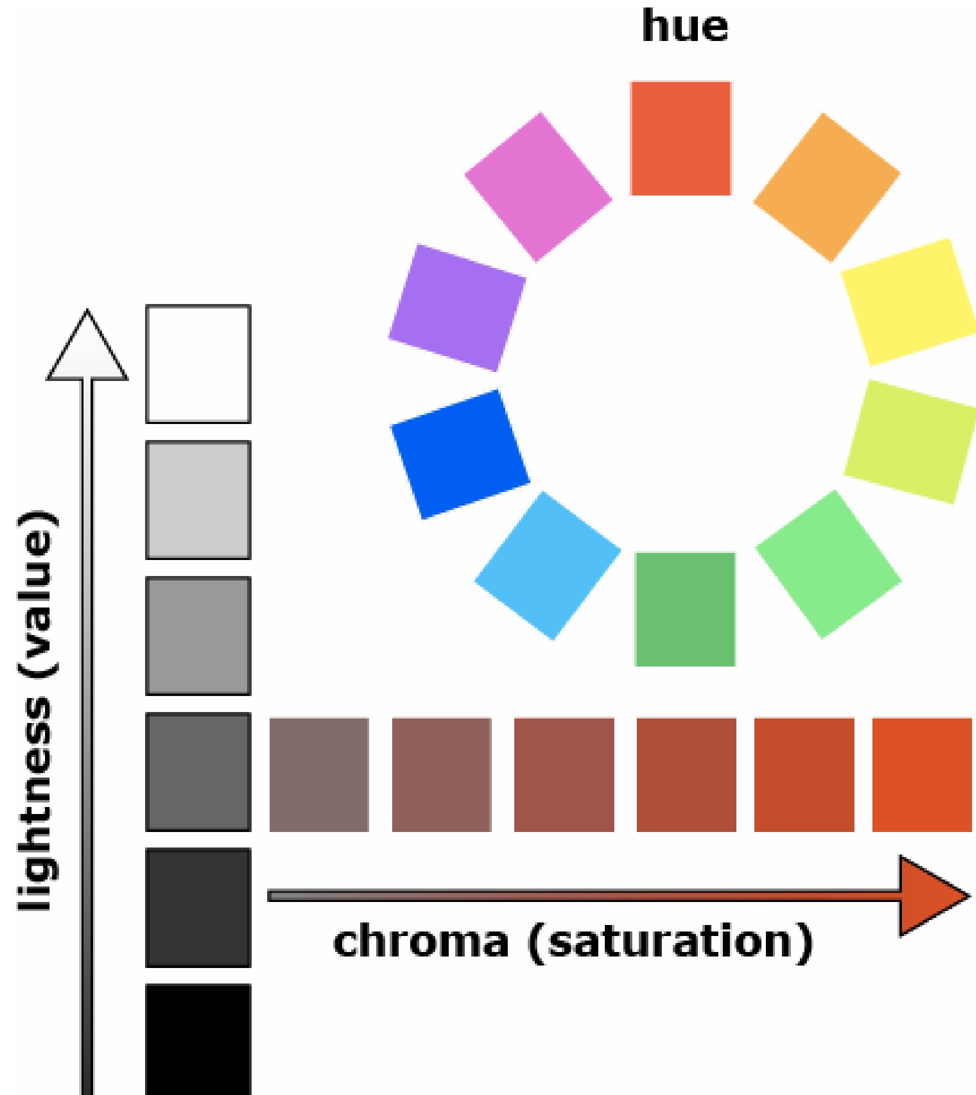
Colour measurement



Colour scales

Visual organization of colours

- **Hue** is how we perceive the colour of objects: red, orange, green, blue, etc.
- **Chroma** describes how close the colour is to either gray or the pure hue.
- **Lightness** is the luminous intensity of a colour.



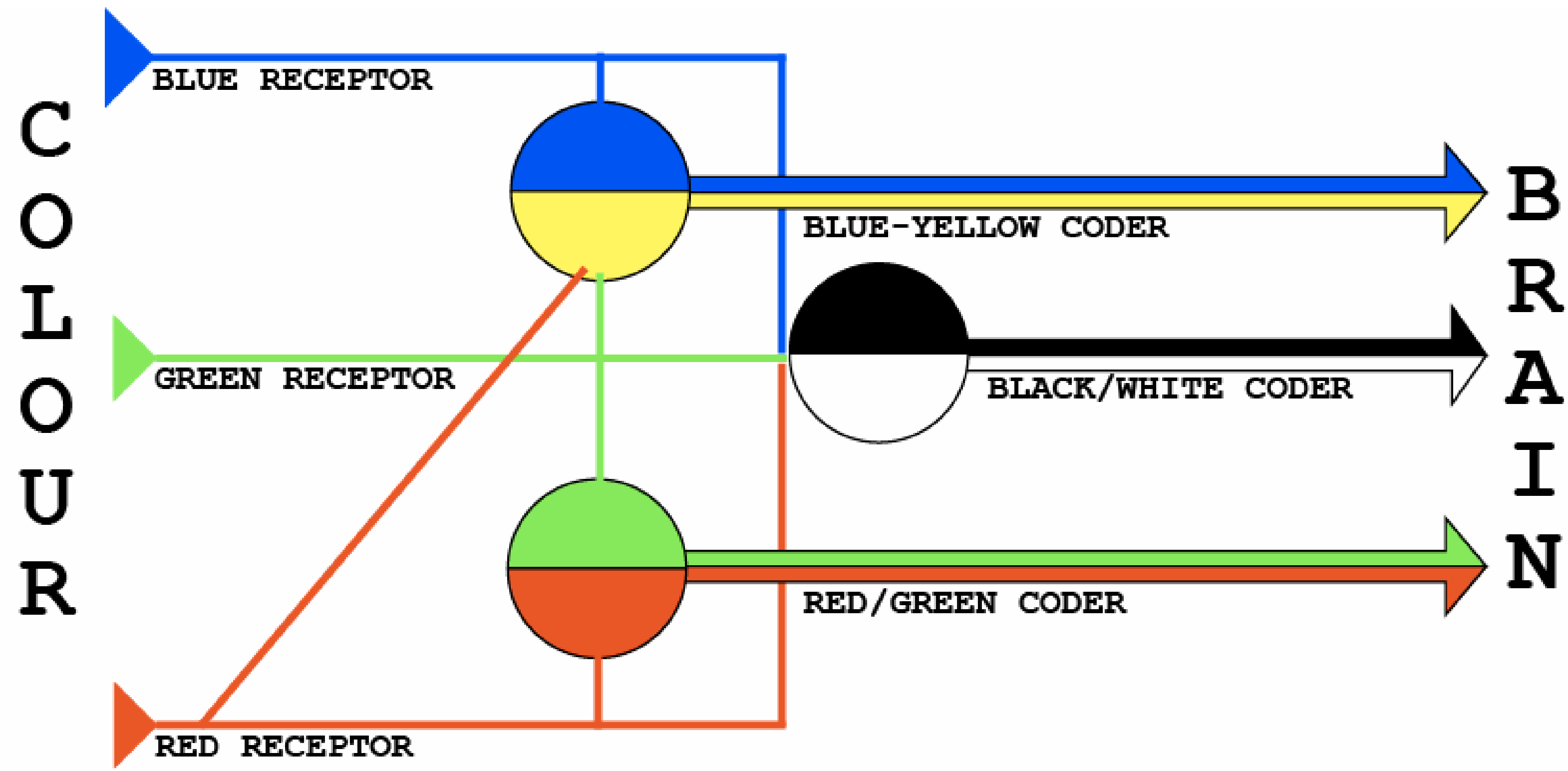
Colour scales

- Visual methods of specifying colour are **subjective**.
- Measuring colour using an instrument gives **objective** results.

- Because XYZ values are not easily understood in terms of object colour, other colour scales have been developed to:
  - Relate better to how we perceive colour
  - Simplify understanding
  - Improve communication of colour differences
  - Be more linear throughout colour space

Opponent-Colours Theory

- **Opponent-Colours Theory** states that the red, green and blue cone responses are re-mixed into opponent coders as they move up the optic nerve to the brain.



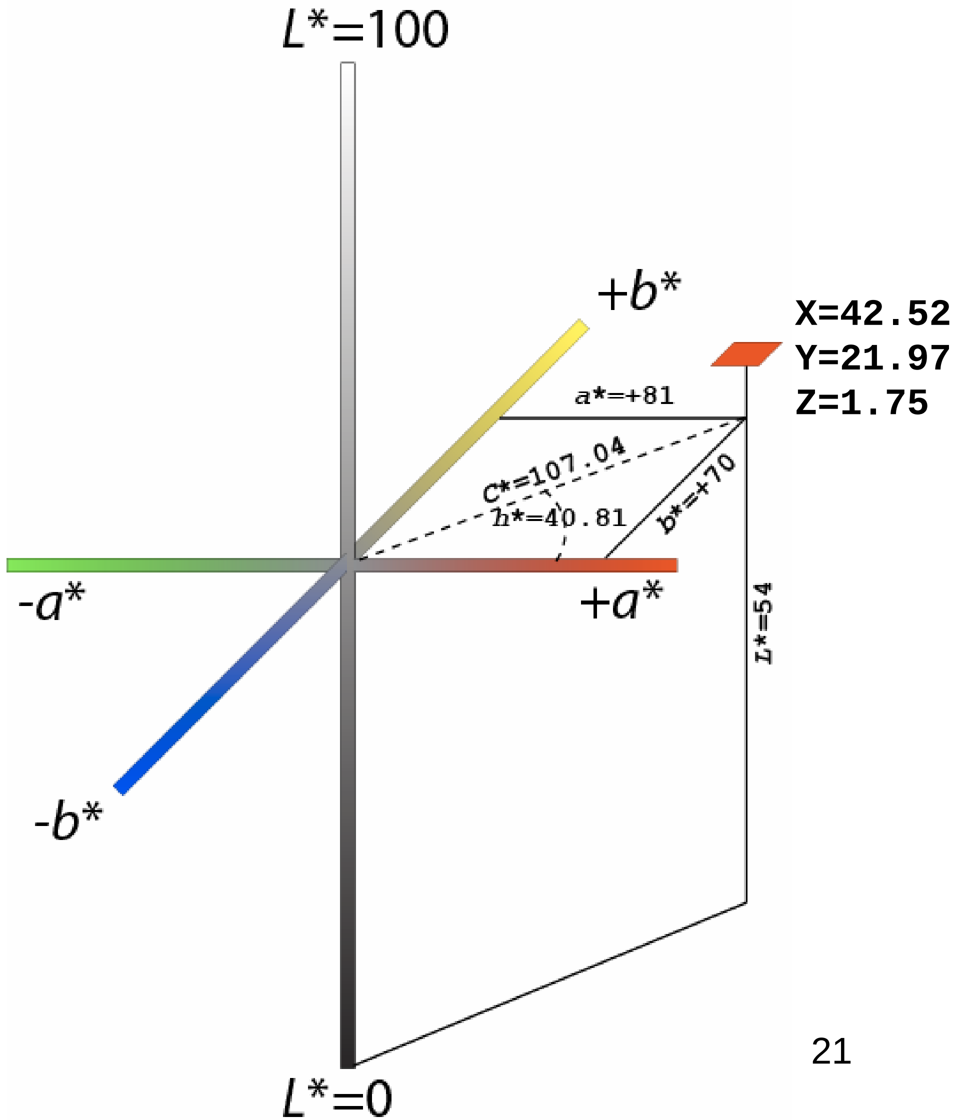
CIE 1974 *L*a*b** (CIELAB) & CIE *L*C*h** (CIELCh)

- ❑ CIELAB is an approximately uniform colour space produced by plotting in rectangular coordinates the quantities *L**, *a**, and *b**
- *L**- lightness
- *a**- red/green
- *b**- yellow/blue

- ❑ CIELCh: a modification of CIELAB scale which transforms rectangular coordinates *L**, *a**, *b** into the cylindrical coordinates *L**, *C**, *h**

$$C^* = \left[(a^*)^2 + (b^*)^2 \right]^{1/2}$$

$$h^* = \arctan(b^* / a^*)$$



CIE 1974 *L*a*b** (CIELAB) & CIE *L*C*h** (CIELCh)

- CIELAB scale is mathematically derived from the X, Y, Z values
- CIELCh describes color in the same way that we verbally communicate color in terms of lightness, chroma, and hue.

- colour differences are always calculated as **sample-standard** values

- total colour difference between two colours in CIELAB:

$$\Delta E^*_{ab} = \left[(\Delta L*)^2 + (\Delta a*)^2 + (\Delta b*)^2 \right]^{1/2}$$

- ΔE^* was intended to be a single number metric for PASS/FAIL decisions

$$L* = 116 \cdot \sqrt[3]{\frac{Y}{Y_n}} - 16$$

$$a* = 500 \cdot \left(\sqrt[3]{\frac{X}{X_n}} - \sqrt[3]{\frac{Y}{Y_n}} \right)$$

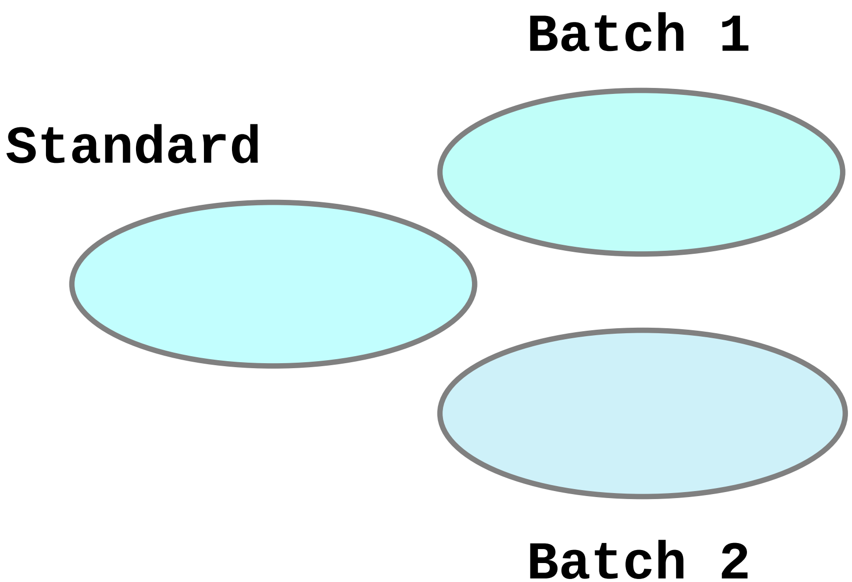
$$b* = 200 \cdot \left(\sqrt[3]{\frac{Y}{Y_n}} - \sqrt[3]{\frac{Z}{Z_n}} \right)$$

! Except very low tristimulus values

X_n, Y_n, Z_n are the tristmulus values for a particular standard Illuminant and Observer, for a sample reflecting 100% the light at all wavelengths

Non-Uniformity of ΔE* in Color Space

- ΔE* is not always reliable by itself. In the following example Batch 1 is visually a good match to the standard. Batch 2 is not. However they both have the same delta ΔE* value. For Batch 2 all of the difference is in the *a** value (less green) and is visually unsuitable.



$$\Delta E^* = \sqrt{0.57^2 + 0.57^2 + 0.57^2} = 1$$

$$\Delta E^* = \sqrt{0^2 + 1^2 + 0^2} = 1$$

Non-uniformity of Colour Space

- We find some colour difference attributes more objectionable than others:

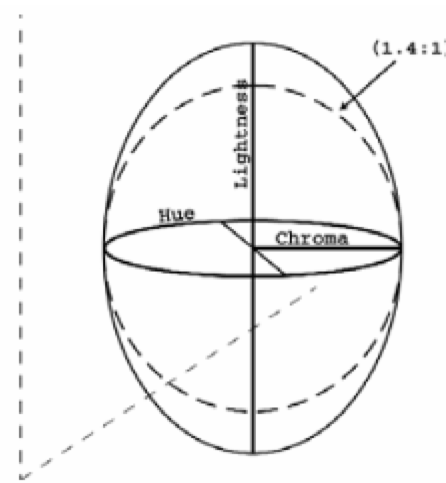
- **Hue** differences are most objectionable

- **Chroma** differences are less objectionable than hue differences

- **Lightness** differences are the least objectionable

ΔE CMC colour difference space

- CMC is a tolerancing system. CMC tolerancing is based on CIELAB (L*C*h) and provides better agreement between visual assessment and measured colour difference.
- CMC tolerancing was developed by the Colour Measurement Committee of the Society of Dyers and Colourists in Great Britain and became public domain in 1988.
- The CMC calculation mathematically defines an ellipsoid around the standard colour with semi-axis corresponding to hue, chroma, and lightness. The ellipsoid represents the volume of acceptable colour and automatically varies in size and shape depending on the position of the colour in colour space.



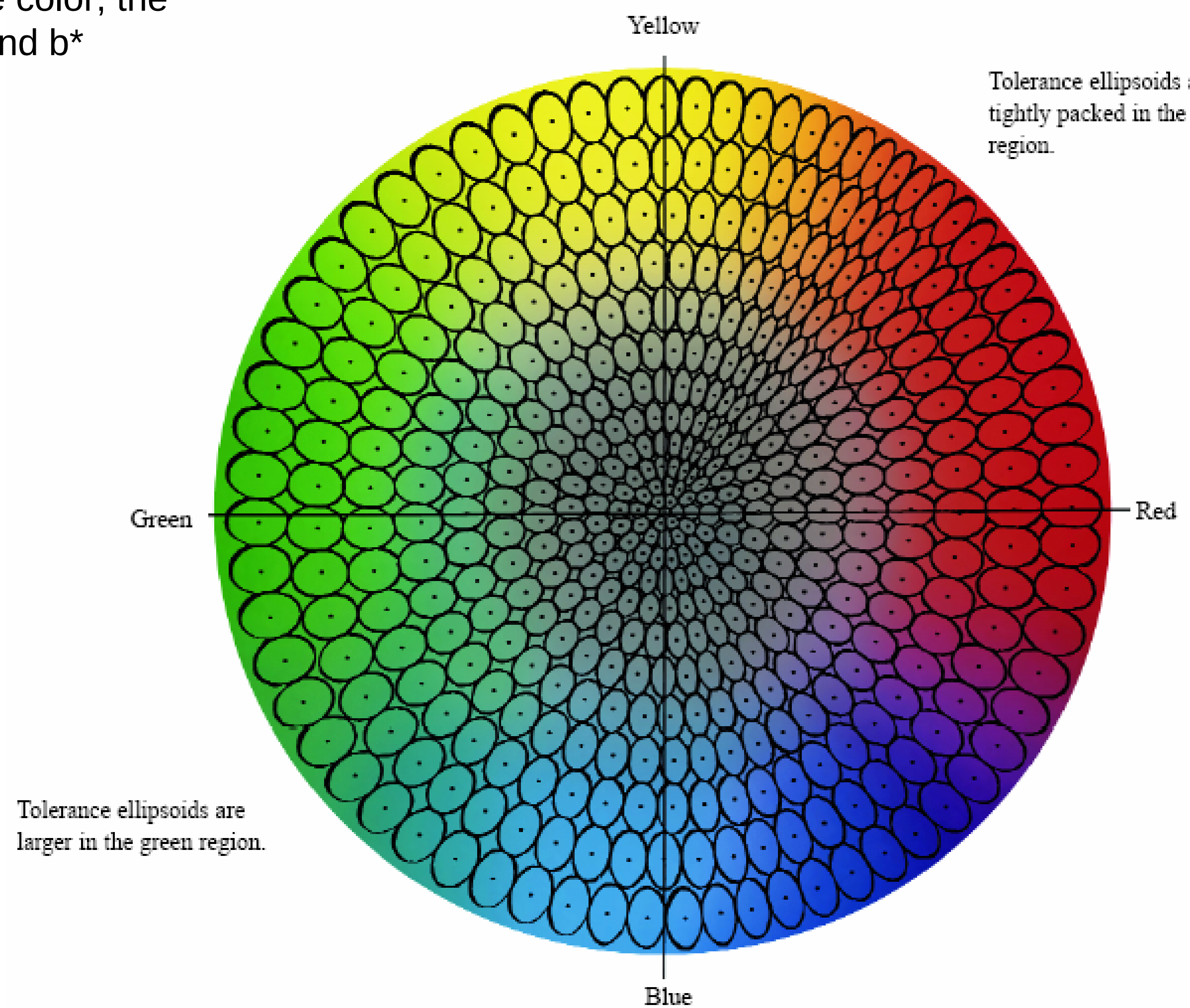
$$\Delta E_{\mathrm{CMC}} = cf \cdot \sqrt{\left(\frac{\Delta L*}{l \cdot \mathrm{SL}}\right)^2 + \left(\frac{\Delta C*}{c \cdot \mathrm{SC}}\right)^2 + \left(\frac{\Delta H*}{\mathrm{SH}}\right)^2}$$

cf- commercial factor (the maximum acceptable limit, the size of the ellipsoid)

l:*c*- lightness to chroma ratio; the textile industry has adopted a ratio of 2:1 while the plastics industry is recommending 1.4:1

Tolerance ellipsoids in colour space

The more chromatic (saturated) the color, the larger the a* and b* tolerance.



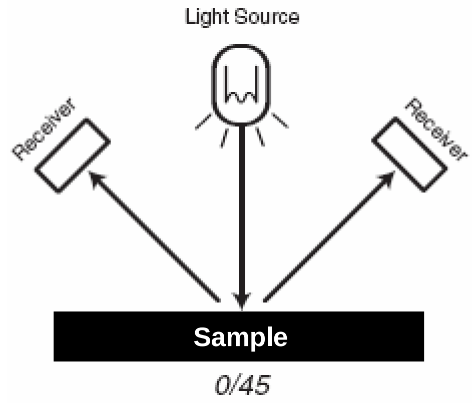
Instrument geometry

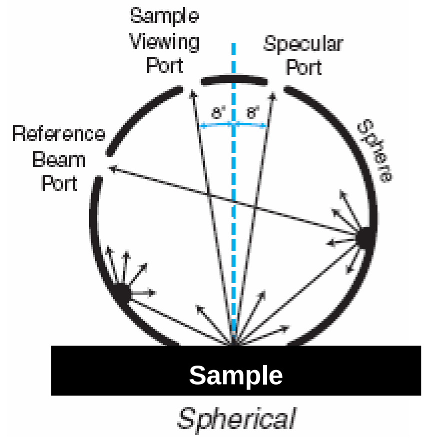
Most commonly used instruments for measuring colour are spectrophotometers. They measure reflected or transmitted light at many points on the visual spectrum, which results in a curve.

The geometry of an instrument defines the arrangement of light source, sample plane and detector. There are two general categories of instrument geometries, **directional** (45º/0º or 0º/45º) and **diffuse** (sphere).

- **45/0** geometry provides measurements that correspond to visual changes in appearance of the sample due to both changes in pigment colour and surface gloss or texture.

- **Diffuse** (sphere) geometry instruments typically use a white coated sphere to diffusely illuminate the sample. The measurement is at an 8º angle (**d/8º**). This negates differences due to surface differences and provides measurements that correspond to changes due only to pigment colour.





Results: copy paper

reference (unirradiated)			25 kGy					50 kGy				
L^* ($\pm T$)	a^* ($\pm T$)	b^* ($\pm T$)	ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{CMC}	ΔL^*	Δa^*	Δb^*	ΔE^*	ΔE_{CMC}
94.56 (±2.18)	2.42 (±0.78)	-11.64 (±1.28)	-0.13	-0.58	2.72	2.79	2.15	-0.04	-1.02	4.87	4.98	3.84

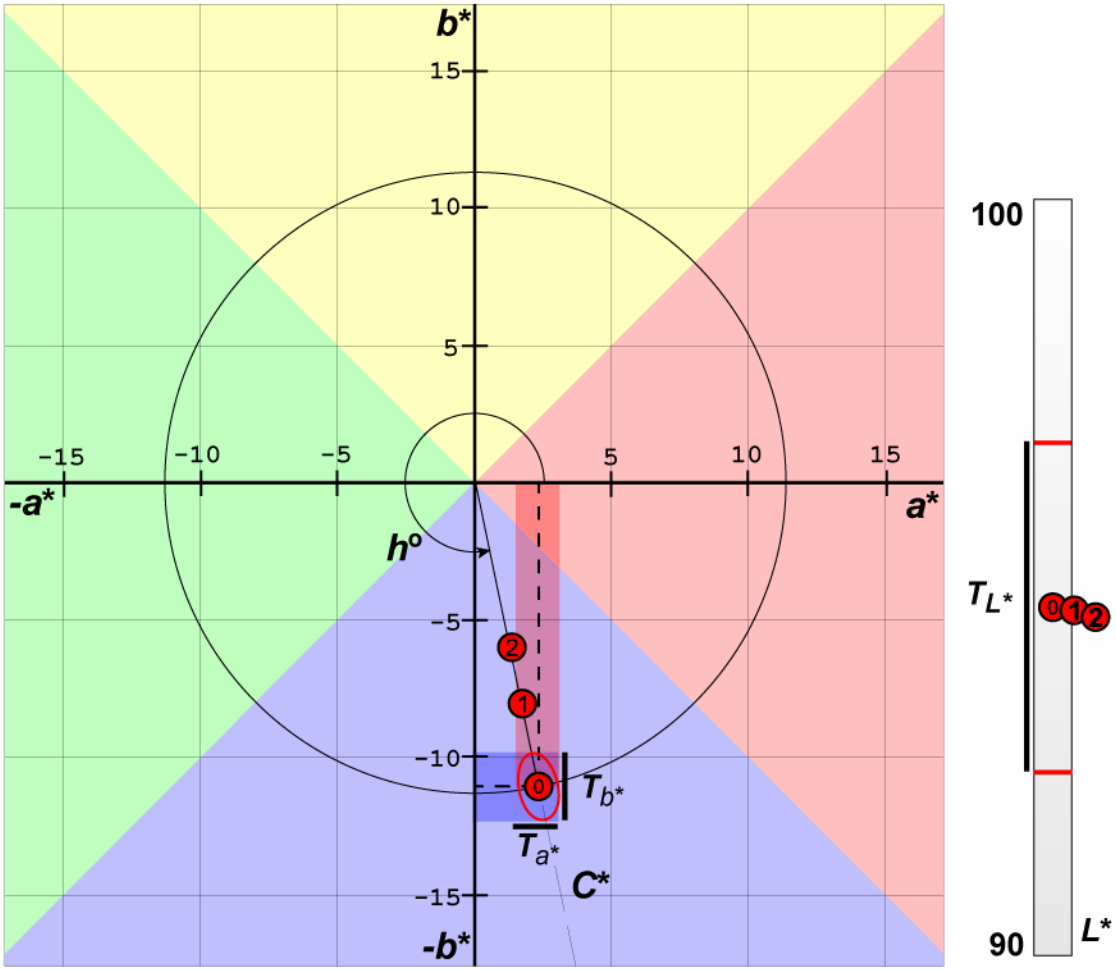
- *T*: rectangular tolerances for *L**, *a**, *b** based on ΔE CMC colour difference formula (*cf* = 1; *l*:*c* = 2:1)
- Illuminant/Observer: D65/10°
- geometry: d/8°

Results: copy paper

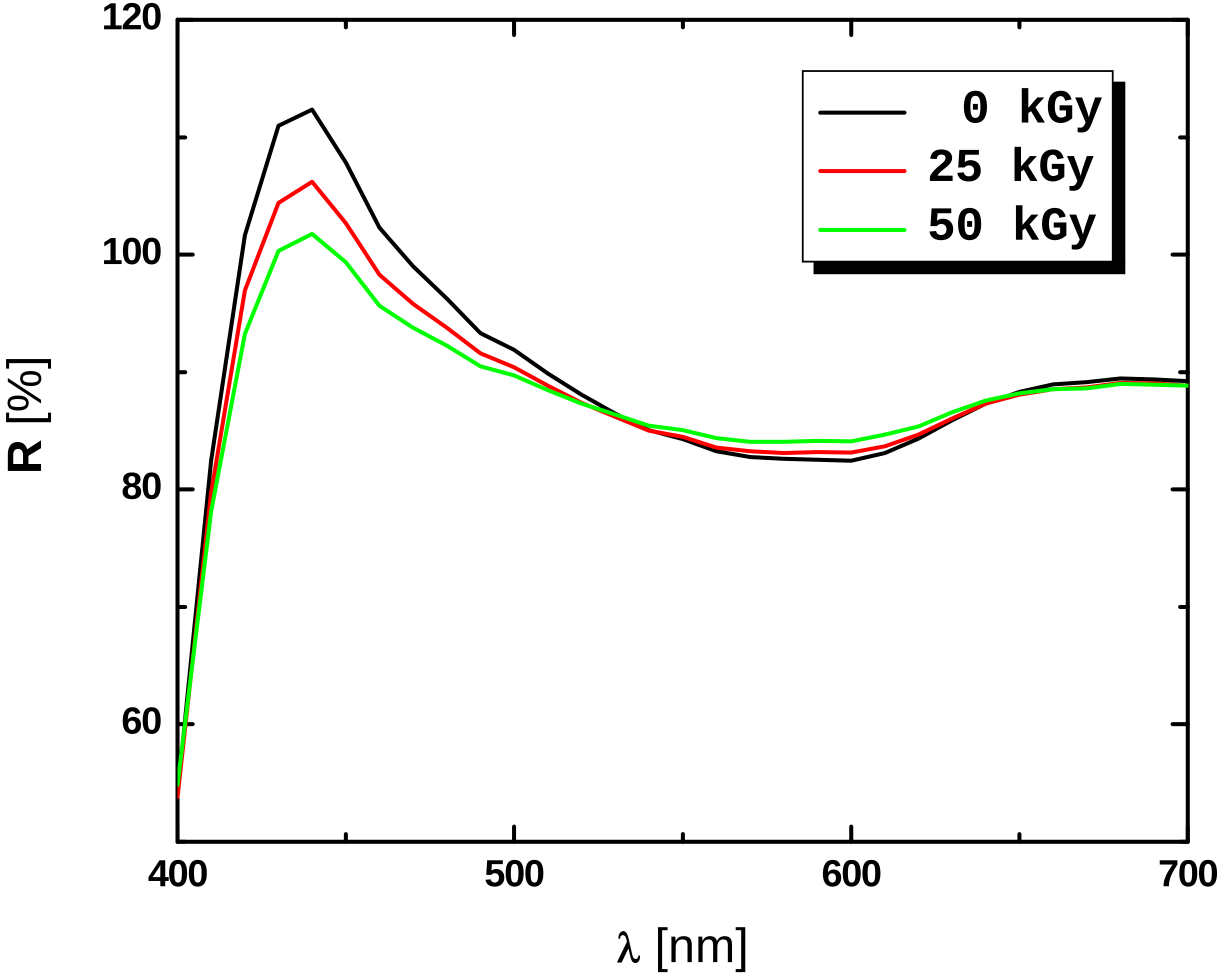
0: unirradiated (reference)

1: irradiated 25 kGy

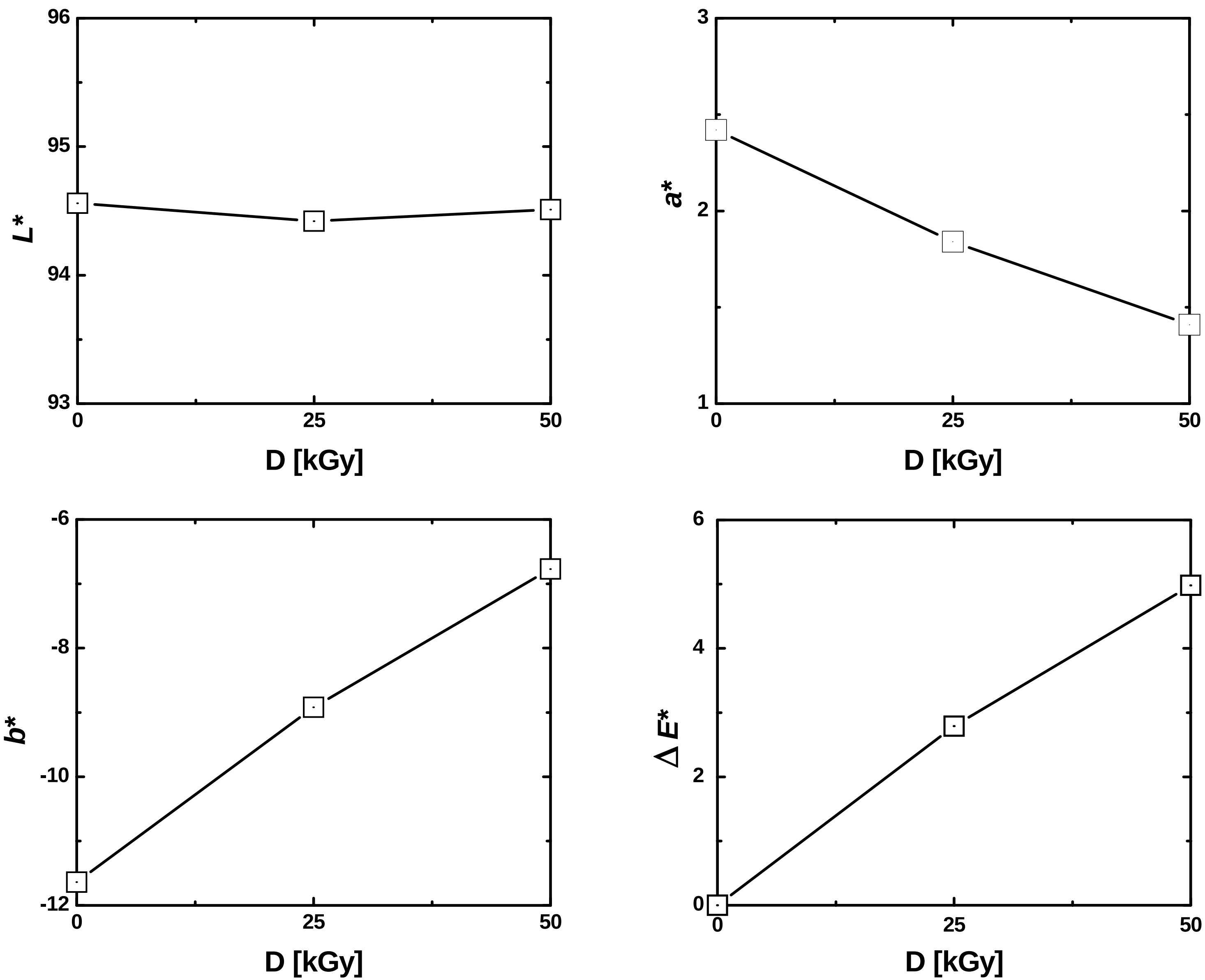
2: irradiated 50 kGy



Reflectance spectral plot



Colour vs. dose



Thank you for your attention!