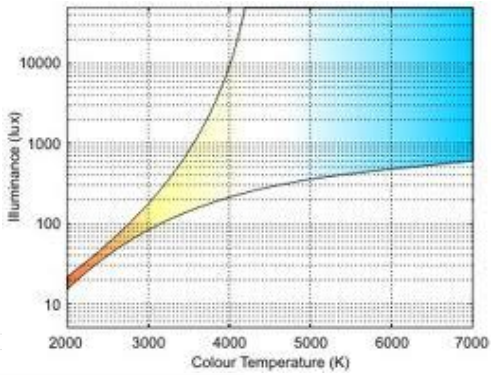
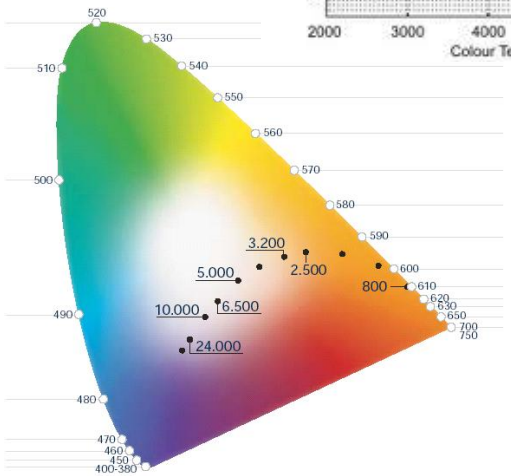
Design of visual environment





Outline

- **CIE Colorimetry for light sources**
  - **Fundamentals of Colorimetry**
  - **Planckian radiators or incandescent light sources**
  - **Correlated color temperature**
  - **Color rendering index**
  - **Daylight simulation**
- **Discussion**
  - **Supplementary reading and learning:**
    - **Psychological factors of color in decoration, advertising, computer graphics, digital cinema, videogames and virtual reality**
  - **Mandatory activity no. 3**

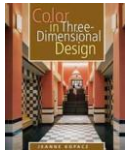
Bibliography & Links

- **Basic:**

- **SMITH, N.A.: *Lighting for Health and Safety*. Oxford: Butterworth-Heinemann, 2000.**

- **LILLO JOVER, J.: *Ergonomía. Evaluación y diseño del entorno visual*. Madrid: Alianza Editorial, Psicología y Educación, 2000.**

- **BOYCE, P.R.: *Human factors in lighting*, 2nd ed., London: Taylor & Francis, 2003.**



- **KOPACZ, J.: *Color in Three-Dimensional Design*. New York: McGraw-Hill, 2004.**

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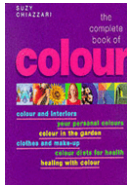
- **Basic:**



- **CHIAZZARI, S.:** ***The complete book of colour : using colour for lifestyle, health and well-being*****. London: Element, 2000.**

- **GARCÍA-GAITE, G.:** ***Iluminación y seguridad laboral*****. Madrid: Fundación Mapfre, 2003.**

- **JACKSON, R., MACDONALD, L., FREEMAN, K.:** ***Computer generated colour: a practical guide to presentation and display*****. Chichester: John Wiley and Sons, 1994.**

- **CIE – International Commission on Illumination: http://www.cie.co.at , Divisions 2, 3 and 5.**

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- **Complementary:**

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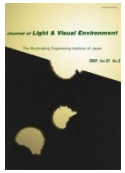
- **GAGE, J.: *Colour and meaning: art, science and symbolism*. London: Thames and Hudson, 2002.**

- **HELLER, E.: *Psicología del color: cómo actúan los colores sobre los sentimientos y la razón*. Barcelona: Gustavo Gili, 2004.**

- **CUTTLE, C.: *Lighting by design*. 2nd ed. Oxford: Architectural Press, Elsevier, 2008.**

Bibliography & Links

- **Complementary:**



- **Comité Español de Iluminación: http://www.ceisp.com/ .**
- **Journal of Light & Visual Environment: http://www.ieij.or.jp/english/publish/JLVE.html .**
- **Light & Engineering: http://www.svetotekhnika.com/lightandengineering_founders.html .**

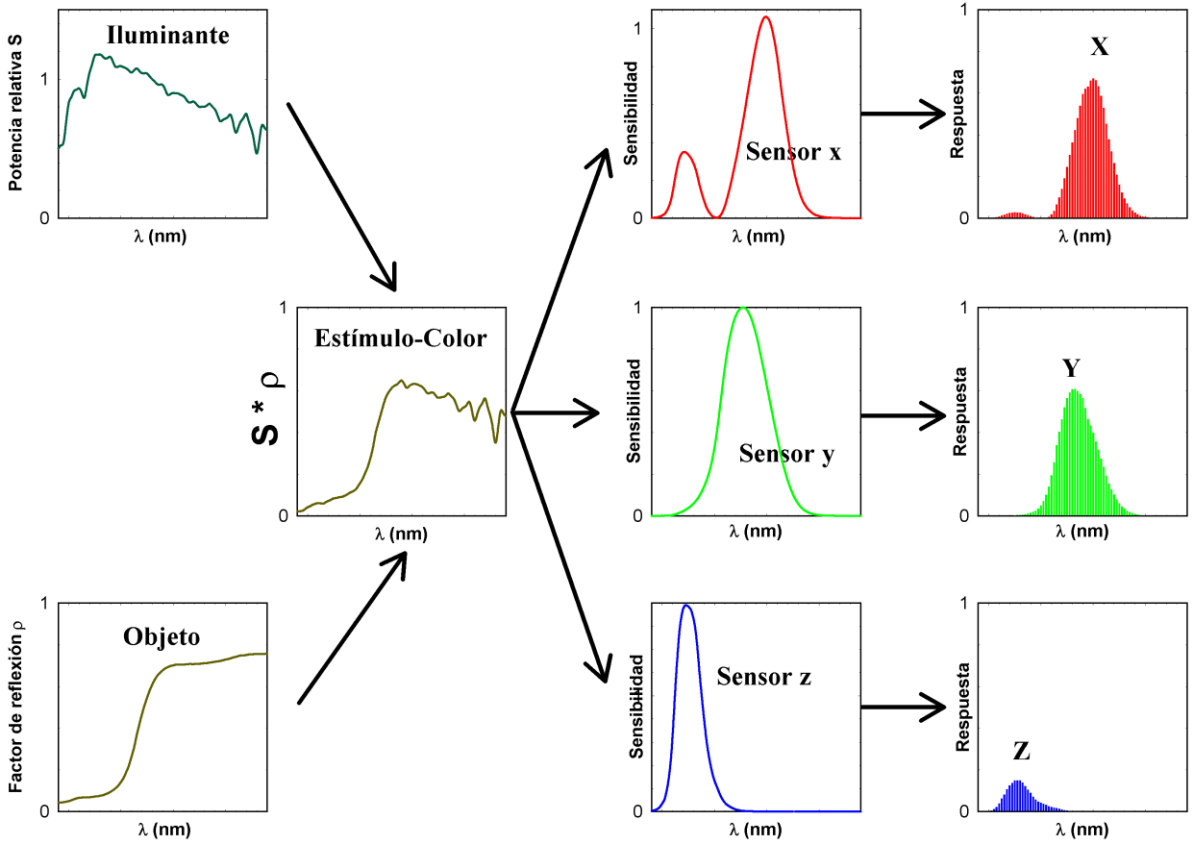
- **The Lighting Journal: http://www.ile.org.uk/ .**
- **Lighting Research & Technology: http://lrt.sagepub.com/**

Introduction: objectives

- **Can we artificially light like (solar) daylight?**
  - **Daylight is highly variable → average**
- **What would be the visual consequences if this is not possible?**
- **When is advisable to choose lamps that simulate daylight?**

Fundamentals of Colorimetry

- **Color space CIE-1931 XYZ (I):**



Tristimulus values (area)

Fundamentals of Colorimetry

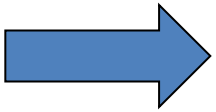
- **Color space CIE-1931 XYZ (II):**

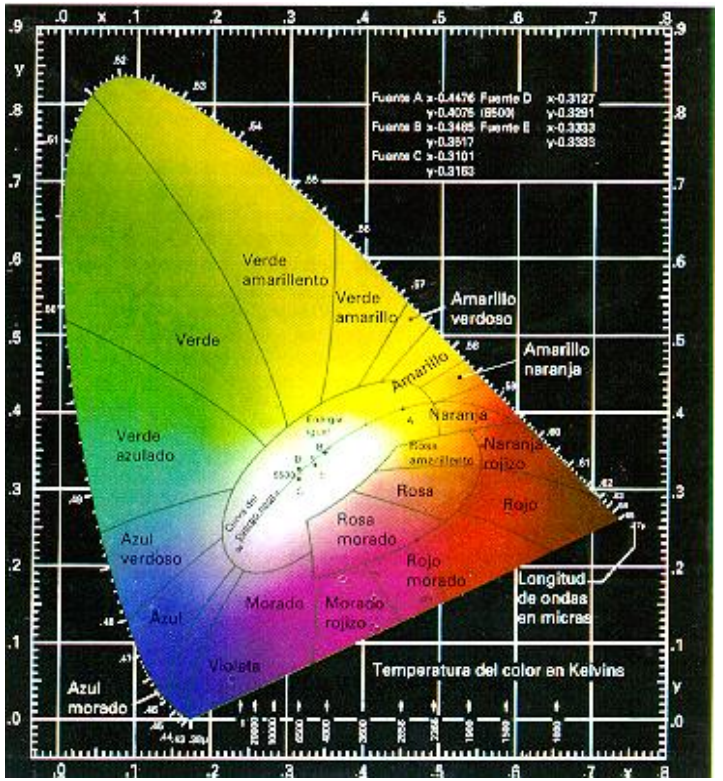
$$X = k \sum_{380nm}^{780nm} S(\lambda)\rho(\lambda)\bar{x}(\lambda)\Delta\lambda$$

$$Y = k \sum_{380nm}^{780nm} S(\lambda)\rho(\lambda)\bar{y}(\lambda)\Delta\lambda$$

$$Z = k \sum_{380nm}^{780nm} S(\lambda)\rho(\lambda)\bar{z}(\lambda)\Delta\lambda$$

$$k = \frac{100}{\sum_{380nm}^{780nm} S(\lambda)\rho(\lambda)\bar{y}(\lambda)\Delta\lambda}$$





Fundamentals of Colorimetry

- **Color space CIE-L*a*b*C_{ab}*h_{ab} (I):**

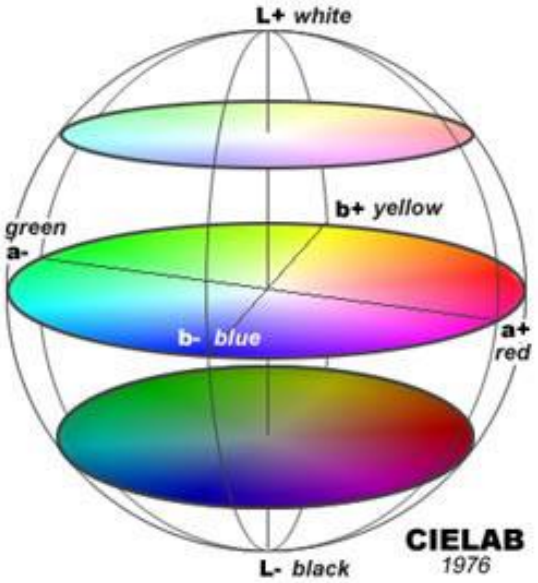
$$L^* = 116\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16$$

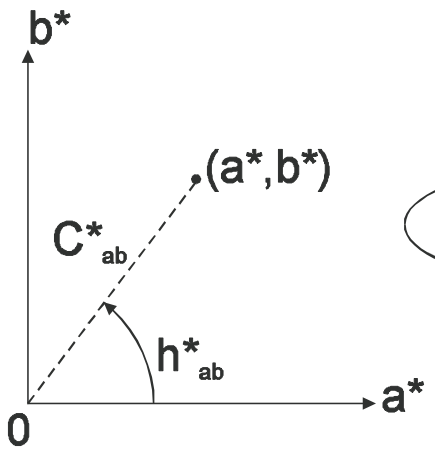
$$a^* = 500\left[\left(\frac{X}{X_n}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right]$$

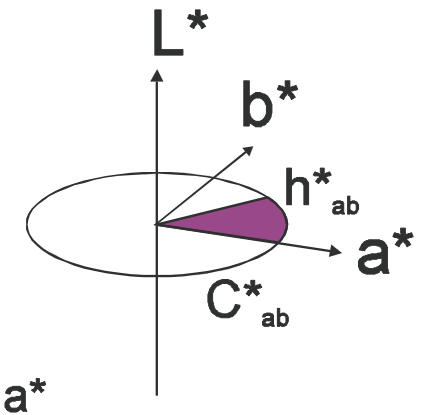
$$b^* = 200\left[\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right]$$

$$C^*_{ab} = \sqrt{\left(a^*\right)^2 + \left(b^*\right)^2}$$

$$h_{ab} = \arctan\left(\frac{b^*}{a^*}\right)$$

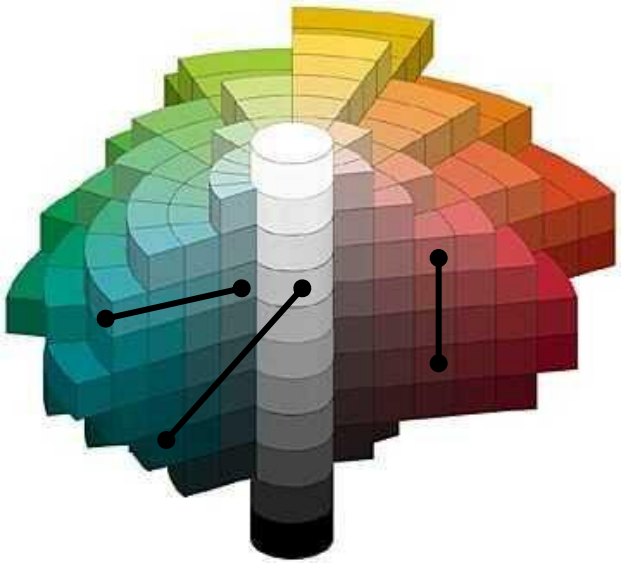






Fundamentals of Colorimetry

- **Color space CIE-L*a*b*C_{ab}*h_{ab} (II):**

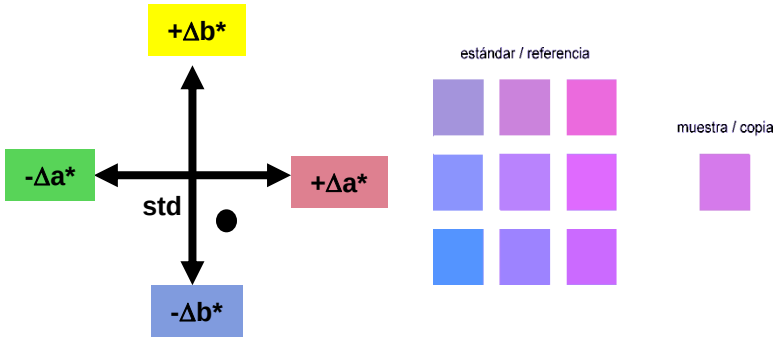


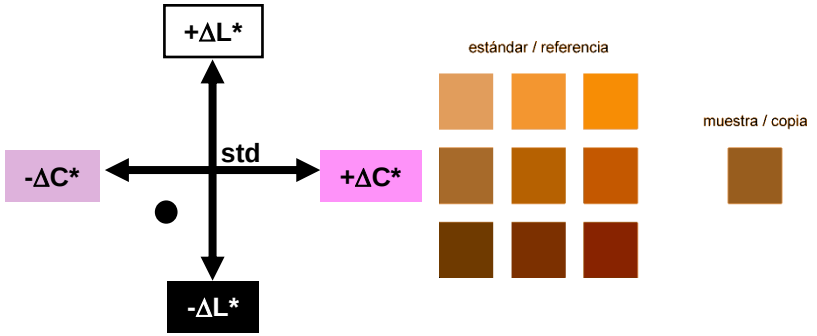
$$\Delta E_{ab} = \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta a^*\right)^2 + \left(\Delta b^*\right)^2}$$

$$\Delta E_{ab} = \sqrt{\left(\Delta L^*\right)^2 + \left(\Delta C^*_{ab}\right)^2 + \left(\Delta H^*_{ab}\right)^2}$$

$$\Delta H^*_{ab} = 2\sqrt{C^*_{ab,std} \cdot C^*_{ab,s}} \cdot \sin\left(\frac{\Delta h^*_{ab}}{2}\right)$$

$$\Delta \equiv \text{sample} - \text{standard}$$





Planckian radiators

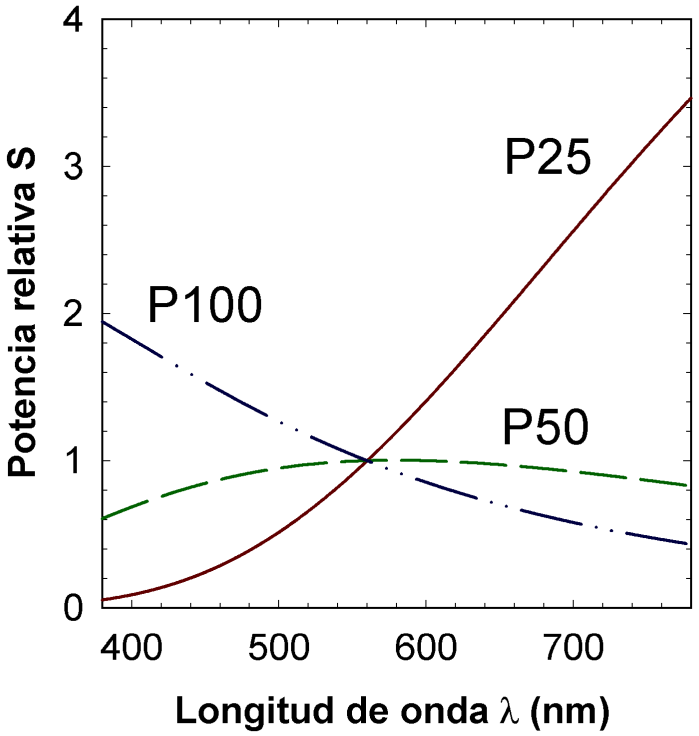
- **Blackbody radiation (Planck) law:**
  - **Incandescent light sources**

$$S_P(\lambda) = \frac{c_1}{\lambda^5} \frac{1}{\exp\left(\frac{c_2}{\lambda T}\right) - 1} \left[\frac{W}{m^3}\right]$$

$$c_1 = 3.74210^{16} \left[W \cdot m^2\right]$$

$$c_2 = 1.438810^{-2} \left[m \cdot K\right]$$

Color temperature



Planckian radiators

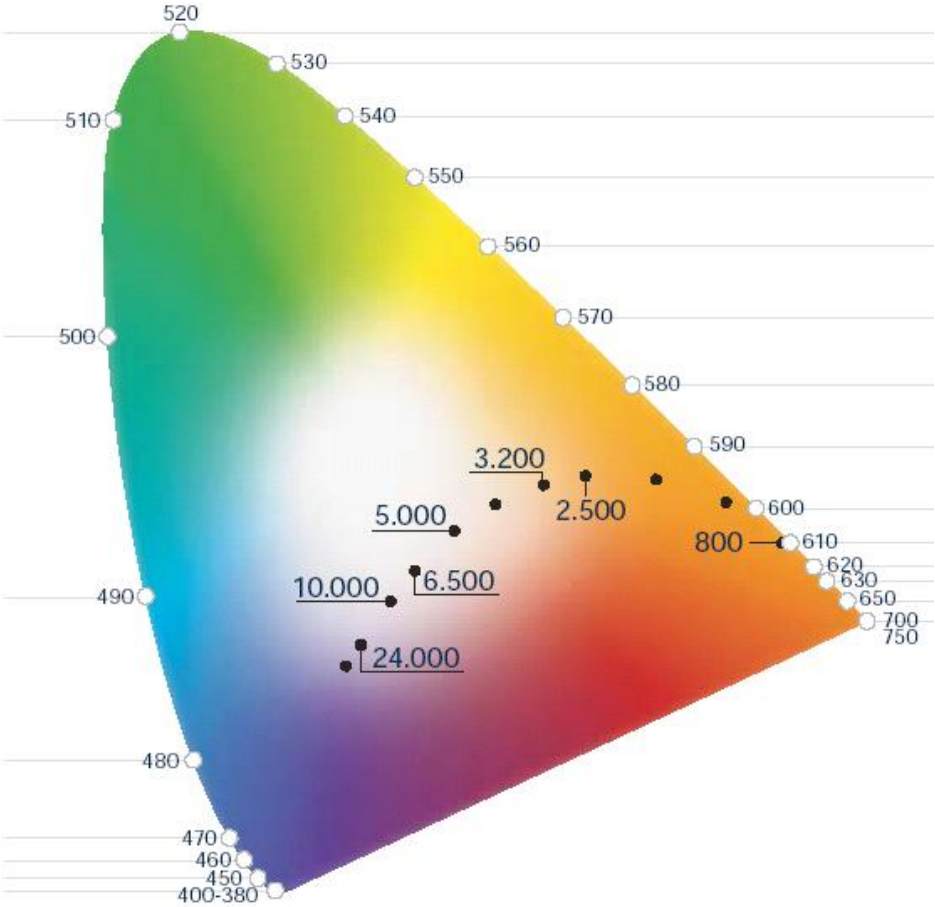
- **Incandescent light sources:**
  - **Color temperature (T)**
  - **Wien law:**

$$\lambda_{MAX} \cdot T = 2.898\,10^{-3}\ [\mathrm{m \cdot K}]$$

  - **Boltzmann law:**

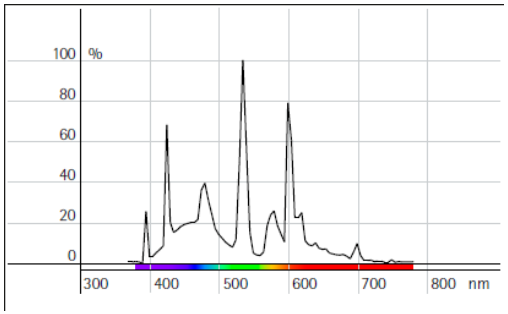
$$M_e \propto T^4\ \left[\mathrm{W \cdot m^{-2}}\right]$$

  - **Psychological appearance:**
    - **Warm: T < 3300 K**
    - **Neutral: T < 5300 K**
    - **Cool: T > 5300 K**

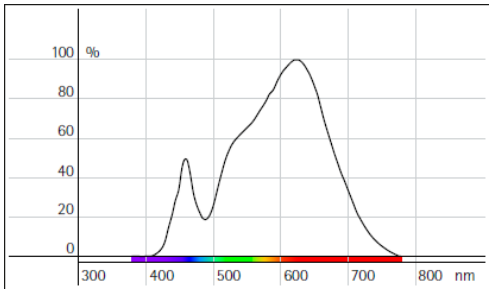


Correlated color temperature

- **Correlated color temperature (T_c) :**
  - **What happens when the lamp spectrum is unlike any Planckian or incandescent radiator?**
  - **How indicate that one lamp is color like that of a Planckian radiator?**



Fluorescent lamp: daylight white



Warm white LED

XYZ?

T_c?

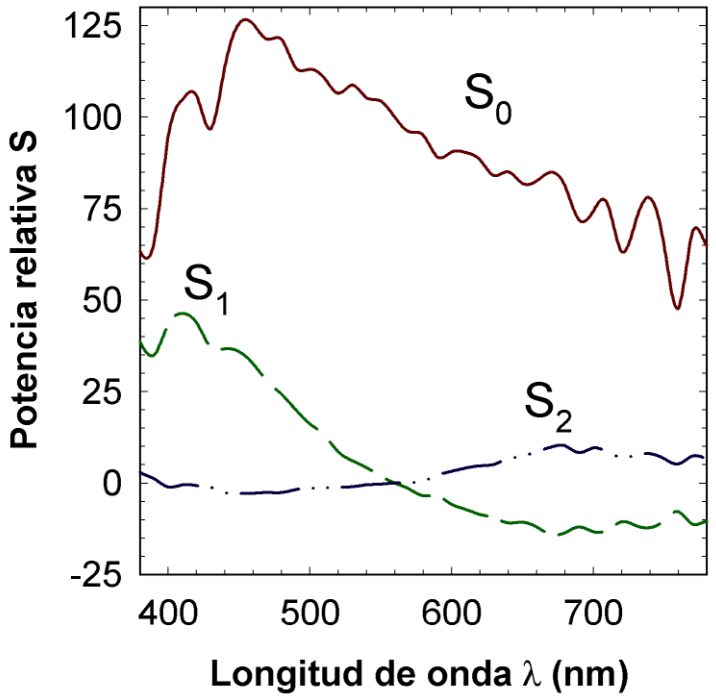
Correlated color temperature

- **Historical example (1964): daylight phases**

$$S_D(\lambda) = S_0(\lambda) + a_1 S_1(\lambda) + a_2 S_2(\lambda)$$

$$a_1 = \frac{-1.3516 - 1.7703 x_D + 5.9114 y_D}{0.0241 + 0.2562 x_D - 0.7341 y_D}$$

$$a_2 = \frac{0.0300 - 31.4424 x_D + 30.0717 y_D}{0.0241 + 0.2562 x_D - 0.7341 y_D}$$



Correlated color temperature

- **Historical example (1964): daylight phases**

if $T_C \in [4000, 7000[$ K

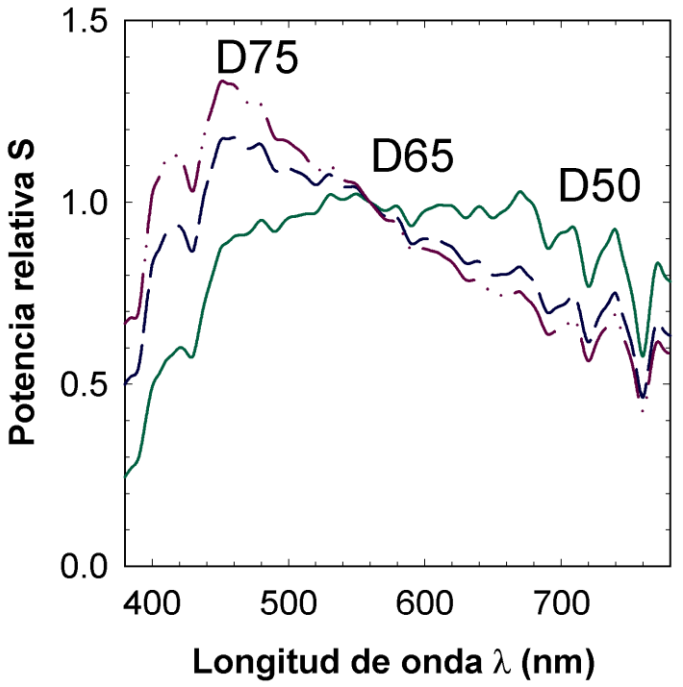
$$x_D = -4.6070\frac{10^9}{T_c^{\,3}} + 2.9678\frac{10^6}{T_c^{\,2}} + 0.09911\frac{10^3}{T_c} + 0.244063$$

$$y_D = -3.000x_D^{\,2} + 2.870x_D - 0.275$$

if $T_C \in [7000, 25000[$ K

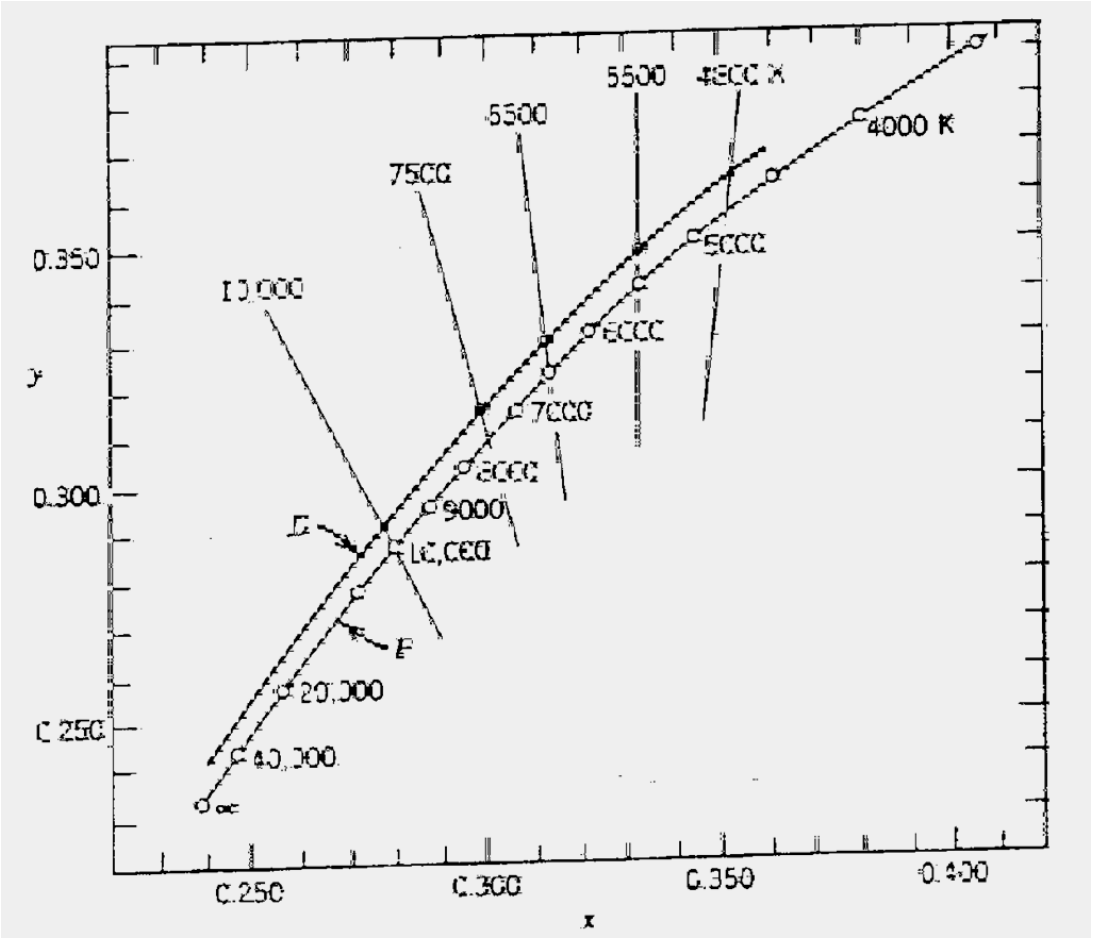
$$x_D = -2.0064\frac{10^9}{T_c^{\,3}} + 1.9018\frac{10^6}{T_c^{\,2}} + 0.24748\frac{10^3}{T_c} + 0.237040$$

$$y_D = -3.000x_D^{\,2} + 2.870x_D - 0.275$$



Correlated color temperature

- **Historical example (1964): daylight phases**
  - **Locus D ≅ locus P**
  - **Temperature isoline**



Correlated color temperature

- **Quick and current algorithm for many cases:**

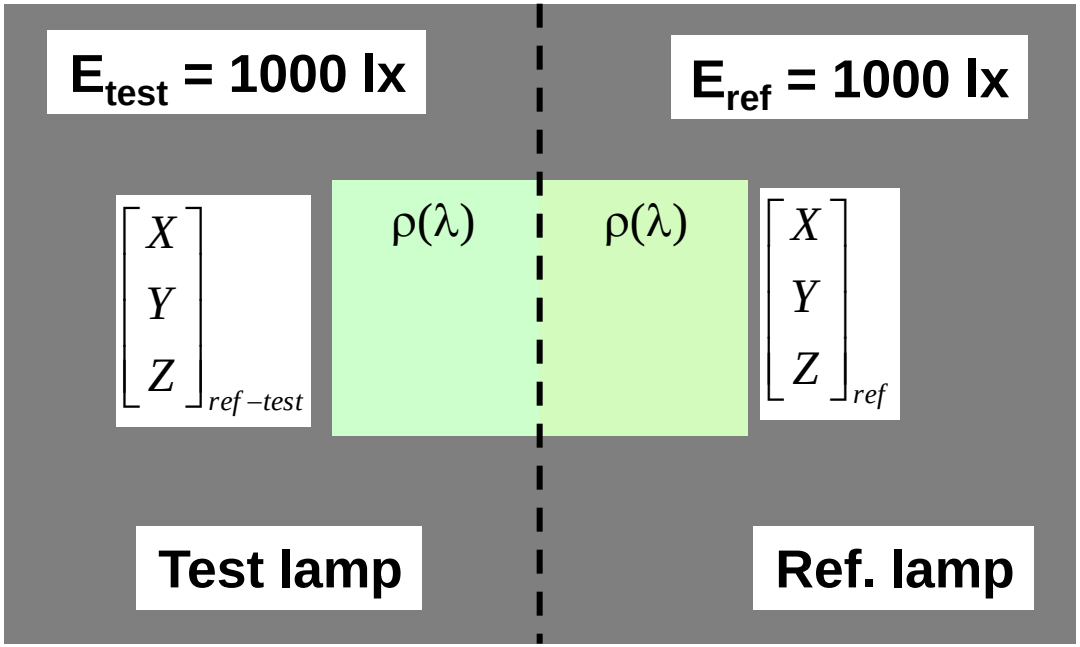
Spectrum S(λ) → **Coordenates *x* , *y***

$$n = \frac{x - x_e}{y - y_e} \quad \Rightarrow \quad T_C = A_0 + A_1 \exp\left(-\frac{n}{t_1}\right) + A_2 \exp\left(-\frac{n}{t_2}\right) + A_3 \exp\left(-\frac{n}{t_3}\right)$$

x_e	y_e	A_0	A_1	t_1	A_2	t_2	A_3	t_3
0.3366	0.1735	-949.863	6253.803	0.92159	28.706	0.20039	0.00004	0.07125

Color rendering index

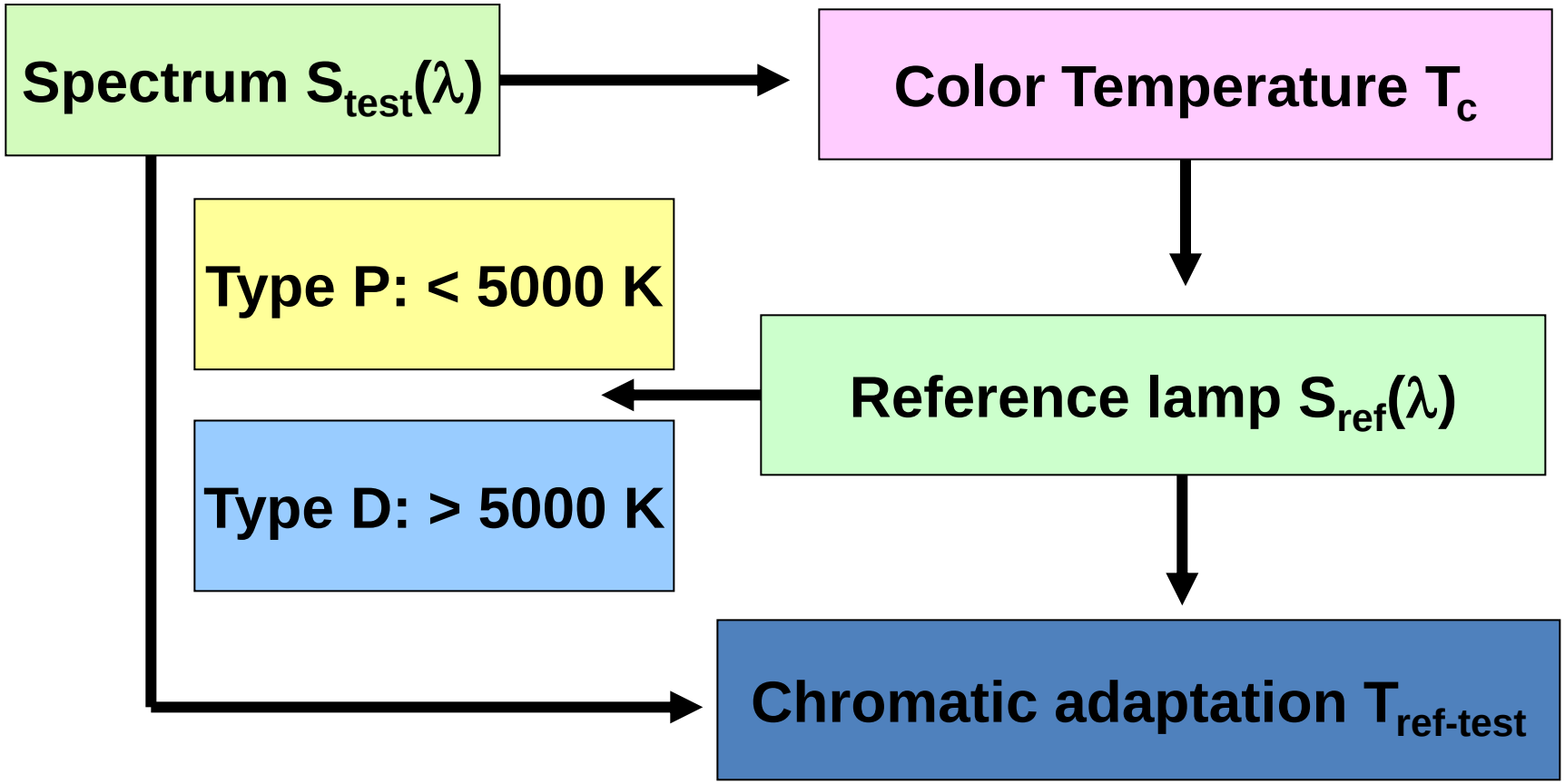
- **What is the effect that one lamp has on color appearance of materials compared to a reference light source? Normative CIE 13.3-1995**



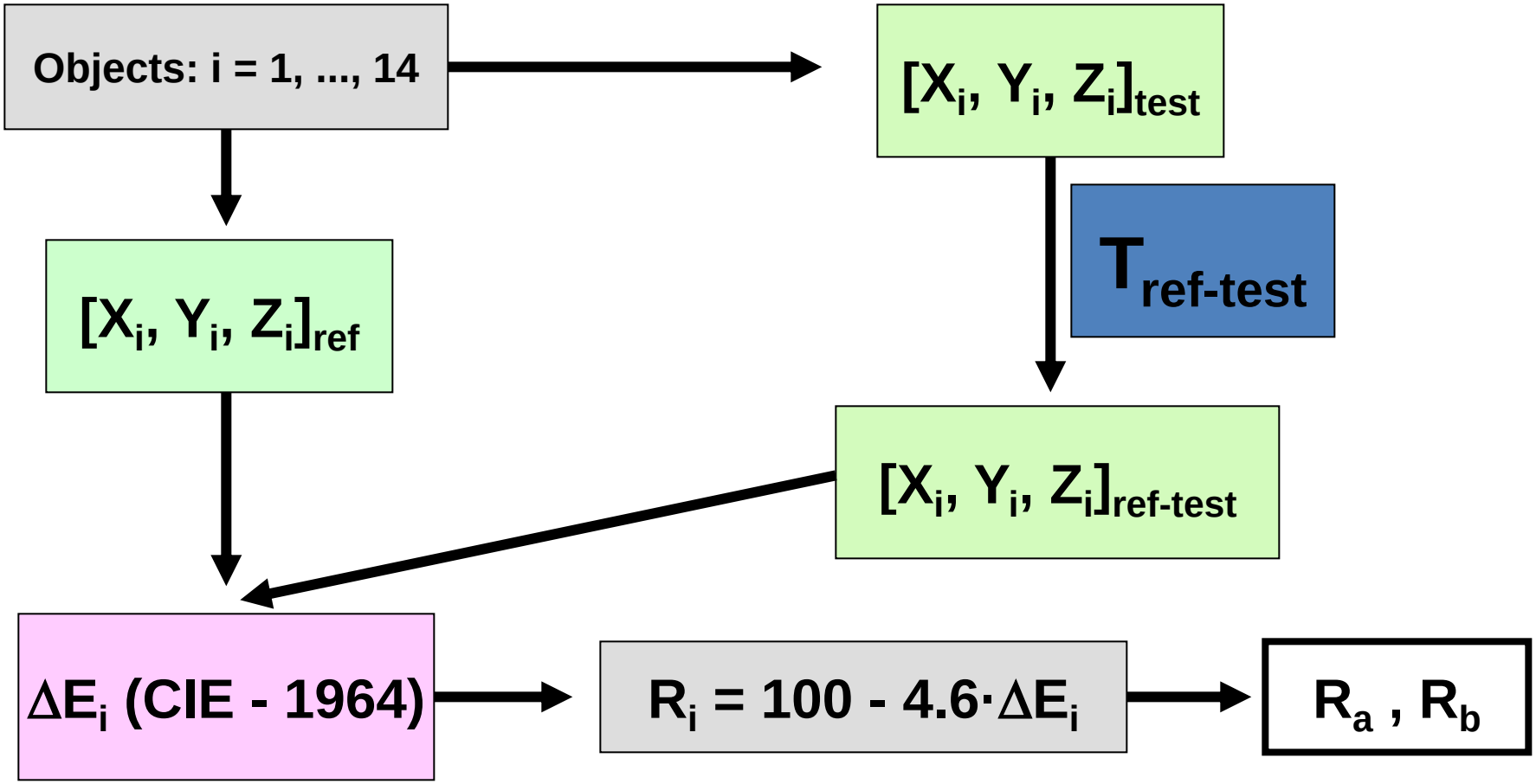
Color rendering index

- Special indexes R_i
- General indexes R_a (the first 8) and R_b (14)

Color rendering index



Color rendering index

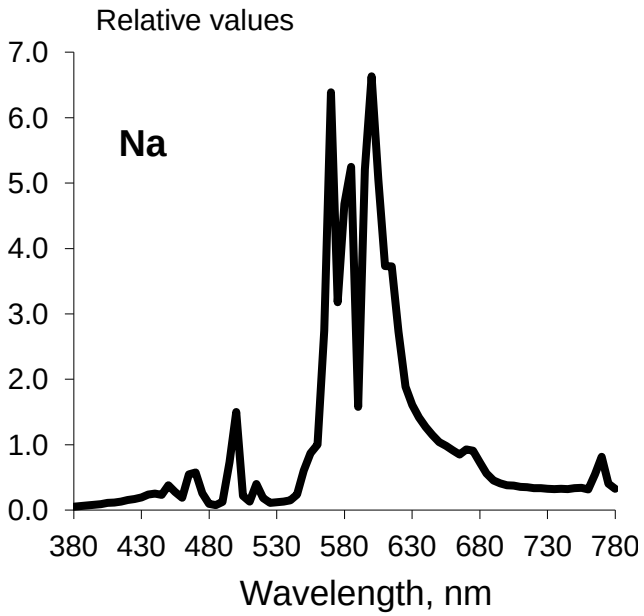


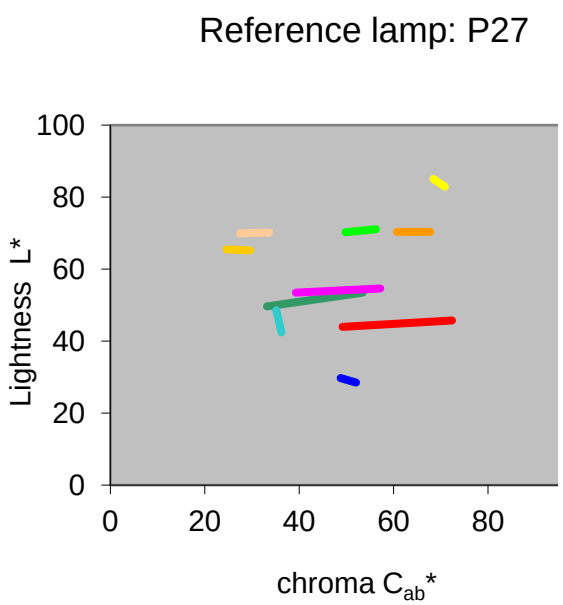
Color rendering index

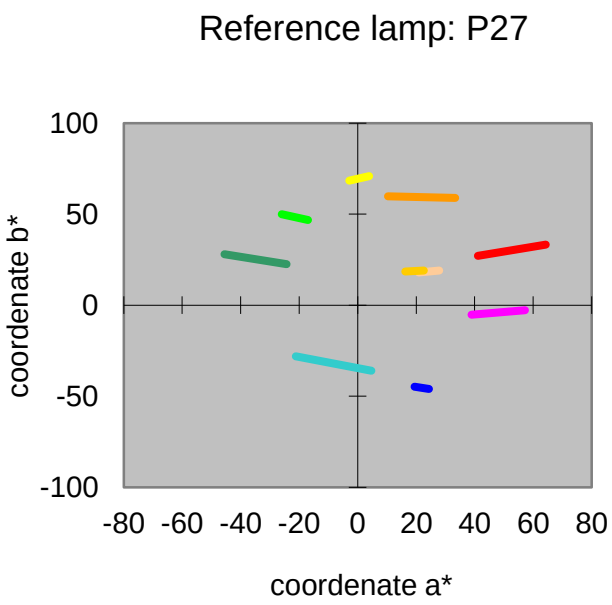
Class	Range R_a	Color appearance	Preferred use	Acceptable use
1A	[90, 100[	Warm Neutral Cool	Color assessments, clinical probes, art galleries, museums	
1B	[80, 90[	Warm Neutral	Home, hotels, restaurants, shops, offices, schools, hospitals	
		Neutral Cool	Graphic Arts, textile and paper industries, industrial work	
2	[60, 80[	Warm Neutral Cool	Industrial work	Offices, schools
3	[40, 60[		Industries handling big objects	Industrial work
4	[20, 40[			

Color rendering index

- **Graphic example: high-pressure Na vs. wLED lamps**
  - **Material test composed by 10 samples (CIE 1999, CIELAB)**



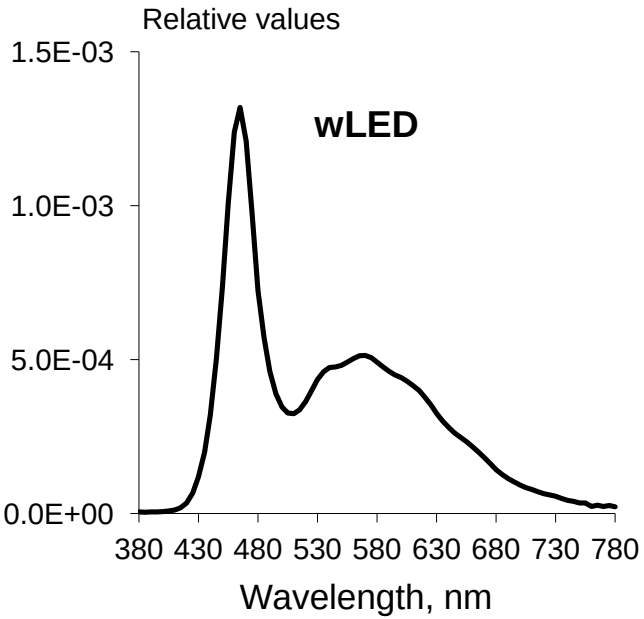


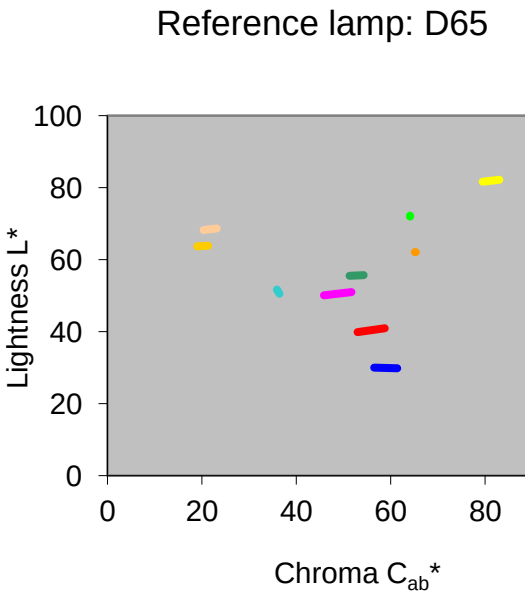


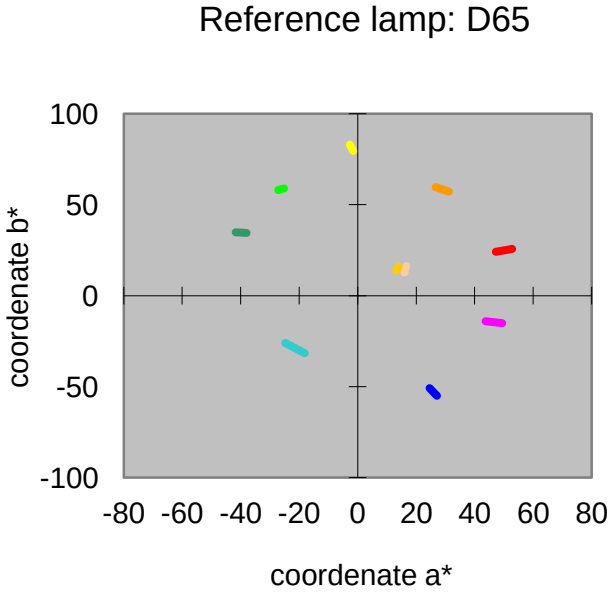
	X	Y	Z	T_c(K)	R_a	R_b	R96
Na	128.74	100	14.59	1970	28.10	20.41	50.70

Color rendering index

- **Graphic example: high-pressure Na vs. wLED lamps**
  - **Material test composed by 10 samples (CIE 1999 revision)**



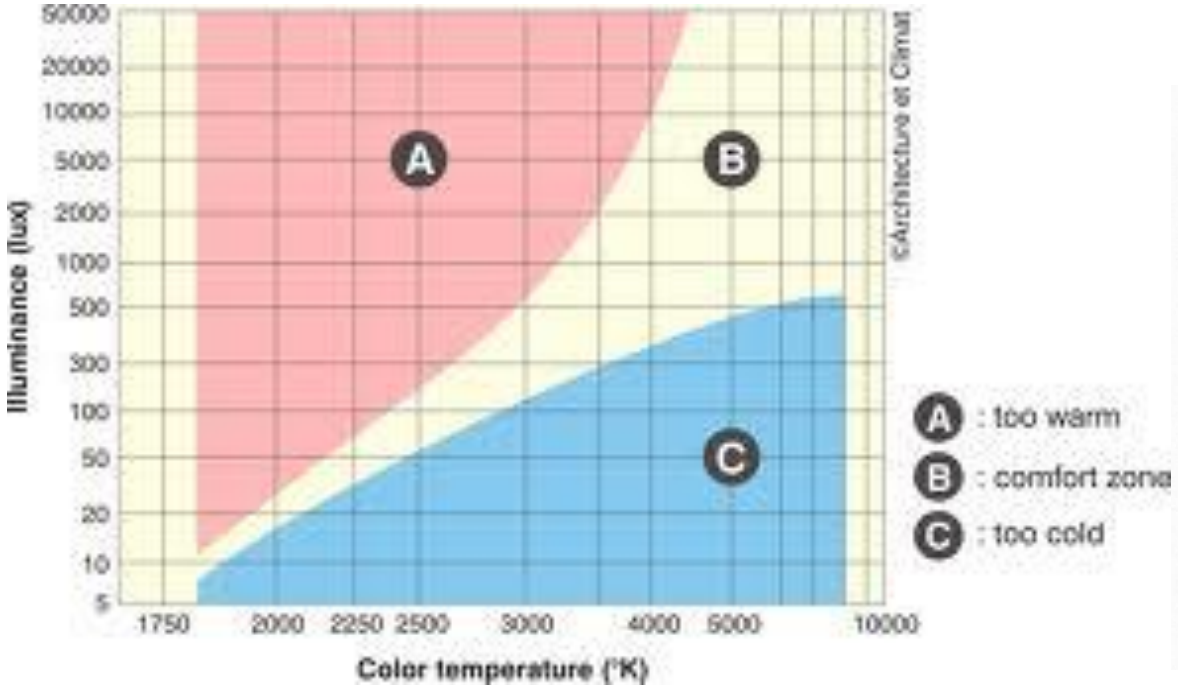




	X	Y	Z	T_c(K)	R_a	R_b	R96
wLED	99.57	100	138.56	8320	84.22	70.61	84.98

Color rendering index

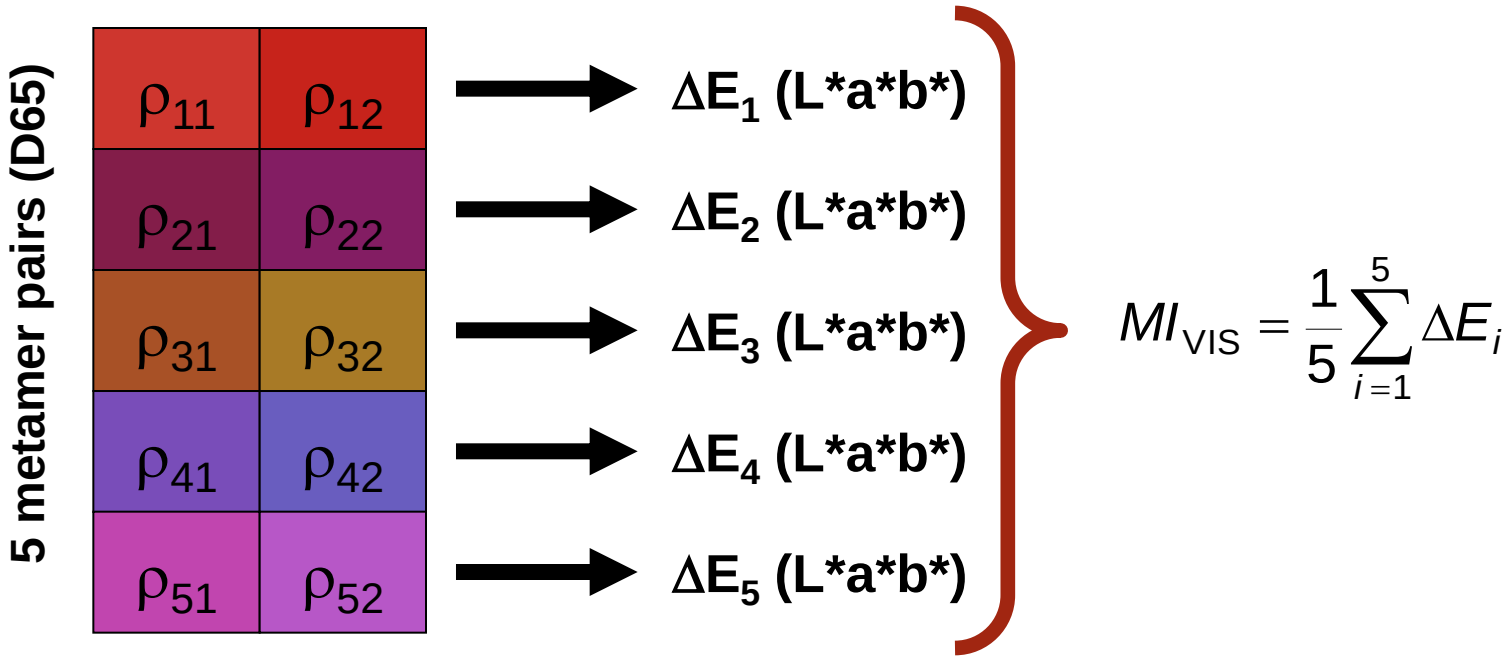
- **Visual comfort zone by Kruithof (1941):**
  - **Whitish-yellowish light (warm) → low light**
  - **Bluish-whitish light (cool) → intense light**
  - **Revision in 2009 for white LEDs by Viénot, Durand and Mahler**



Lamp technical label

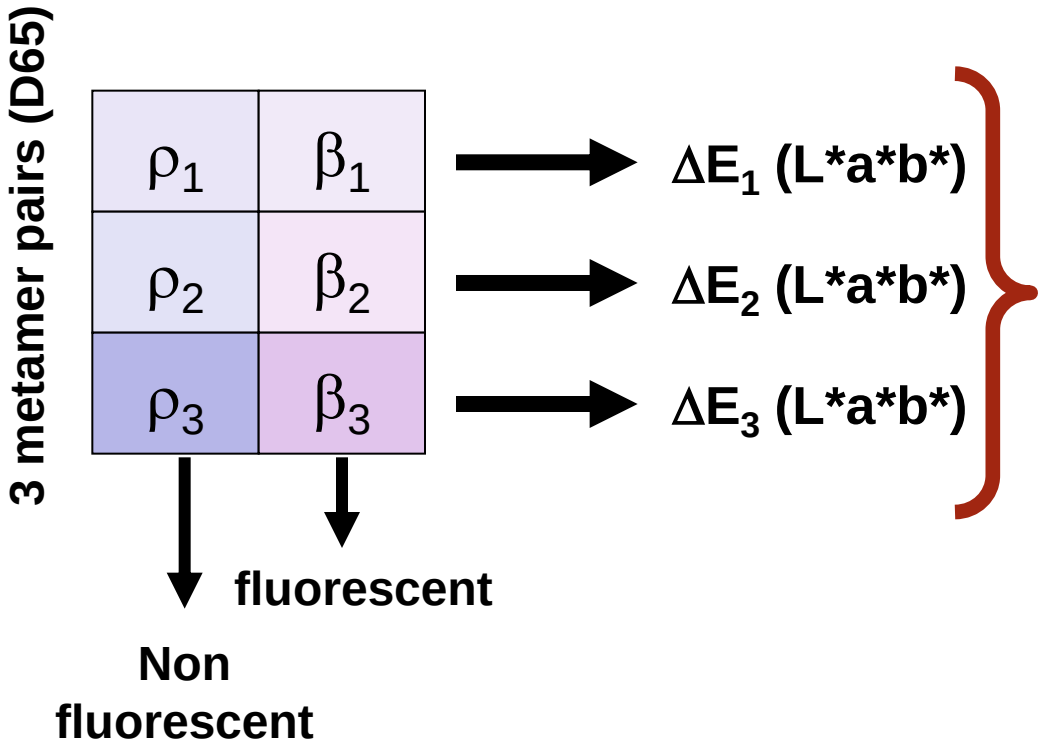
Daylight simulation

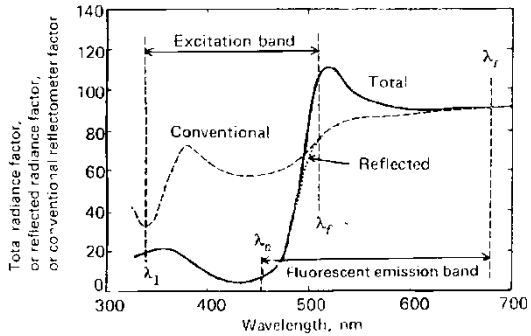
- **Quality factor for lamps trying to simulate the attributes of the solar daylight (D65): CIE 51.2-1999**
  - **Visible spectral component (VIS)**



Daylight simulation

- **Quality factor for lamps trying to simulate the attributes of the solar daylight (D65): CIE 51.2-1999**
  - **Ultraviolet spectral component (UV)**





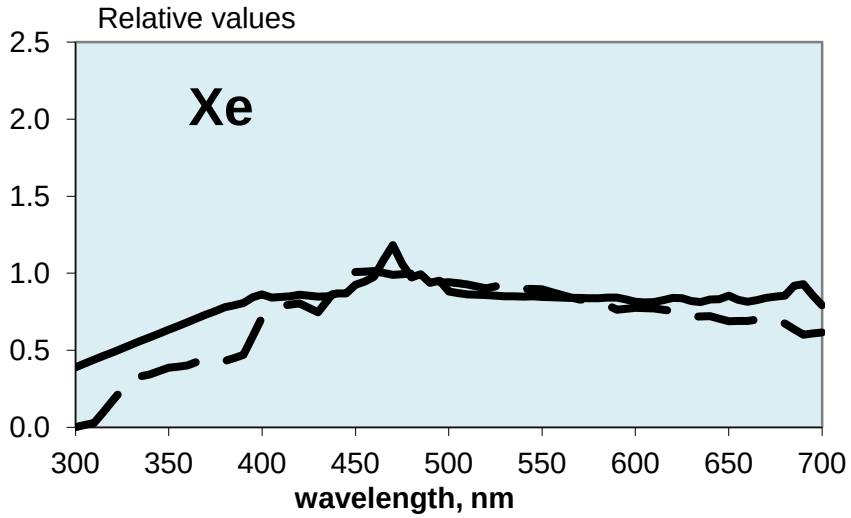
$$MI_{UV} = \frac{1}{3}\sum_{i=1}^{3}\Delta E_i$$

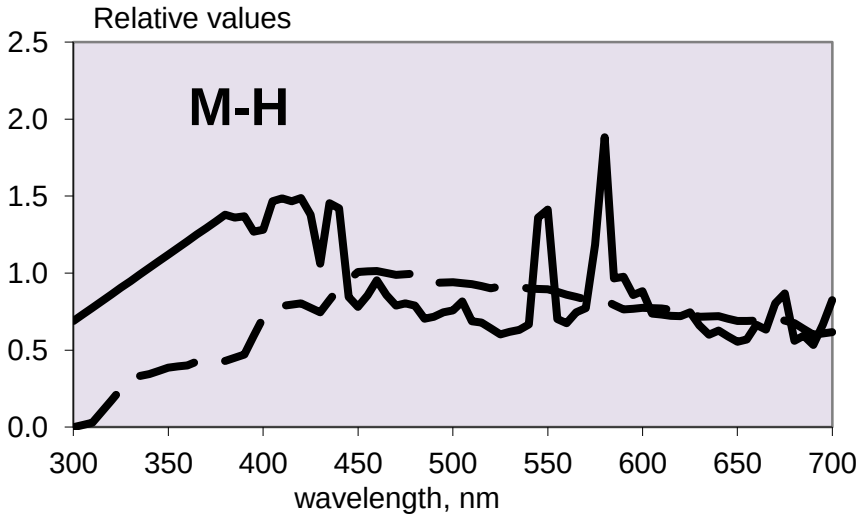
Daylight simulation

- **Final evaluation: combination of two letters**

ΔE (L*a*b*) =	[0, 0.25[	[0.25, 0.50[	[0.50, 1[	[1, 2 [	[2, +∞[
Category	A	B	C	D	E

- **Graphic example: Xe vs. Metal-Halide lamps**

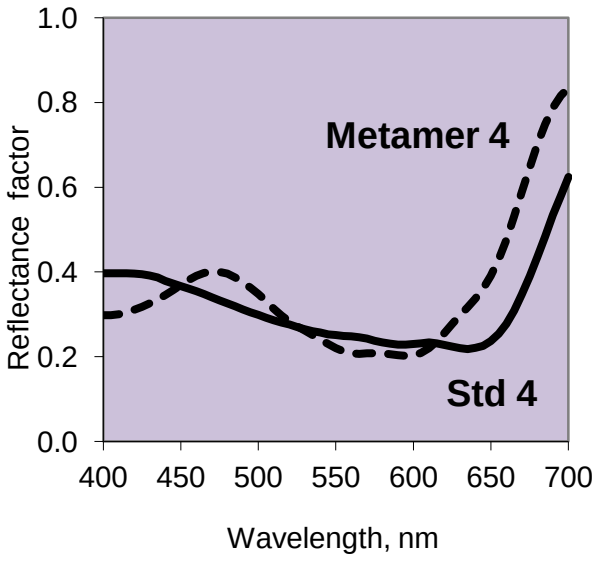


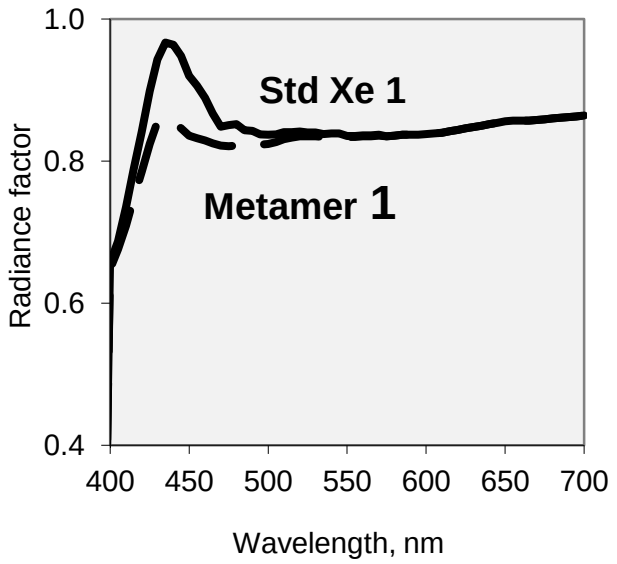


Daylight simulation

- **Graphic example: Xe vs. Metal-Halide lamps**

	X_{10}	Y_{10}	Z_{10}	T_c(K)	MI_{VIS}	MI_{UV}	Balance
D65	94.75	94.75	94.75	6500	A	A	AA
Xe	98.87	98.87	98.87	6050	B	E	BE
M-H	105.35	105.35	105.35	5980	--	--	--

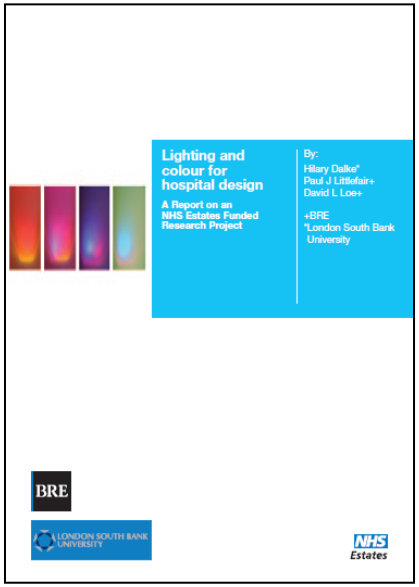




Supplementary reading and learning

- **Read the supplementary lesson no. 6 downloaded from Virtual Campus about color psychology applied to decoration and advertising**

- **Compare with this book about lighting & color design for hospitals**
  - **Resemblances?**
  - **Differences?**
  - **Implementations for digital culture?**



Proposed activity nº 3

- **Relative Weight: 2.5 %**
- **Delivery process by Virtual Campus evaluation**
- **Individual Task:**
  - **Download the numerical exercises sheet no. 3**
  - **Read, solve the exercise no. 5**
    - **Use tutoring tool in case of doubts**
  - **Submit it using practice delivery tool by Virtual Campus. Deadline: 15th November**