基礎色彩學

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中 華 民 國 九十三 年 九 月 三十 日

Outline

- What is color?
- 色彩學說
  - 三原色學說
  - 對立顏色學說
  - 視覺
- 色彩空間
  - CIE 1931 x,y
  - uv色度圖 , u'v'色度圖
  - CIE LUV色彩空間
  - CIE LAB色彩空間
- 色彩系統
  - 光源
  - 色彩加成性
  - 色彩相減性

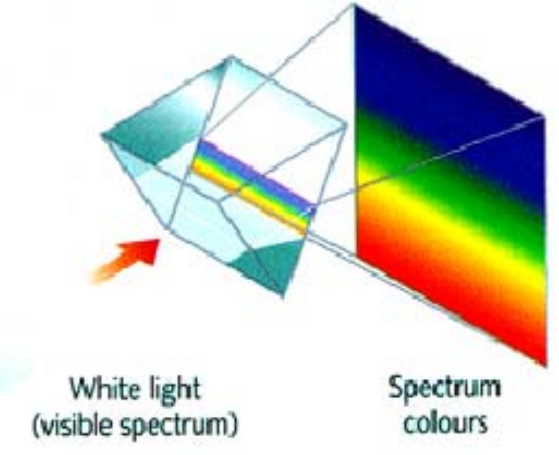
色彩是上帝的傑作

一道彩虹劃過天際
人生充滿喜悅與美夢

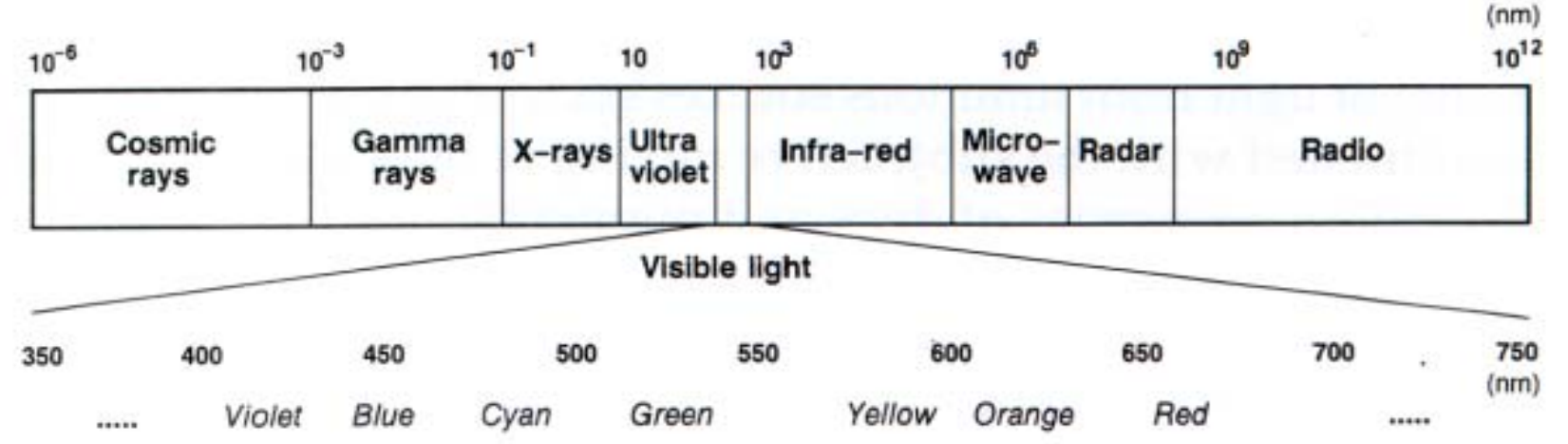
紅 橙 黃 綠 藍 靛 紫

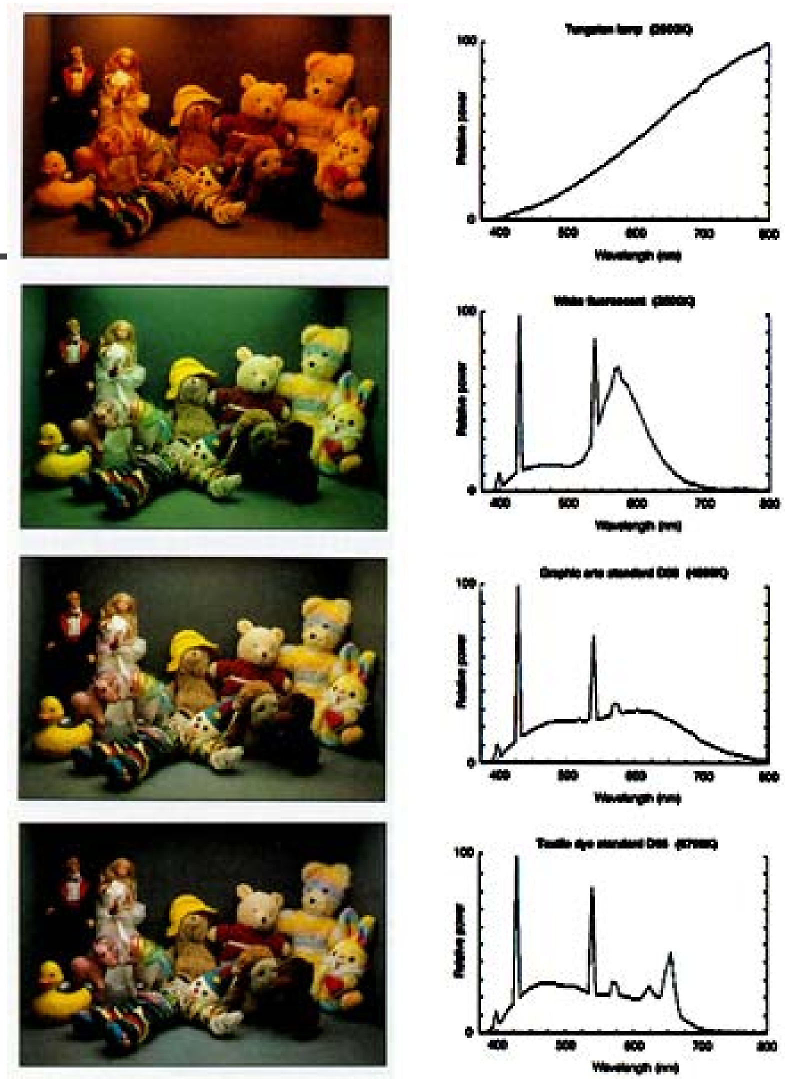
自然之美

- Newton (1643 ~ 1727)

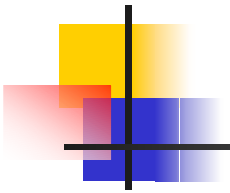


色彩是電磁波


(nm)
10^{-6}
10^{-3}
10^{-1}
10
10^{3}
10^{6}
10^{9}
10^{12}
Cosmic rays
Gamma rays
X-rays
Ultra violet
Infra-red
Micro-wave
Radar
Radio
Visible light
350
400
450
500
550
600
650
700
750
(nm)
.....
Violet
Blue
Cyan
Green
Yellow
Orange
Red
.....



顏色由光頻譜
來決定!!

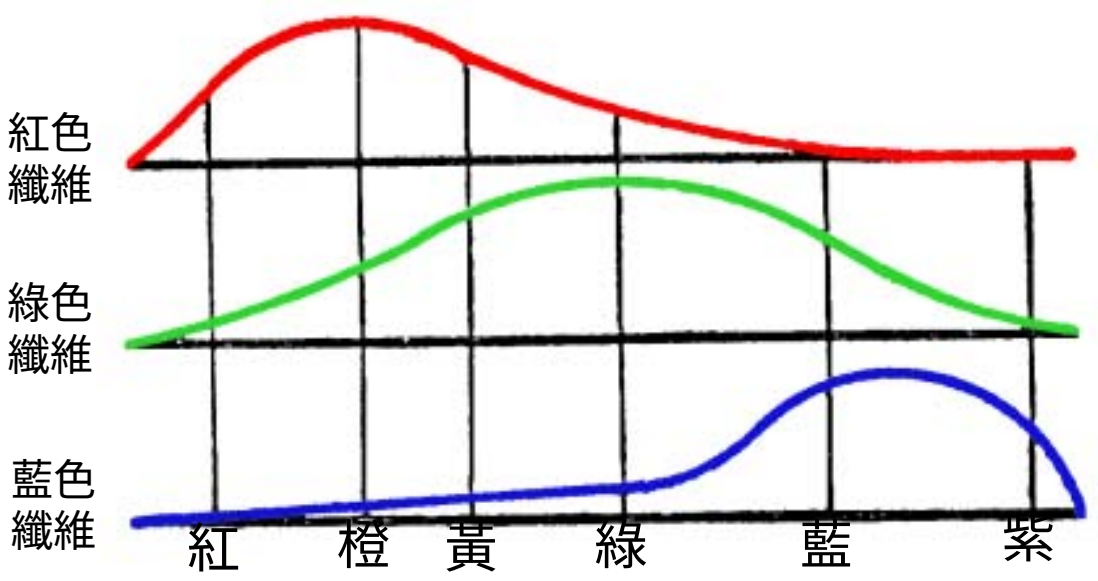


色彩學說

- 三原色學說
- 對立顏色學說
- 視覺

三原色學說

- Young 1802



Grassmann法則(1894)

色光[F1]=色光[F2] ，色光[F3]=色光[F4]

- 比例法則

  a[F1]=a[F2]　b[F3]=b[F4]

- 加法法則

  [F1]+[F3]=[F2]+[F4]

  [F1]+[F4]=[F2]+[F3]

- 減法法則

  [F1]-[F3]=[F2]-[F4]

  [F1]-[F4]=[F2]-[F3]

色盲

正　常

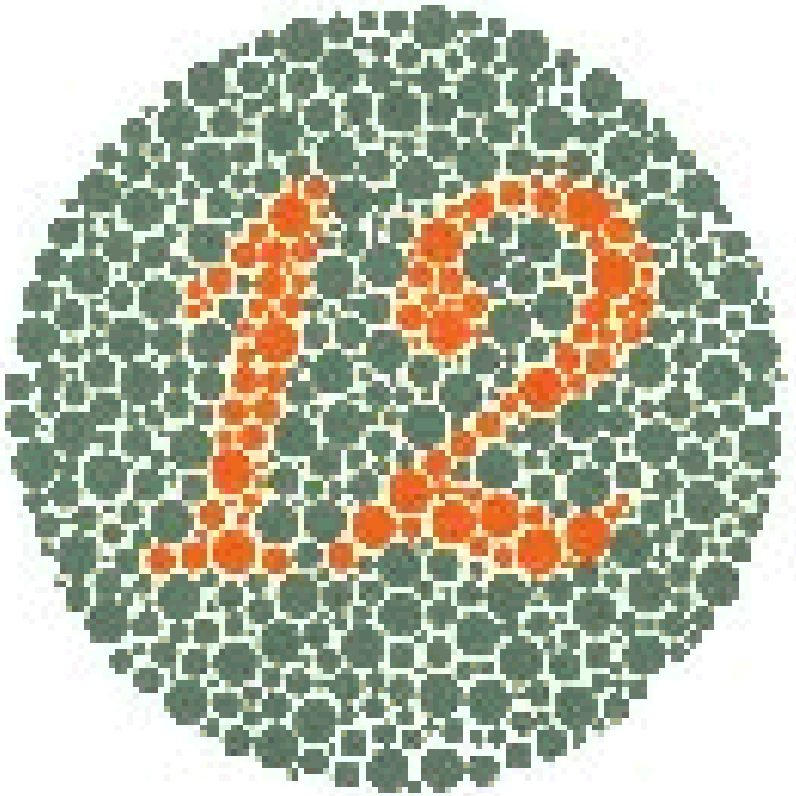
紅色盲

綠色盲

紅-綠色盲

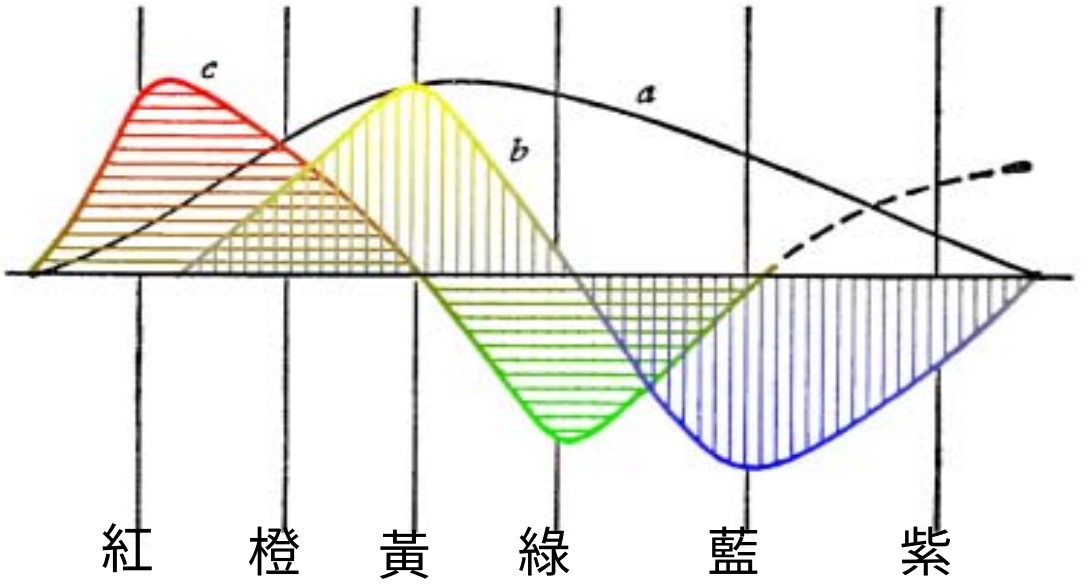
全色盲

色盲

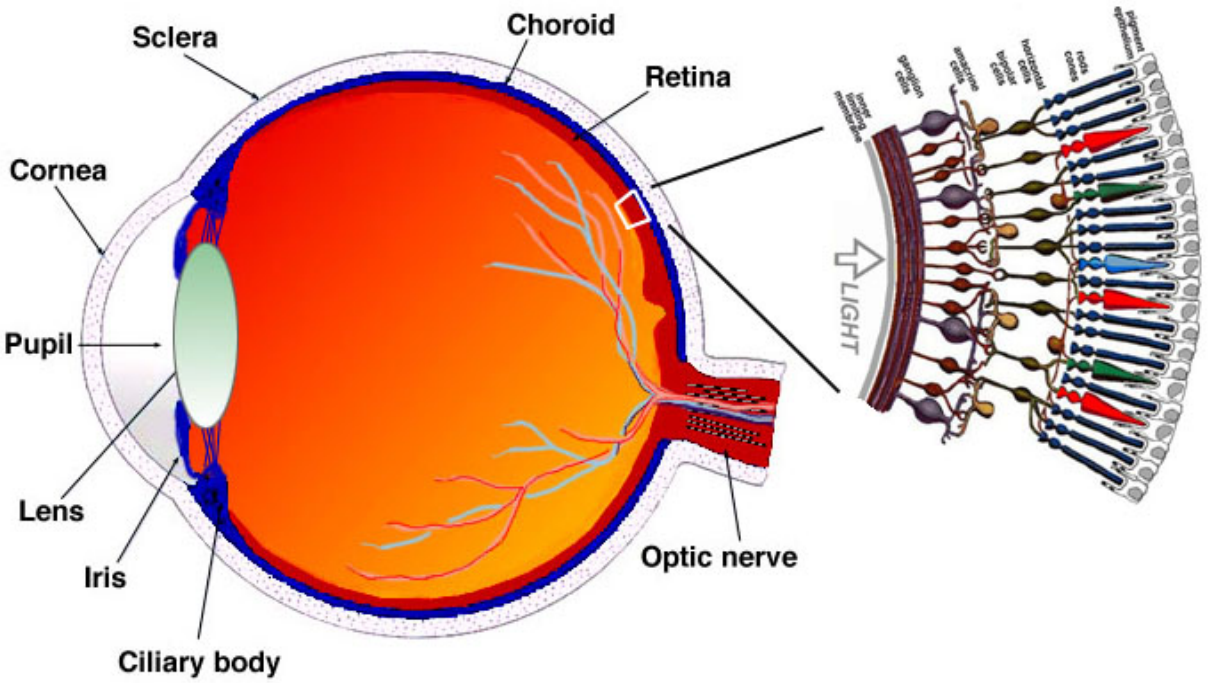


對立顏色學說

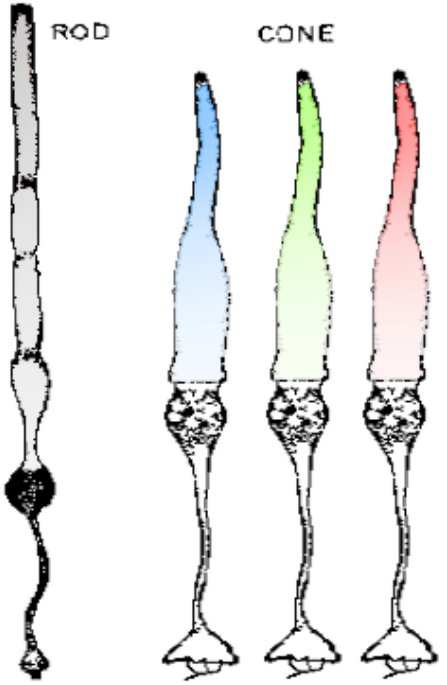
- Hering 1878



視　覺

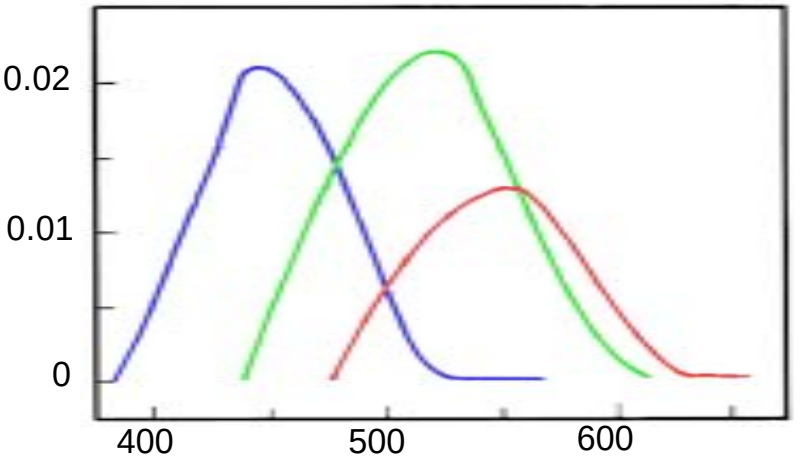

Sclera
Choroid
Retina
Cornea
Pupil
Lens
Iris
Ciliary body
Optic nerve
LIGHT

視　覺

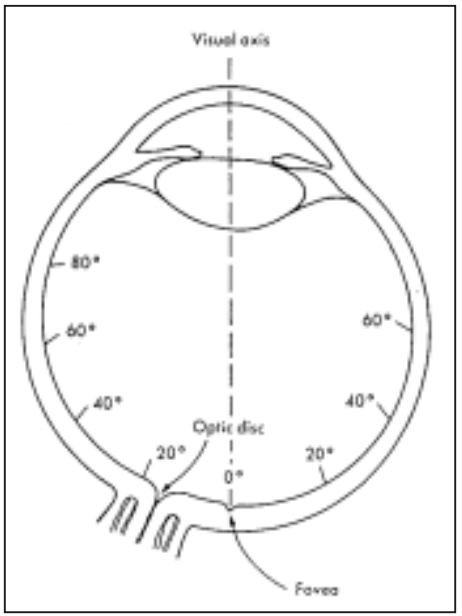


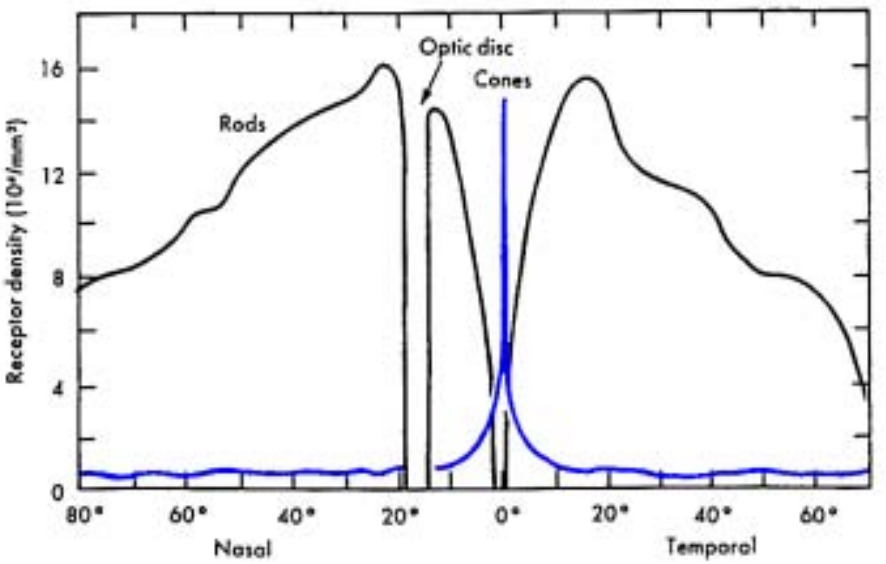
桿狀細胞：10^{-6}~10　cd/m^2

錐狀細胞：10^{-3}~10^{8}　cd/m^2

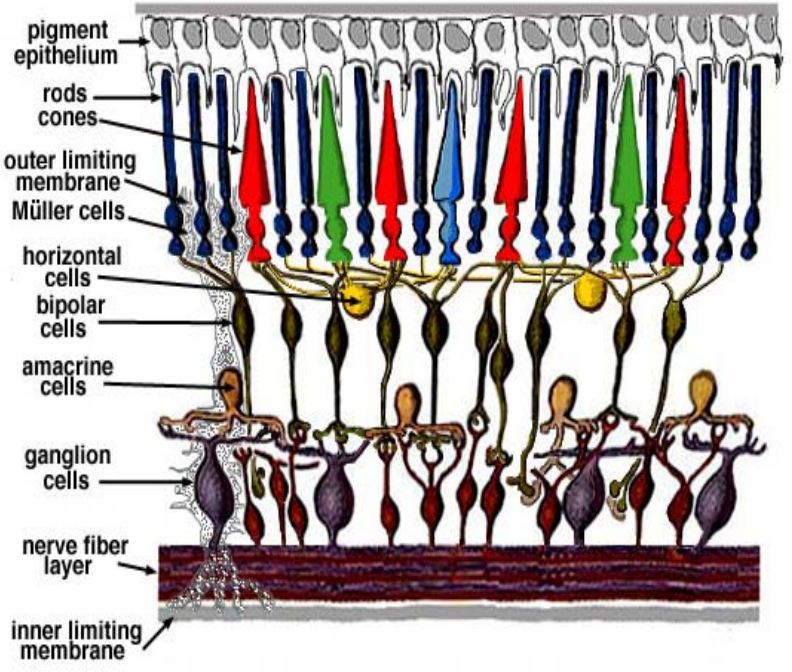


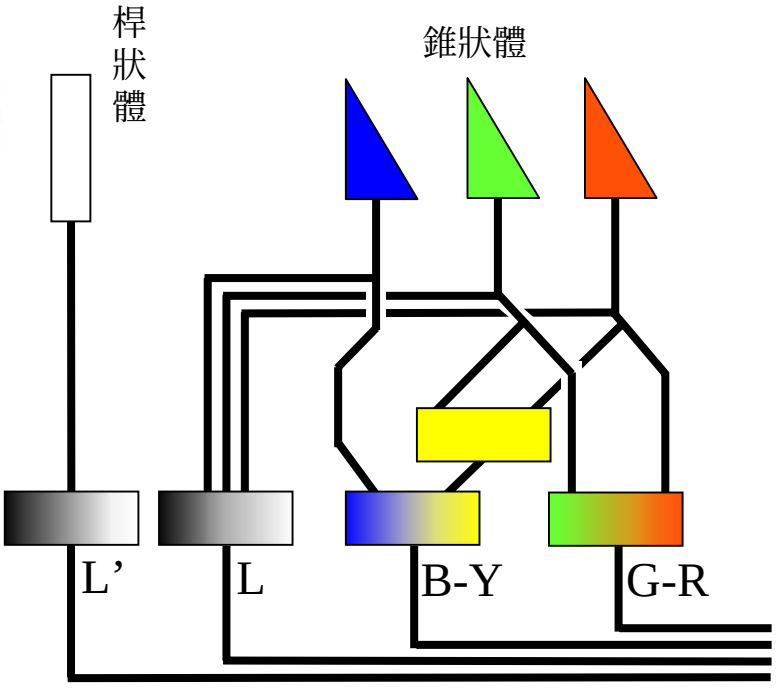
視　覺


Visual axis
80°
60°
60°
40°
40°
Optic disc
20°
20°
0°
Fovea

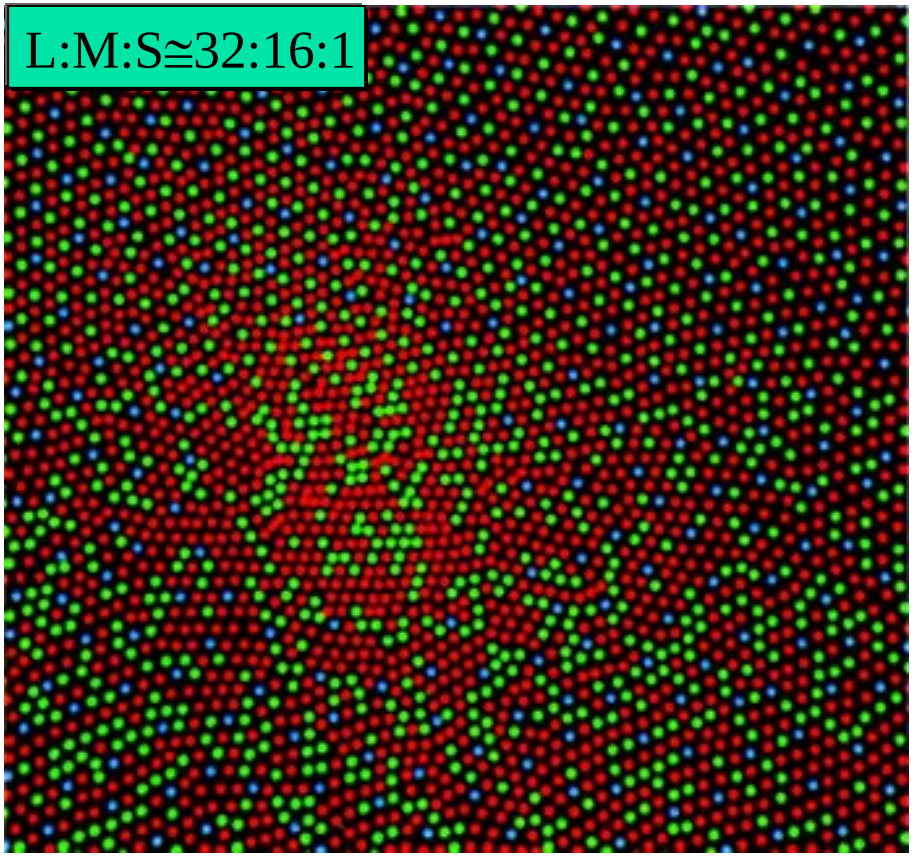

Optic disc
Cones
Rods
Receptor density (10⁴/mm²)
16
12
8
4
0
80°
60°
40°
20°
0°
20°
40°
60°
Nasal
Temporal

階段說


pigment epithelium
rods
cones
outer limiting membrane
Müller cells
horizontal cells
bipolar cells
amacrine cells
ganglion cells
nerve fiber layer
inner limiting membrane


桿狀體
錐狀體
L'
L
B-Y
G-R

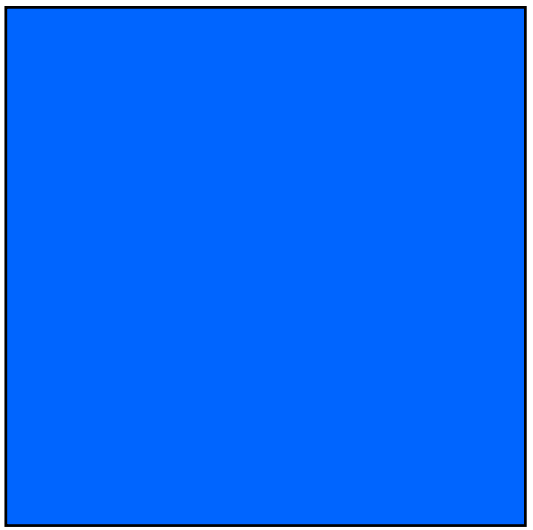
Human Retina



色彩空間

- CIE 1931 x,y
- uv色度圖 , u’v’色度圖
- Munsell System
- CIE LUV色彩空間
- CIE LAB色彩空間

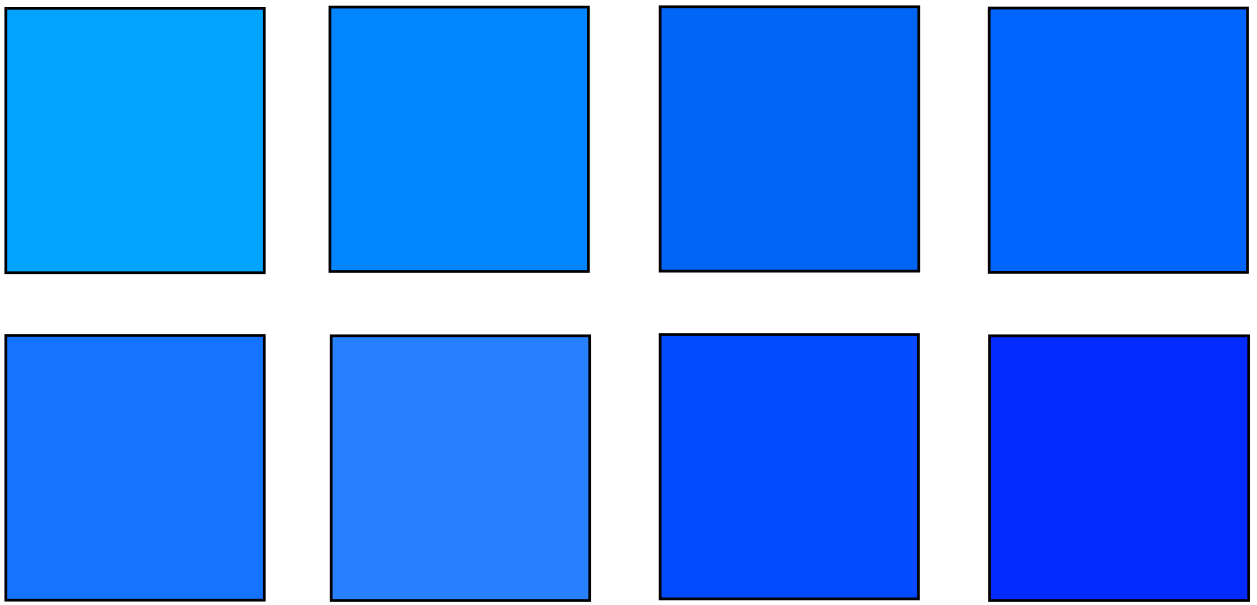
色彩的描述



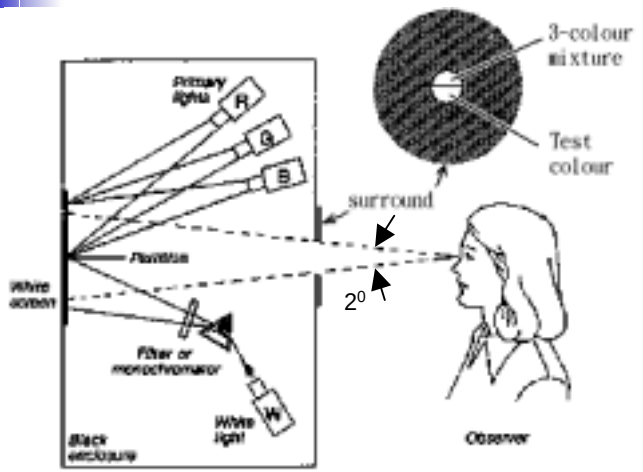
1. 藍色
2. 淡藍色
3. 水藍色
4. 天藍色
5. 青色
6. 青藍色
7. 藍青色
8. 晴時維也納清晨天空的藍色

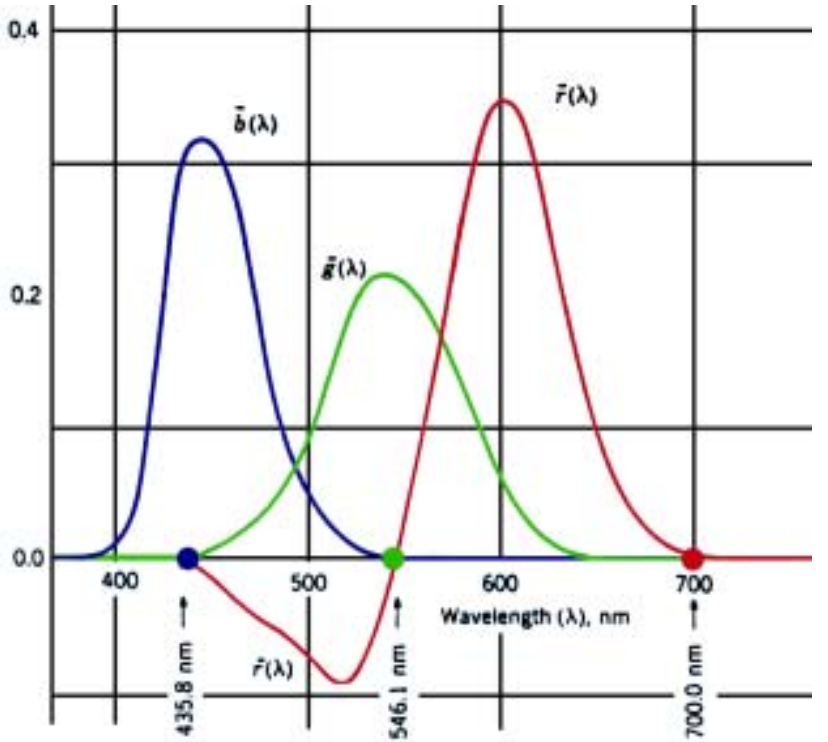
...

色彩的描述



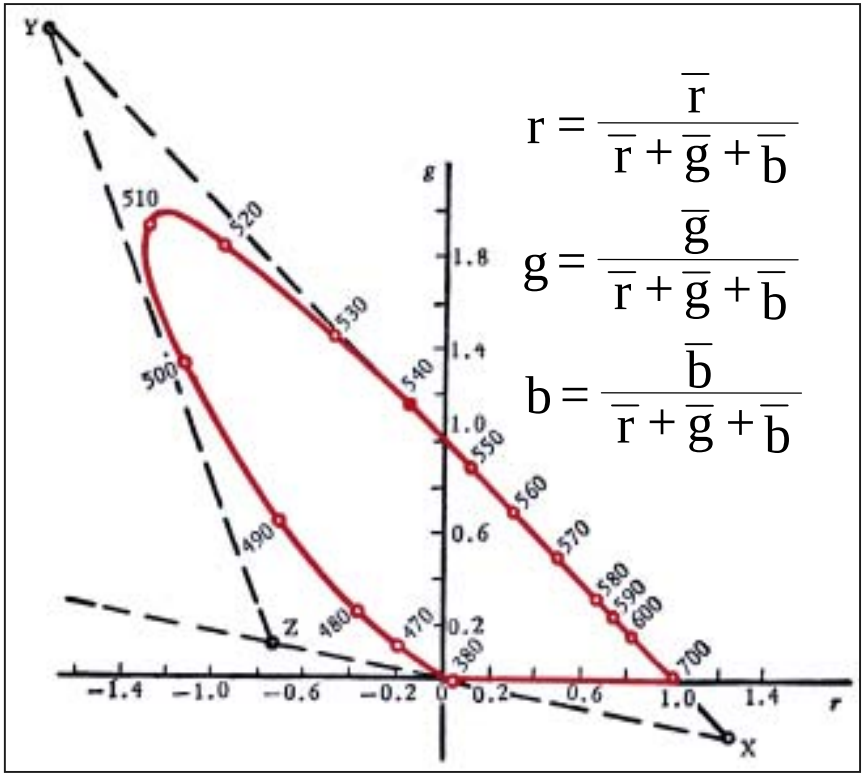
色彩量化





- **R = 700.0 nm**
- **G = 546.1 nm**
- **B = 435.8 nm**

CIE RGB to CIE XYZ



$$r = \frac{\bar{r}}{\bar{r}+\bar{g}+\bar{b}}$$

$$g = \frac{\bar{g}}{\bar{r}+\bar{g}+\bar{b}}$$

$$b = \frac{\bar{b}}{\bar{r}+\bar{g}+\bar{b}}$$

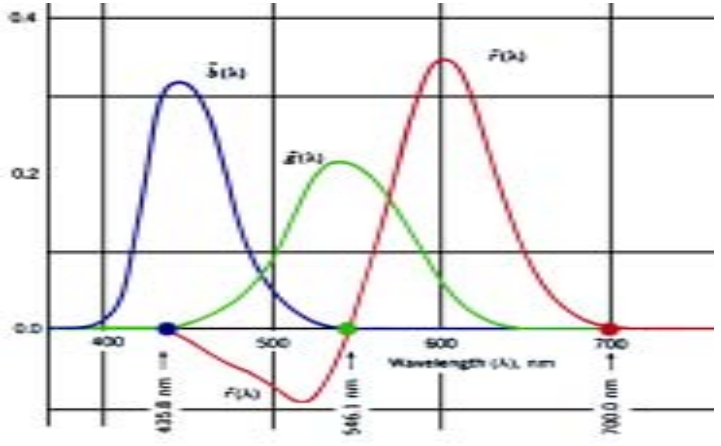
虛擬三原色

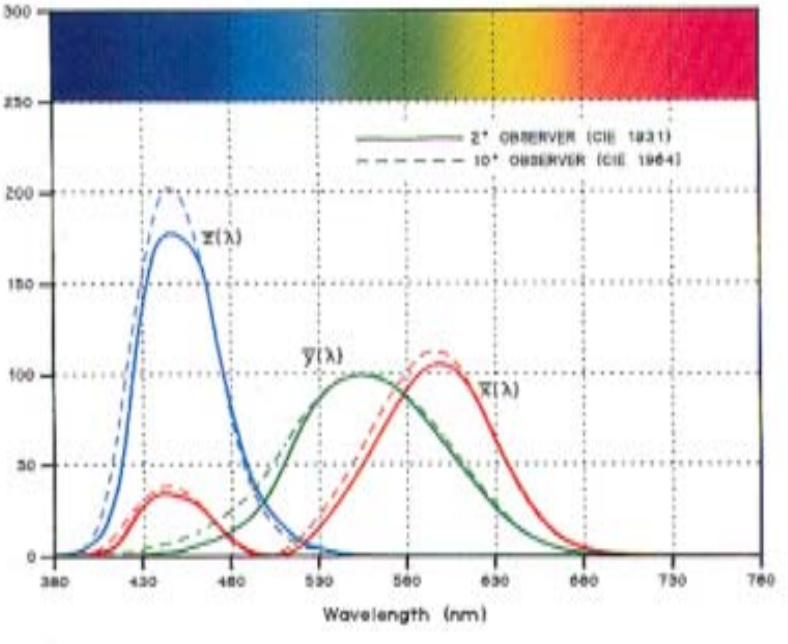
X,Y,Z

- 避免出現負值
- 540 ~ 700nm 為直線
- XZ線為無亮度線

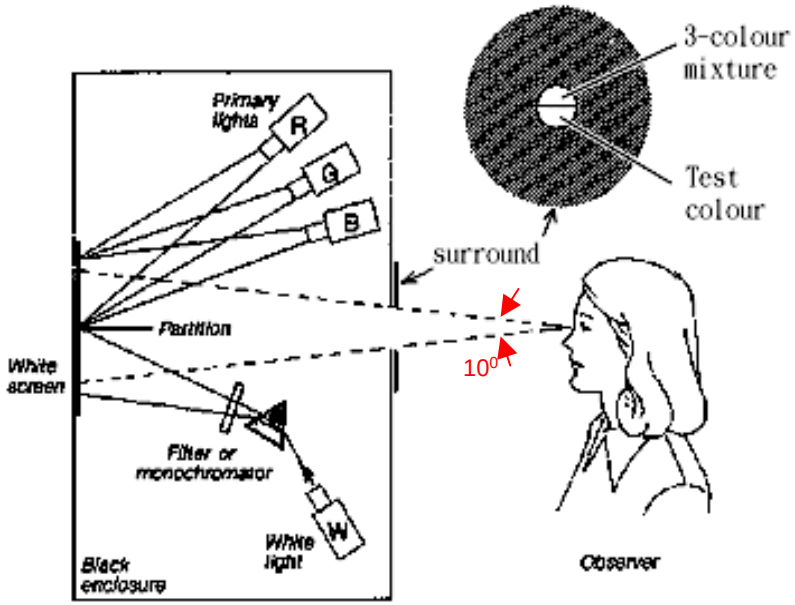
Color Matching Functions

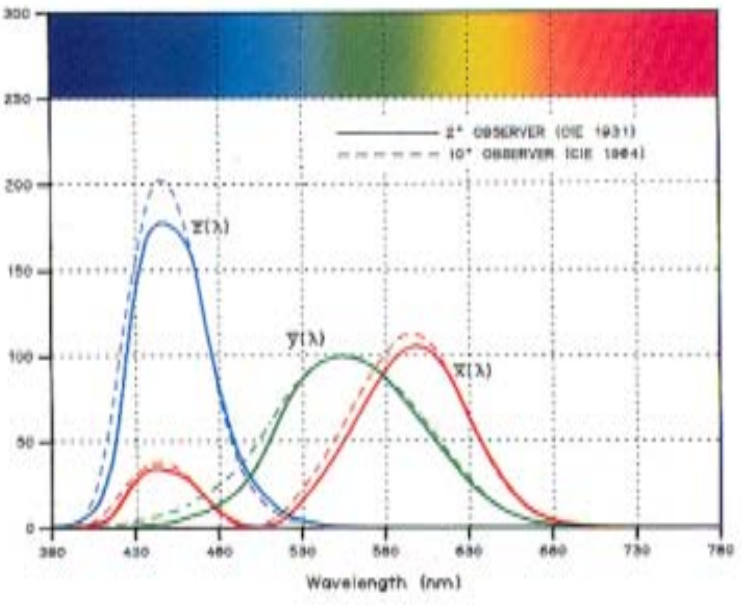
$$\begin{pmatrix} \bar{x} \\ \bar{y} \\ \bar{z} \end{pmatrix} = \begin{pmatrix} 2.768 & 1.751 & 1.130 \\ 1.000 & 4.590 & 0.060 \\ 0.000 & 0.056 & 5.594 \end{pmatrix} \begin{pmatrix} \bar{r} \\ \bar{g} \\ \bar{b} \end{pmatrix}$$



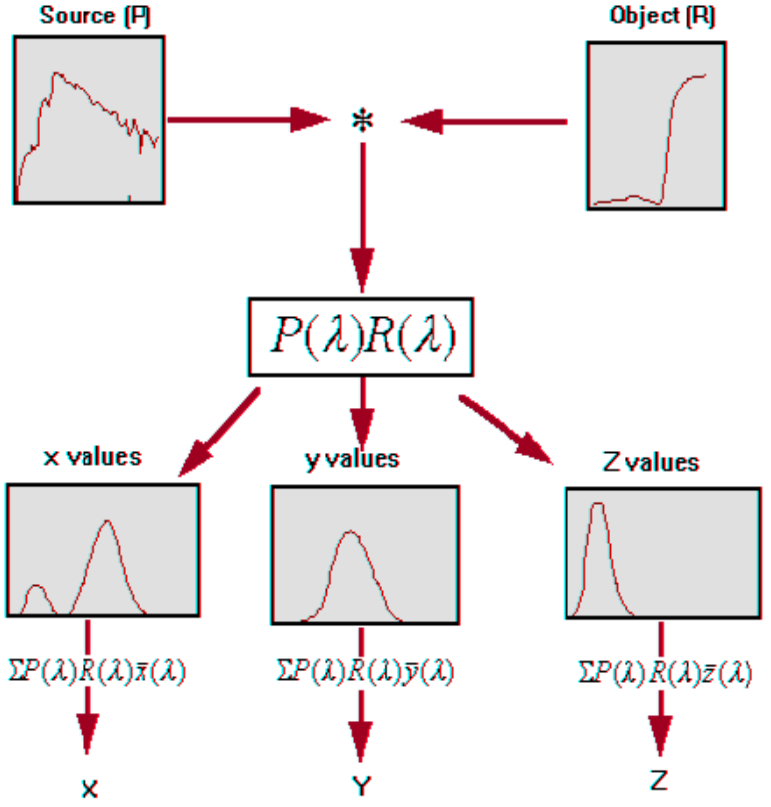


色彩量化


3-colour
mixture
Test
colour
surround
Primary
lights
R
G
B
Partition
White
screen
Filter or
monochromator
White
light
W
Black
enclosure
Observer
10°


2° OBSERVER (CIE 1931)
10° OBSERVER (CIE 1964)
x̄(λ)
ȳ(λ)
z̄(λ)
300
250
200
150
100
50
0
380
430
480
530
580
630
680
730
780
Wavelength (nm)

CIE 三刺激值-XYZ



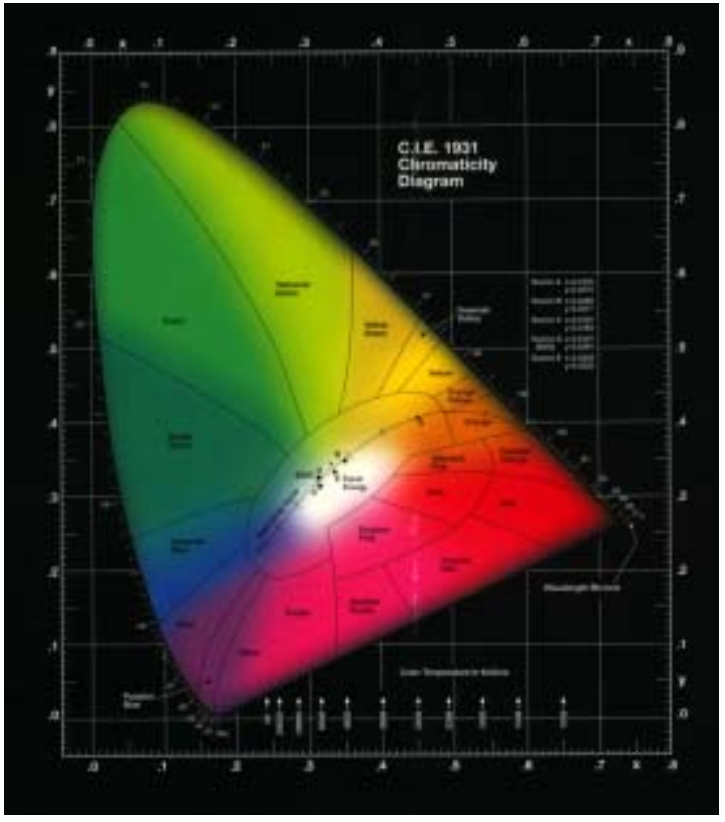
$$X = k \sum_{380}^{780} P(\lambda)\, R(\lambda)\, \bar{x}(\lambda)$$

$$Y = k \sum_{380}^{780} P(\lambda)\, R(\lambda)\, \bar{y}(\lambda)$$

$$Z = k \sum_{380}^{780} P(\lambda)\, R(\lambda)\, \bar{z}(\lambda)$$

$$k = 100 / \sum_{380}^{780} P(\lambda)\, \bar{y}(\lambda)$$

CIE 1931 色度圖



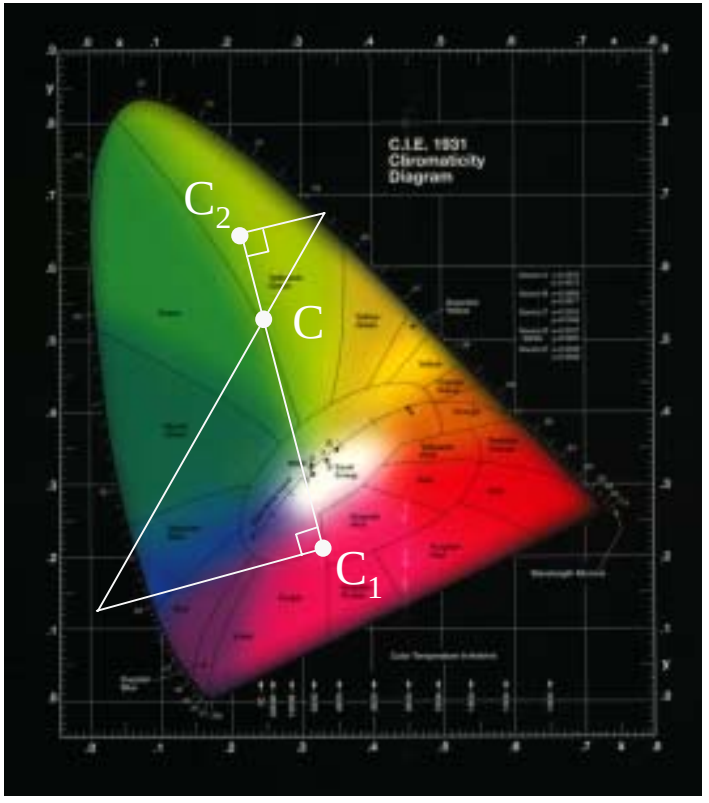
- CIE 1931 (xy) Chromaticity Diagram

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = 1 - x - y$$

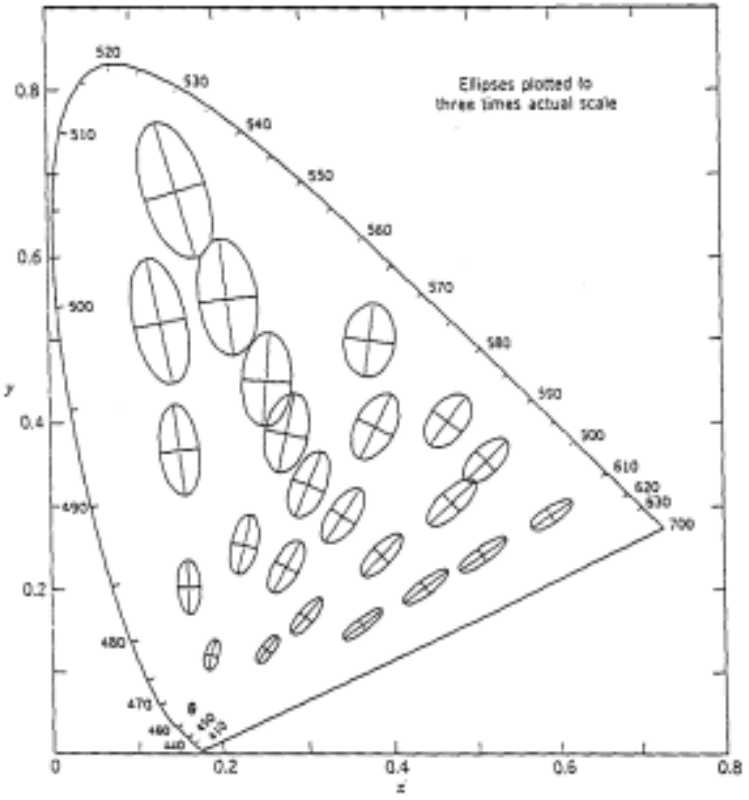
混色現象



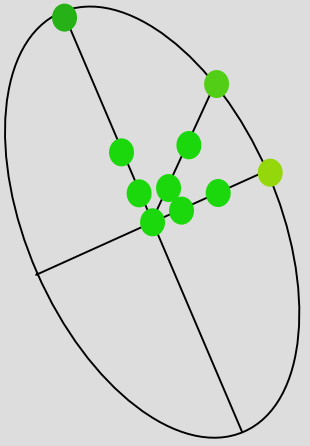
重心定律

$$\frac{C_2}{C_1} = \frac{\overline{C\,C_1}}{\overline{C\,C_2}} = \frac{X_1+Y_1+Z_1}{X_2+Y_2+Z_2}$$

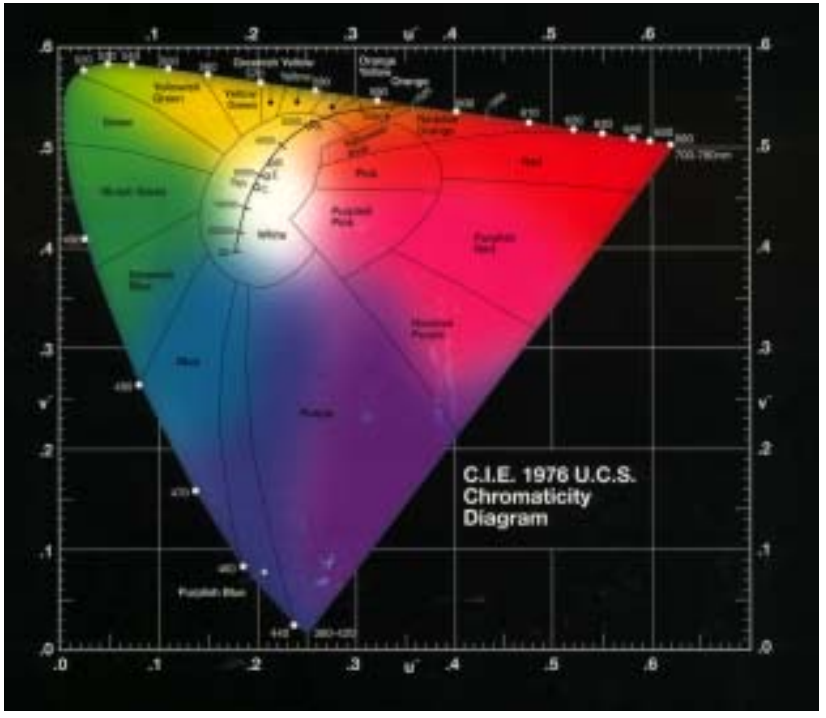
CIE 1931 色度圖色差現象



MacAdam橢圓 1942



uv色度圖 , u'v'色度圖



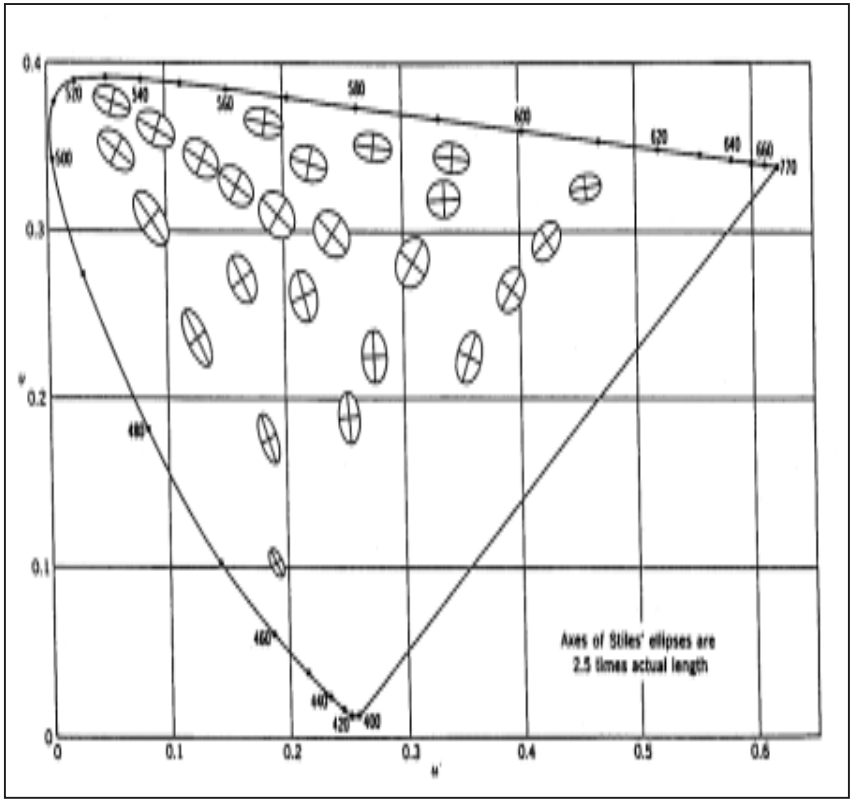
1960

$$u = 4x/(-2x+12y+3)$$
$$= 4X/(X+15Y+3Z)$$
$$v = 6y/(-2x+12y+3)$$
$$= 6Y/(X+15Y+3Z)$$

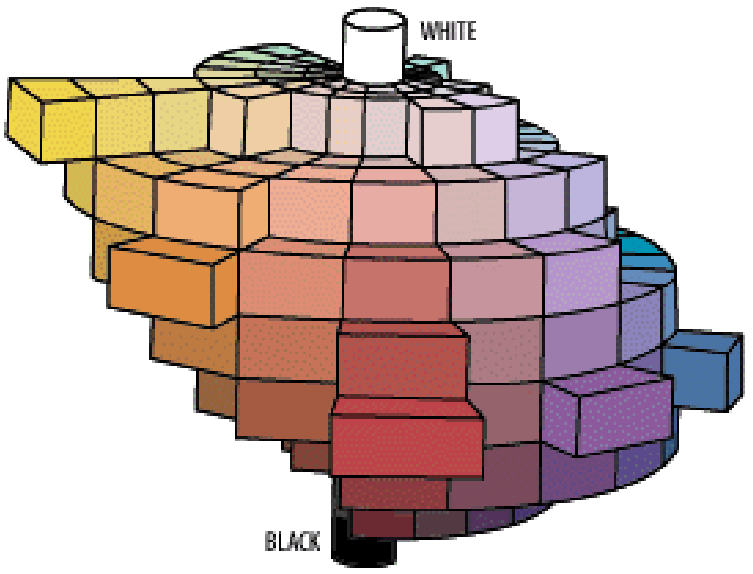
1976

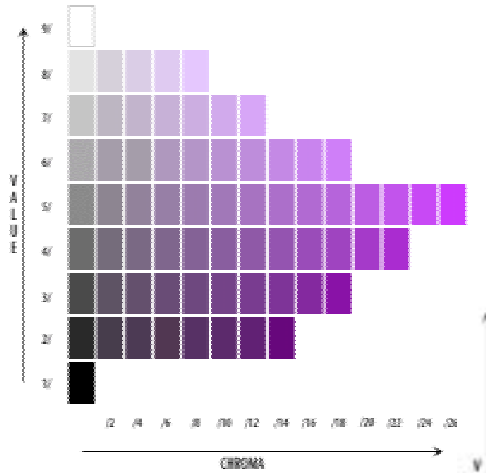
$$u' = 4x/(-2x+12y+3)$$
$$= 4X/(X+15Y+3Z)$$
$$v' = 9y/(-2x+12y+3)$$
$$= 9Y/(X+15Y+3Z)$$

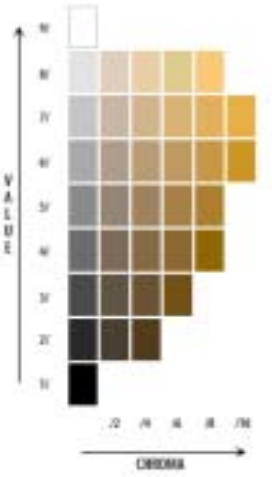
CIE 1976 u'v' 色差現象



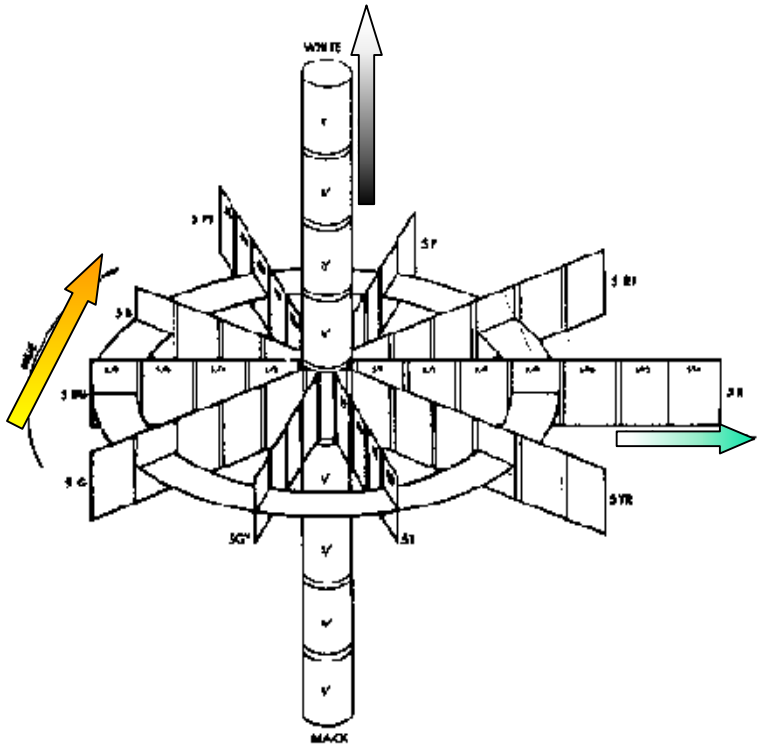
Munsell System

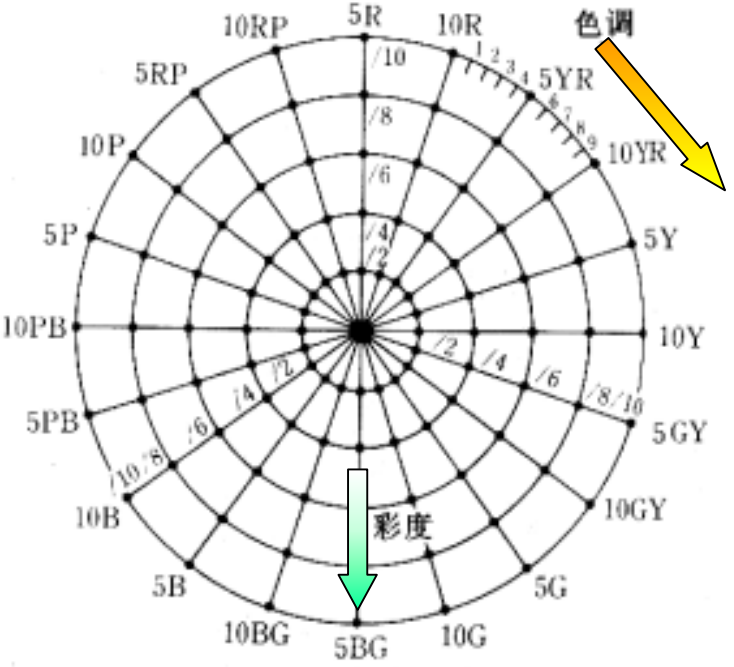






Munsell System





CIE LUV色彩空間

- $L^* = 25(100Y/Y_n)^{1/3} - 16 \qquad (1 \le Y \le 100)$
- $u^* = 13\, L^* (u' - u'_n)$
- $v^* = 13\, L^* (v' - v'_n)$

$u' = 4X/(X+15Y+3Z)$ $\qquad v' = 9Y/(X+15Y+3Z)$

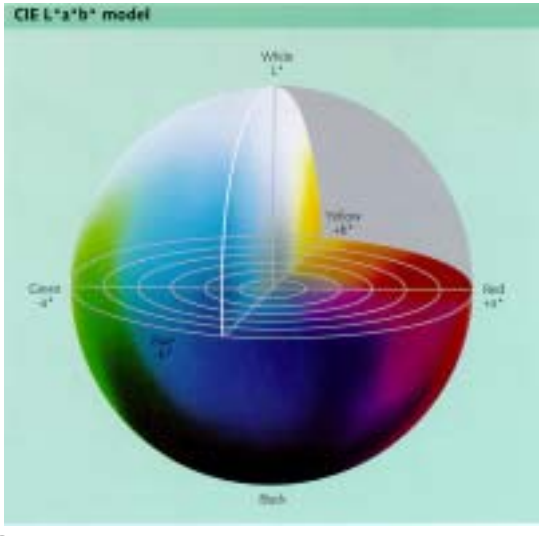
$u'_n = 4Xn/(Xn+15Yn+3Zn)$ $\qquad v'_n = 9Yn/(Xn+15Yn+3Zn)$

Xn, Yn, Zn 為參考白之 X, Y, Z 值

$$\Delta E_{uv}^* = [(\Delta L^*)^2 + (\Delta u^*)^2 + (\Delta v^*)^2]^{1/2}$$

CIE LAB色彩空間

- $L^* = 116(Y/Yn)^{1/3} - 16$ for $Y/Yn > 0.00885$
- $L^* = 903.3\,(Y/Yn)$ for $Y/Yn <= 0.008856$
- $a^* = 500[f\,(X/Xn) - f\,(Y/Yn)]$
- $b^* = 200[f\,(Y/Yn) - f\,(Z/Zn)]$



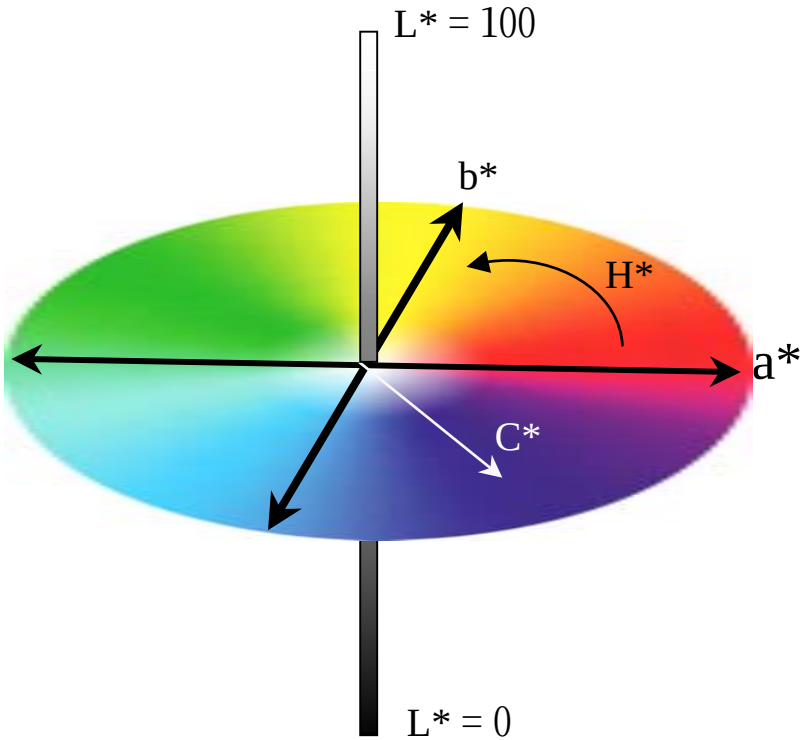
- if X/Xn, <= 0.008856

  $f\,(X/Xn) = 7.787(X/Xn) + 16/116$

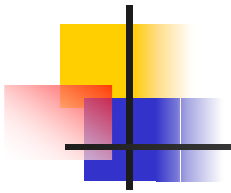
  else $f\,(X/Xn) = (X/Xn)^{1/3}$ Y/Yn and Z/Zn 相同
- Xn, Yn, Zn 為參考白之 X, Y, Z 值

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

CIE LAB色彩空間



- L* 明度(Lightness)
- a* 紅綠度
- b* 黃藍度
- H* 色相角(Hue)
- C* 彩度(Chroma)



色彩系統

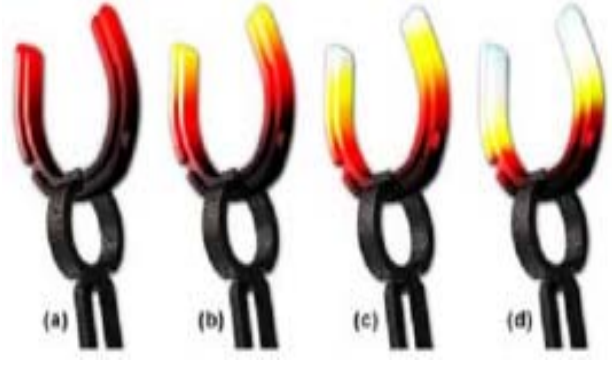
- 光源
- 色彩加成性
- 色彩相減性

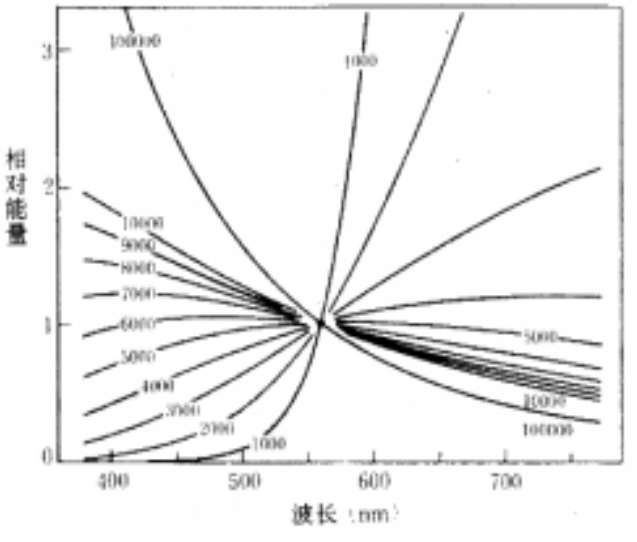
光　　源

- 自然日光
- 常用的標準光源
  - CIE A (2856K)
    鎢絲燈
  - CIE C (6774K)
    Munsell Color
  - CIE Daylight
    - D65
- 常用的補充標準光源
  - CIE B (4874K)
    Munsell Color
  - CIE Daylight
    - D50　(印刷界)
  - CIE Fluorescent 螢光
    - F2 冷白 (4150K)
    - F7 晝白 (6500K)

黑體輻射 (Black-body Radiation)

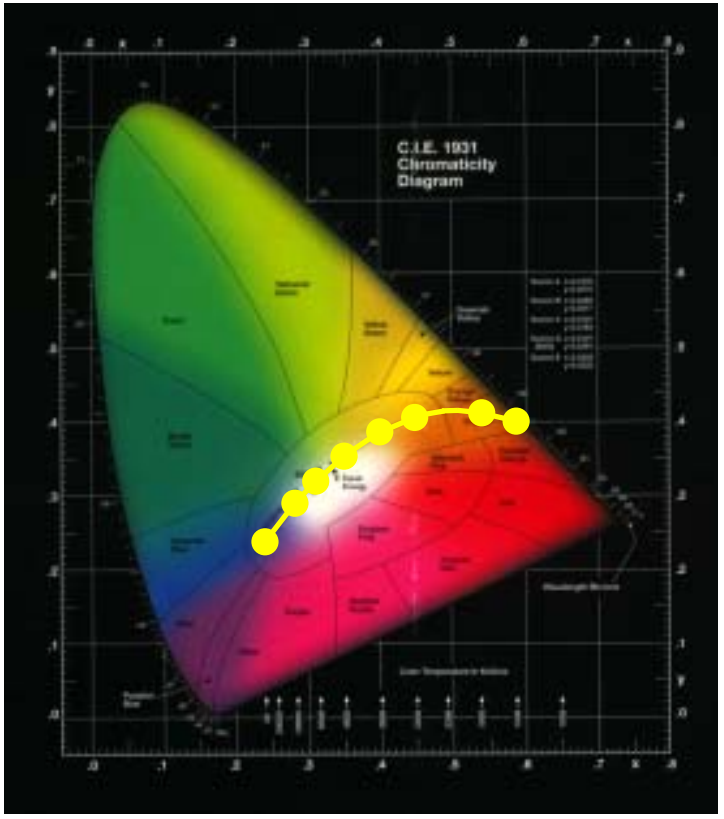
- 當對鐵等不燃物加熱時，會逐物體漸發紅光，進一步加到高溫時，物體色由紅變黃最後變白色，將這樣得到的光輻射稱之為黑體輻射。



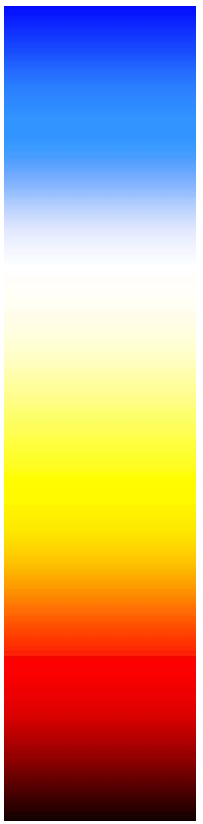


不同絕對溫度下黑體輻射的光譜分佈（在560nm處正規化為1）

黑體軌跡



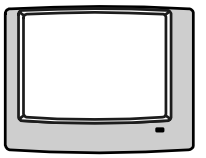
光源色温



7000K

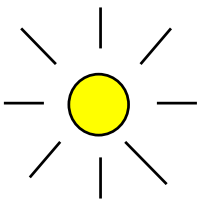
顯示屏的 “白光”

陰暗天空

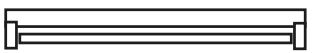


5000K

正午日光



熒光燈

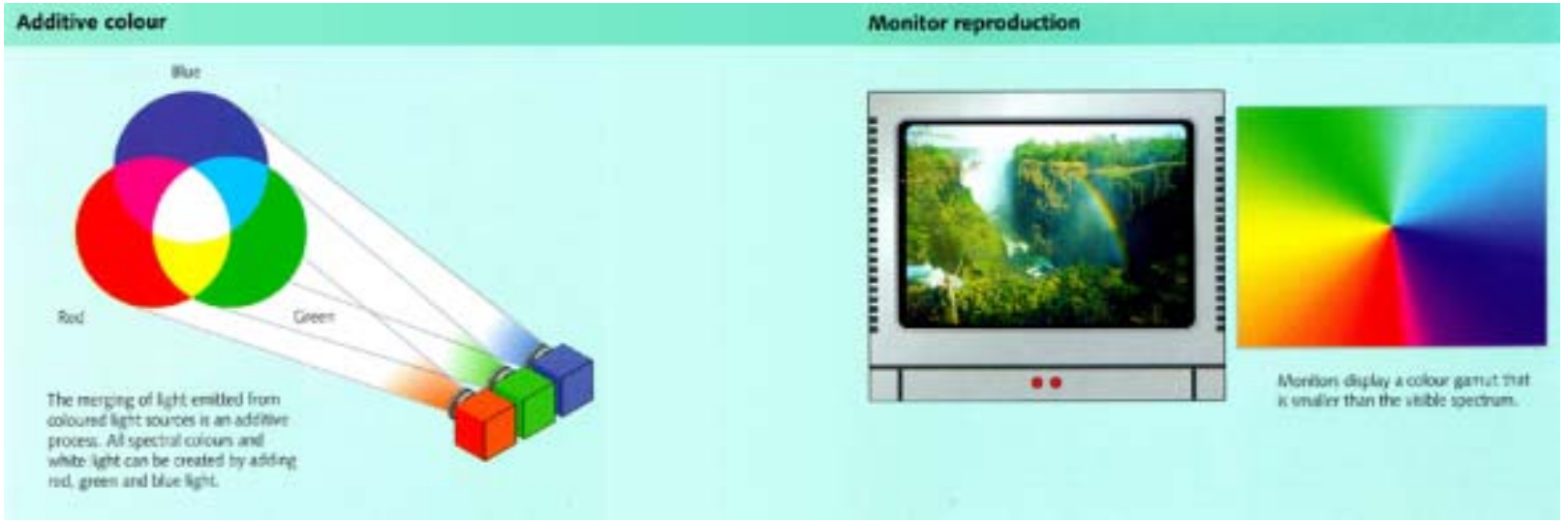


3000K

白熾燈

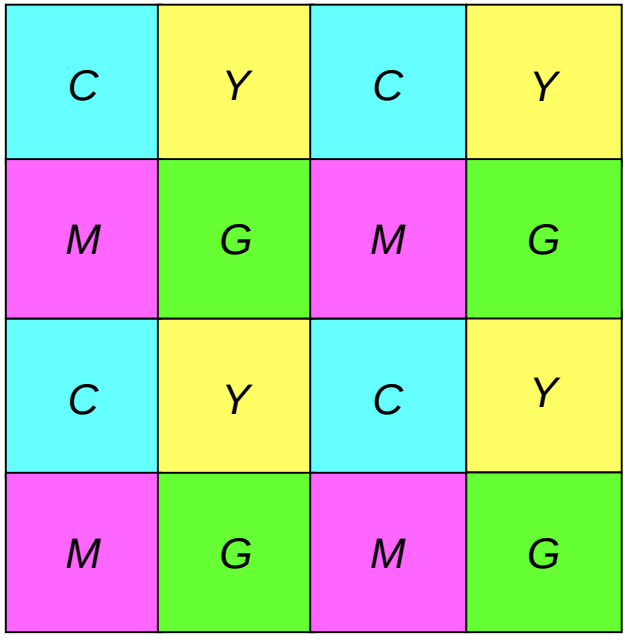
日落陽光

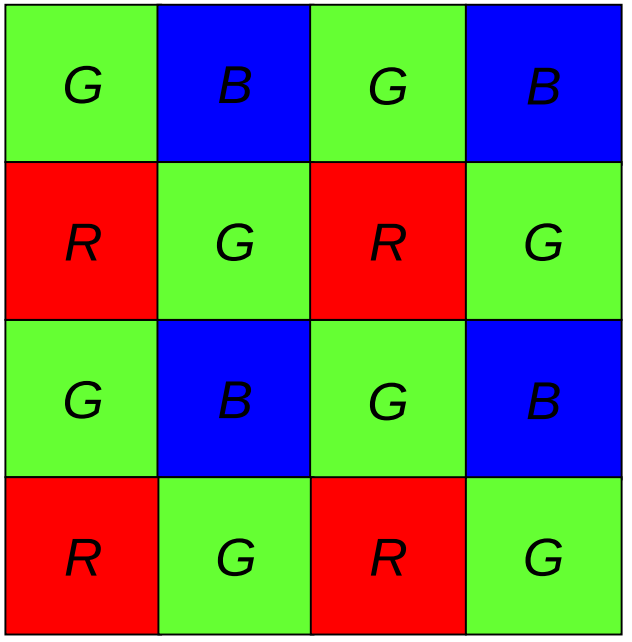
色彩加成性



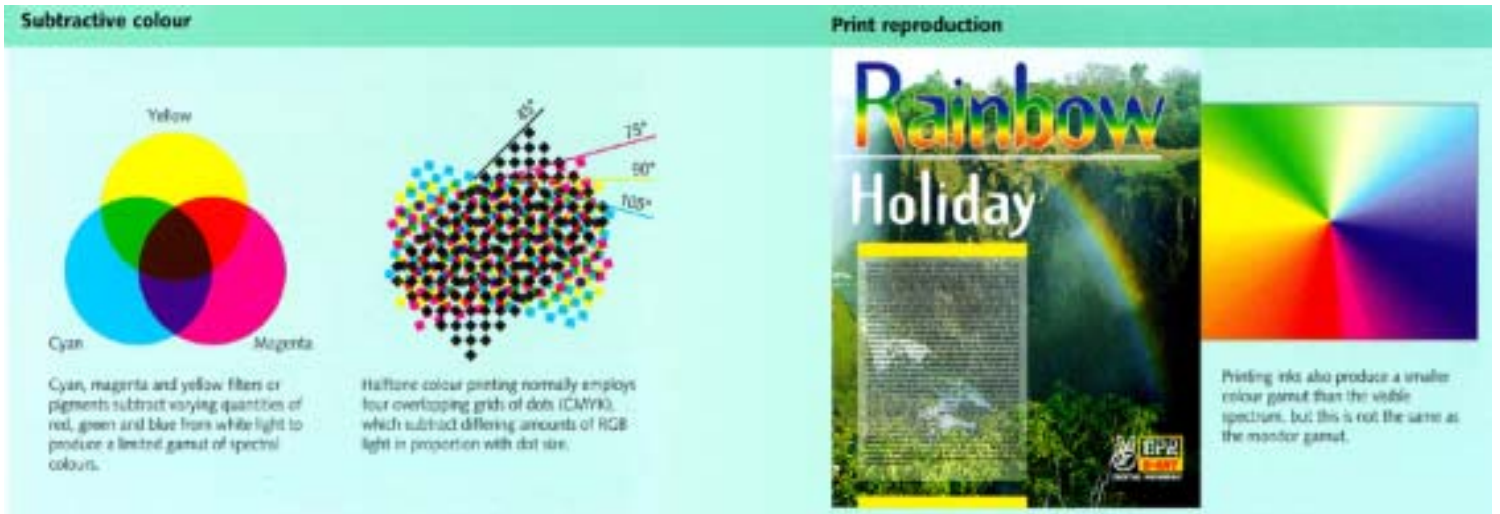
The picture quoted from Agfa digital colour prepress volume 4

Digital Camera Sensor



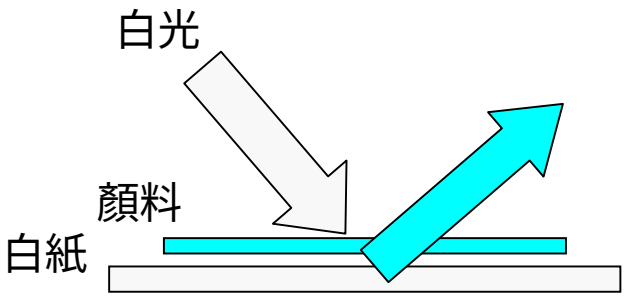


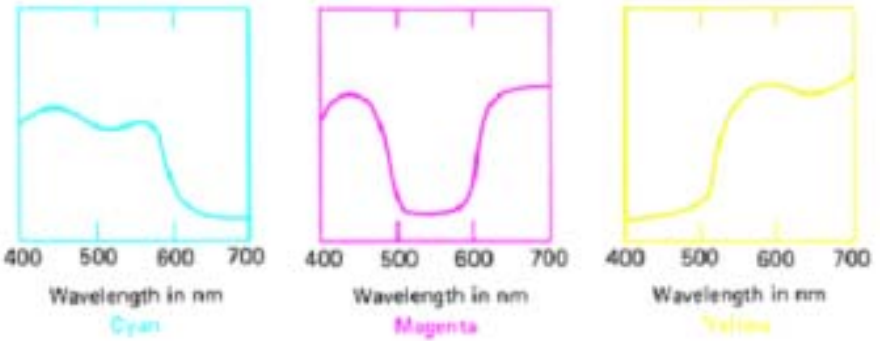
色彩相減性

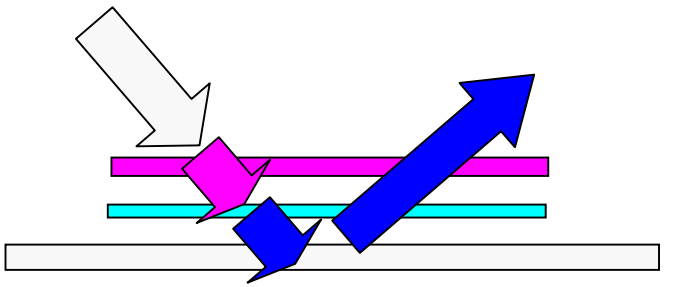


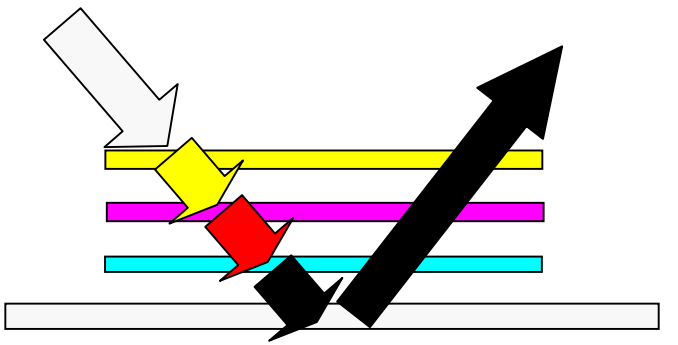
The picture quoted from Agfa digital colour prepress volume 4

色彩相減性


白光
顔料
白紙


400 500 600 700
Wavelength in nm
Cyan
400 500 600 700
Wavelength in nm
Magenta
400 500 600 700
Wavelength in nm





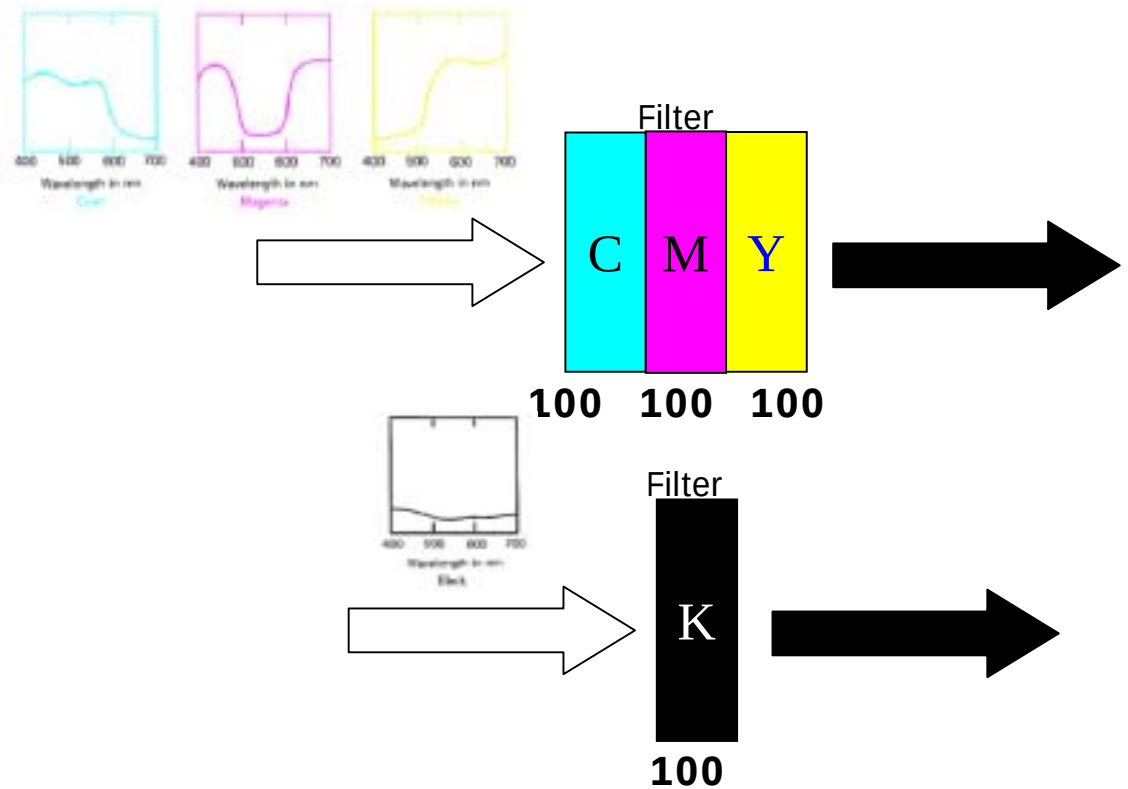
灰色平衡 (Gray Balance)

- 當使用CMY三色複製灰色漸層或階層的原稿複製起來必需是中性灰色，不可帶有偏色。
- 任何影像中的灰色部份必需是灰色的。
- 絕不可以看起來有粉紅色、藍藍的或黃黃的感覺。

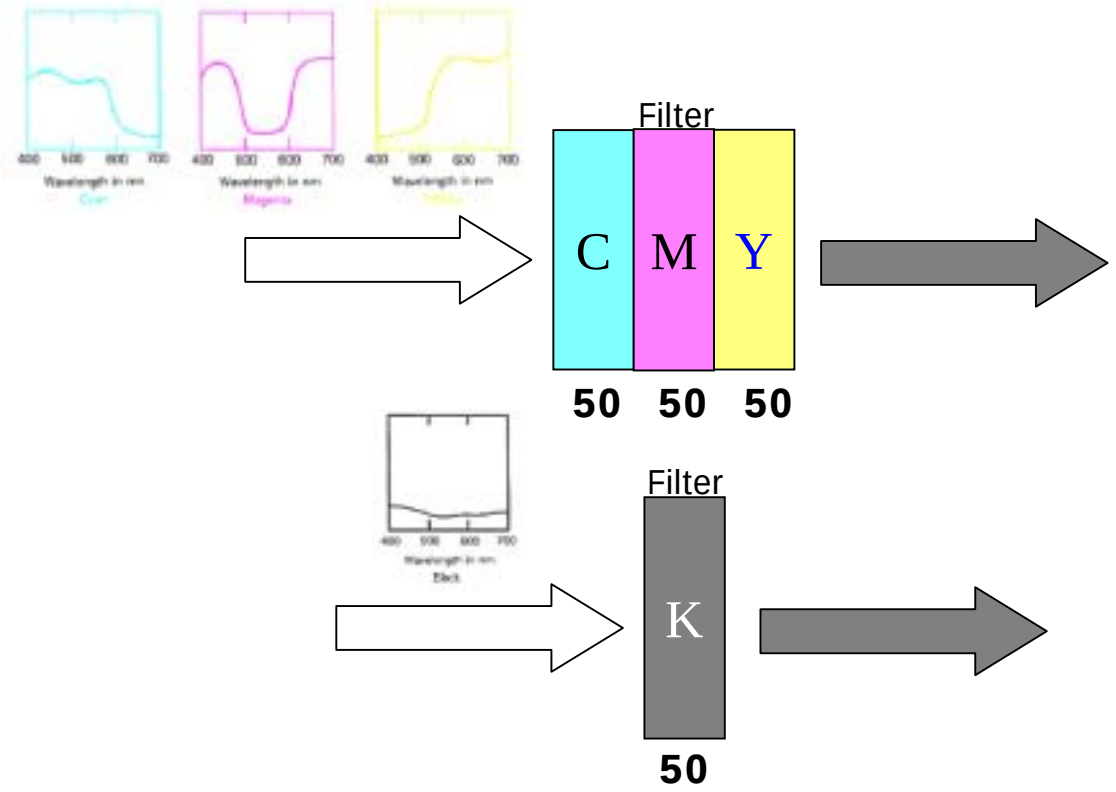
灰色平衡

灰色不平衡

CMYK-GCR取代法則



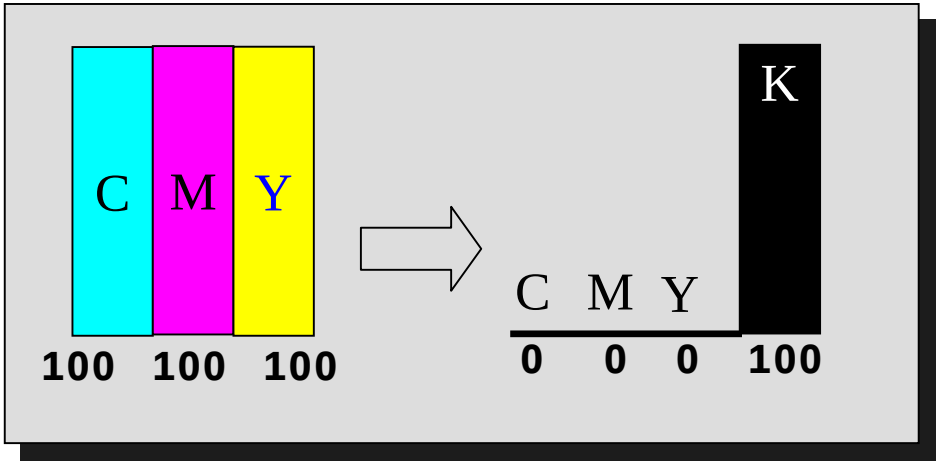
CMYK-GCR取代法則

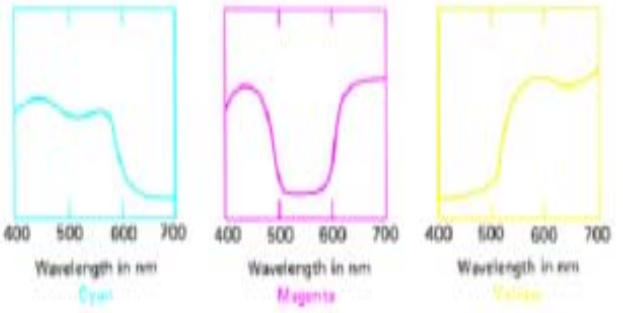


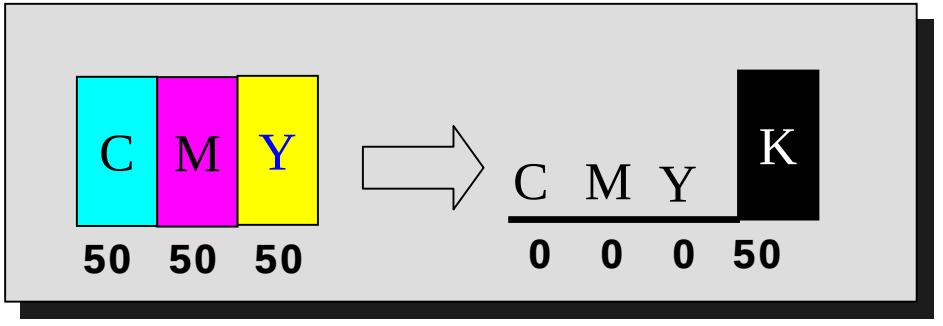
GCR

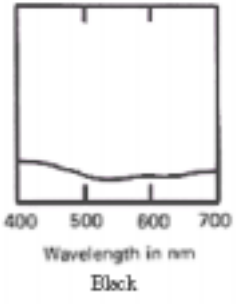
1. 灰色置換Gray Component Replace。
2. 使用適當的黑版來置換灰色部份。
3. 降低使用印墨量，乾燥時間。
4. 增加黑墨可使鮮銳度及反差加強。

CMYK-GCR取代法則

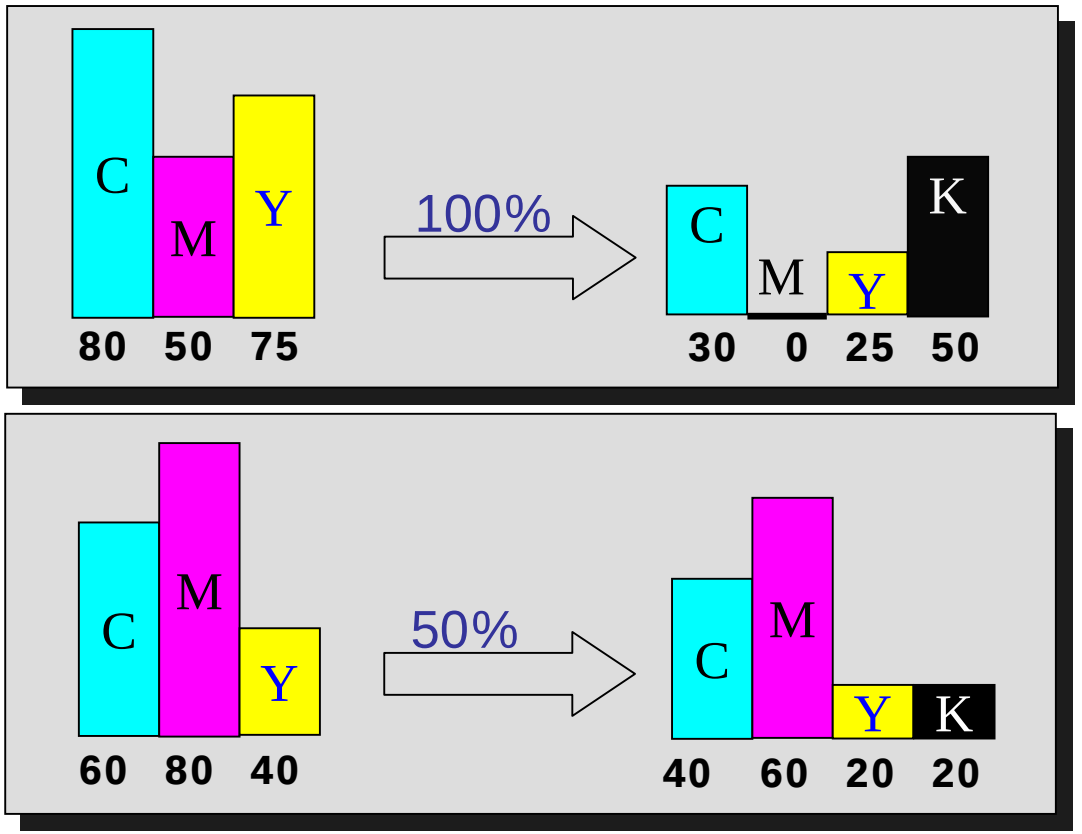




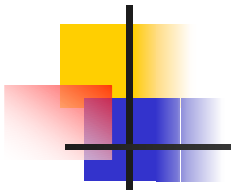




CMYK-GCR取代法則



四色印刷色序



- What is color?
- 色彩學說
  - 三原色學說
  - 對立顏色學說
  - 視覺
- 色彩空間
  - CIE 1931 x,y
  - uv色度圖 , u’v’色度圖
  - CIE LUV色彩空間
  - CIE LAB色彩空間
- 色彩系統
  - 光源
  - 色彩加成性
  - 色彩相減性


彩色技術
實驗室