Light as Electromagnetic Wave.

$C(x, y, t, \lambda)$ = energy density of electromagnetic wave.

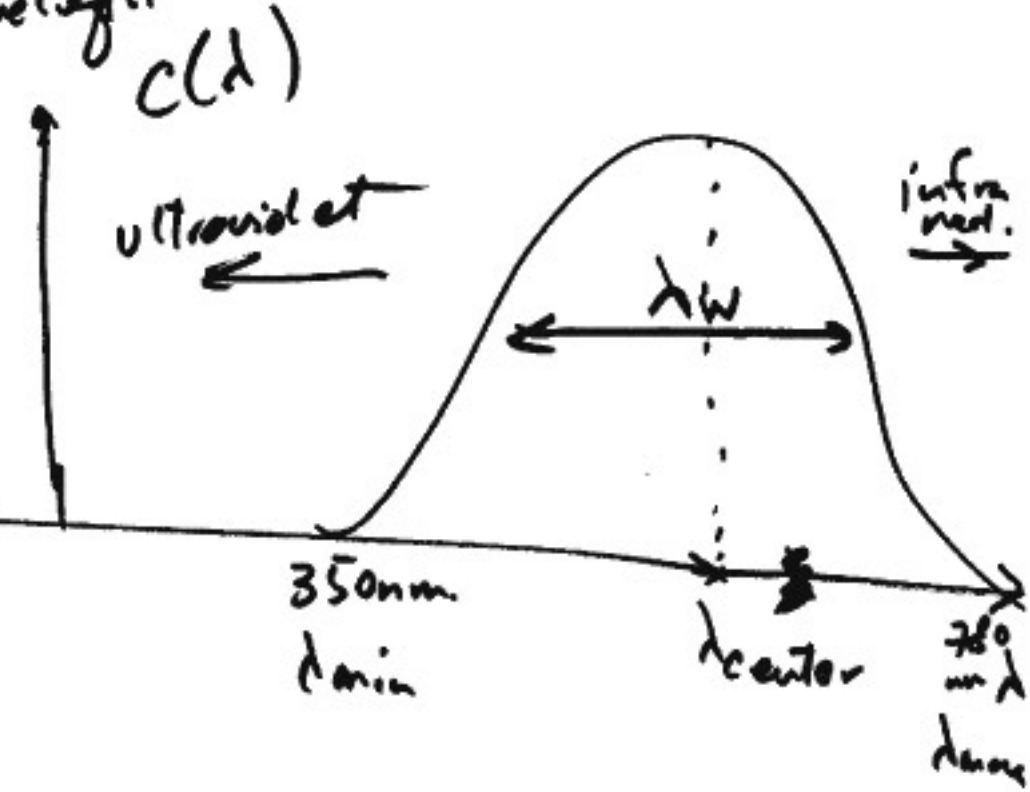
location

Time

wavelength.

energy per (area x Time x wavelength)

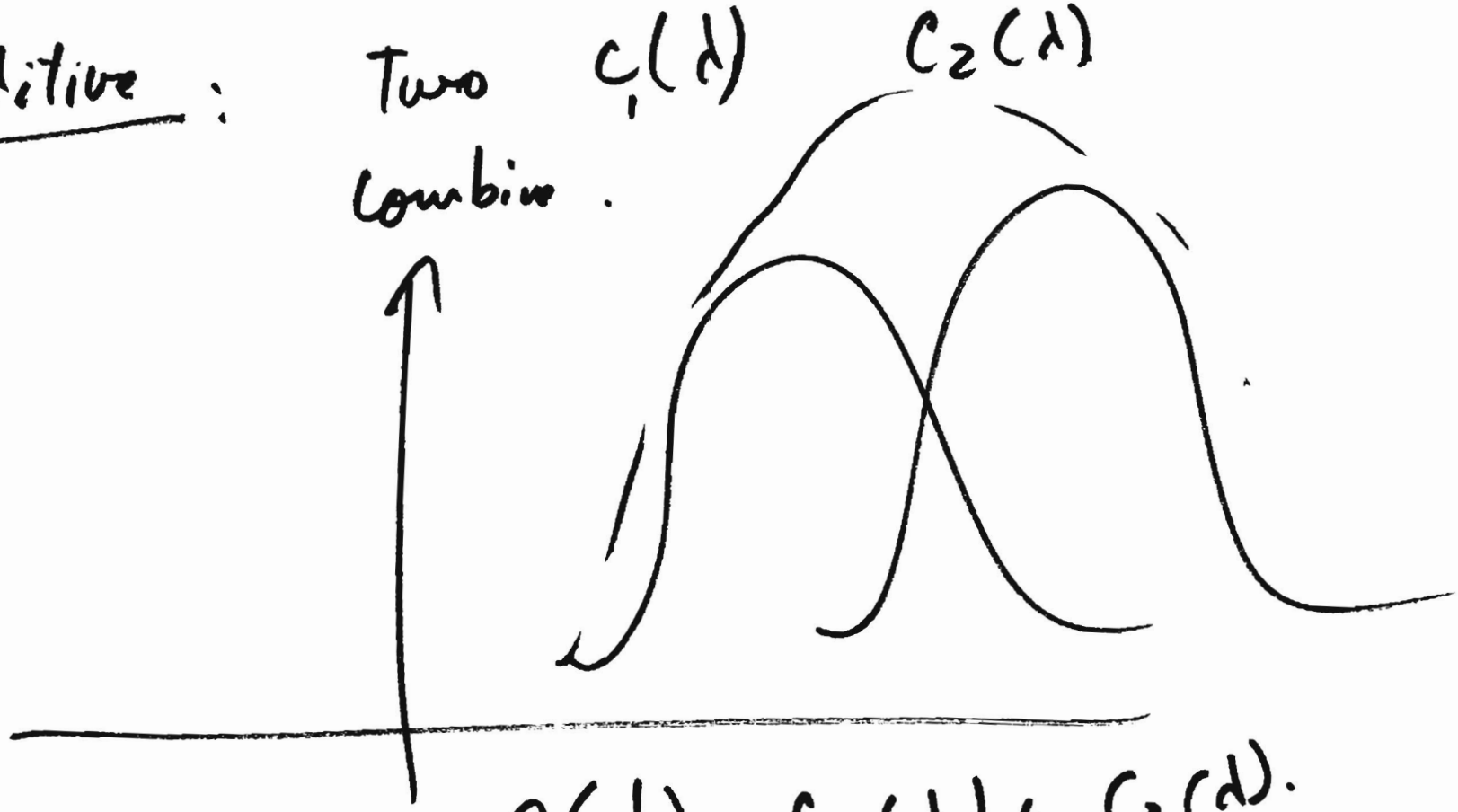
joules / (m^3. s.)



physical Domain.	very approximate	Perceptual Domain
$\int_{\lambda_{min}}^{\lambda_{max}} C(\lambda)\, d\lambda$	how bright?	Brightness.
λ_{center}	color.	Hue
$\approx 700nm$		Red.
$\approx 550nm$		green.
$\approx 450nm$		Blue.
λ_w	viridon dell.	Saturation

Additive / subtractive color system

Additive: Two $c_1(\lambda)$ $c_2(\lambda)$ combine.



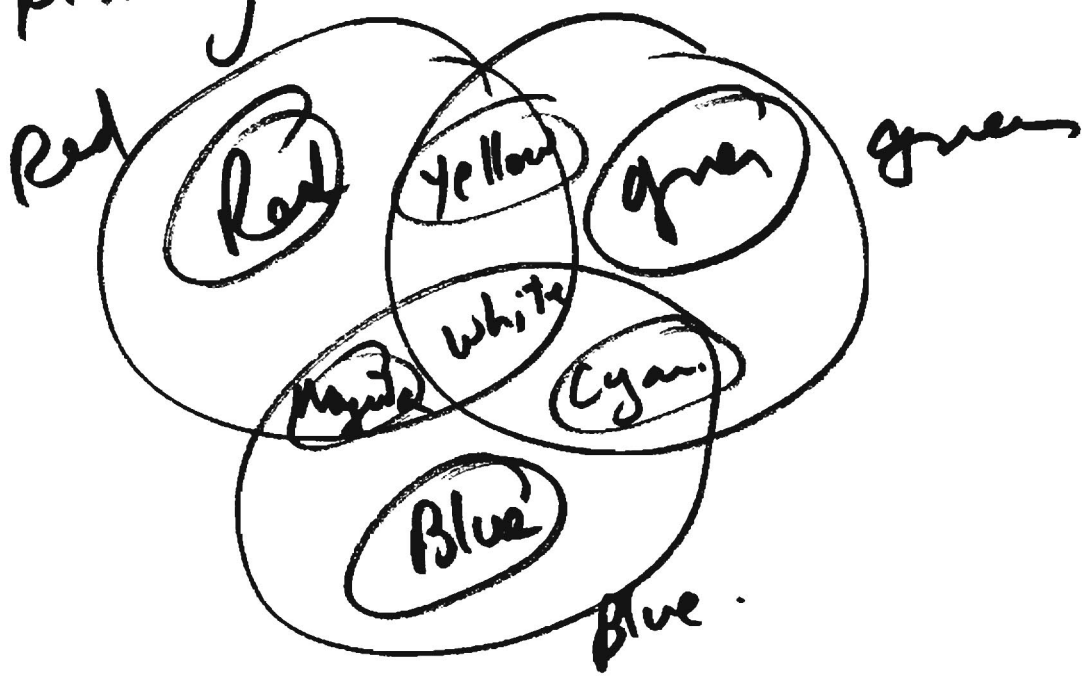
$$C(\lambda) = c_1(\lambda) + c_2(\lambda).$$

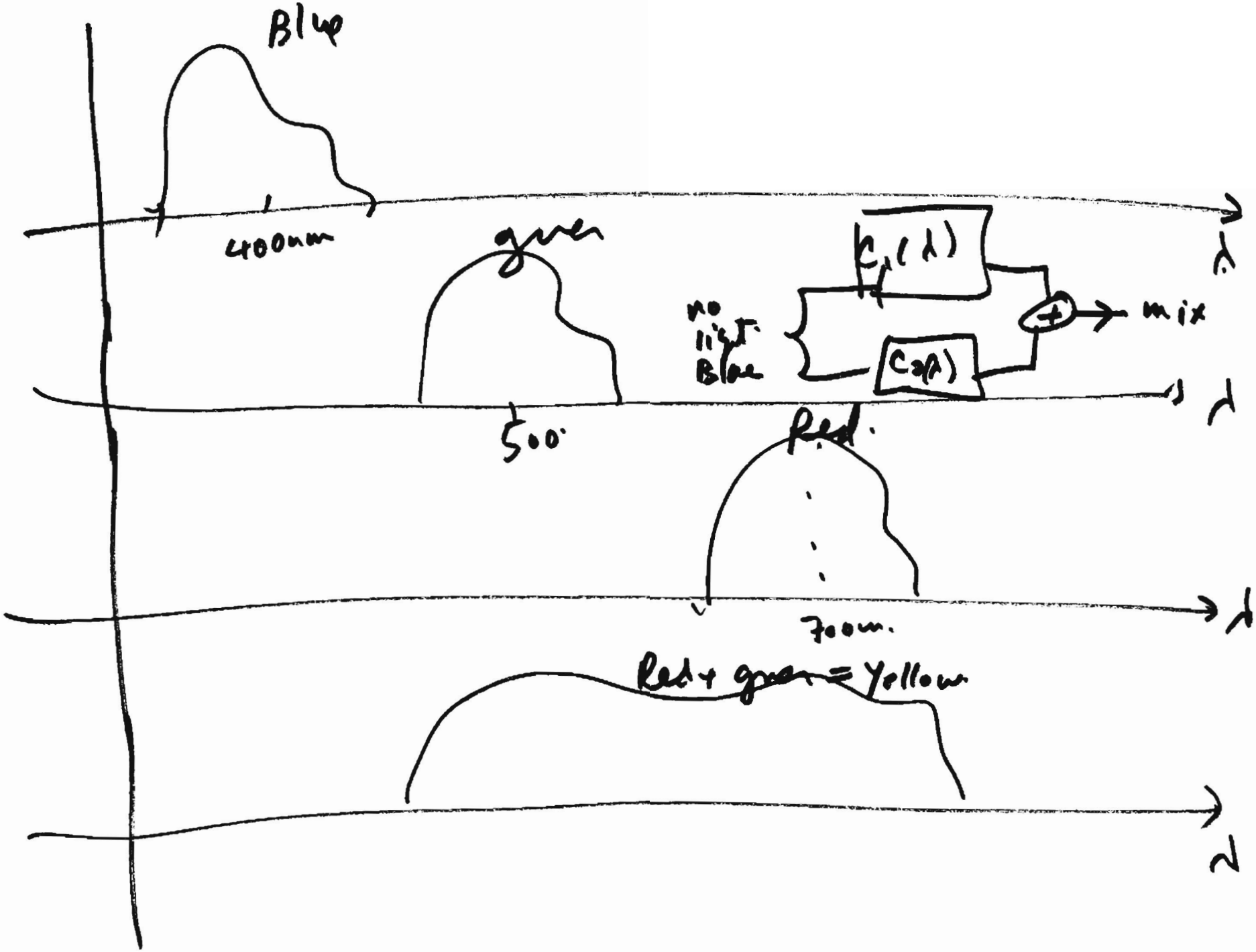
additive system: $\longrightarrow$ Add light at diff. wavelength a new color

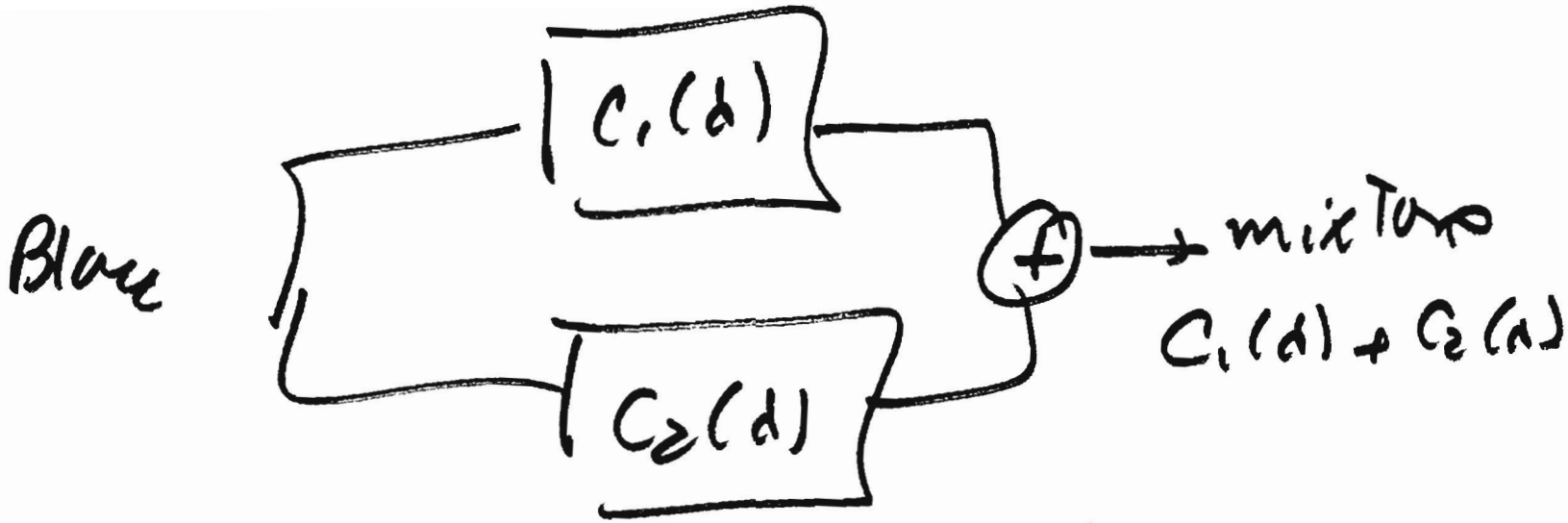
Ex additive sys → TV.

Red Gun
Blue "
Green gun

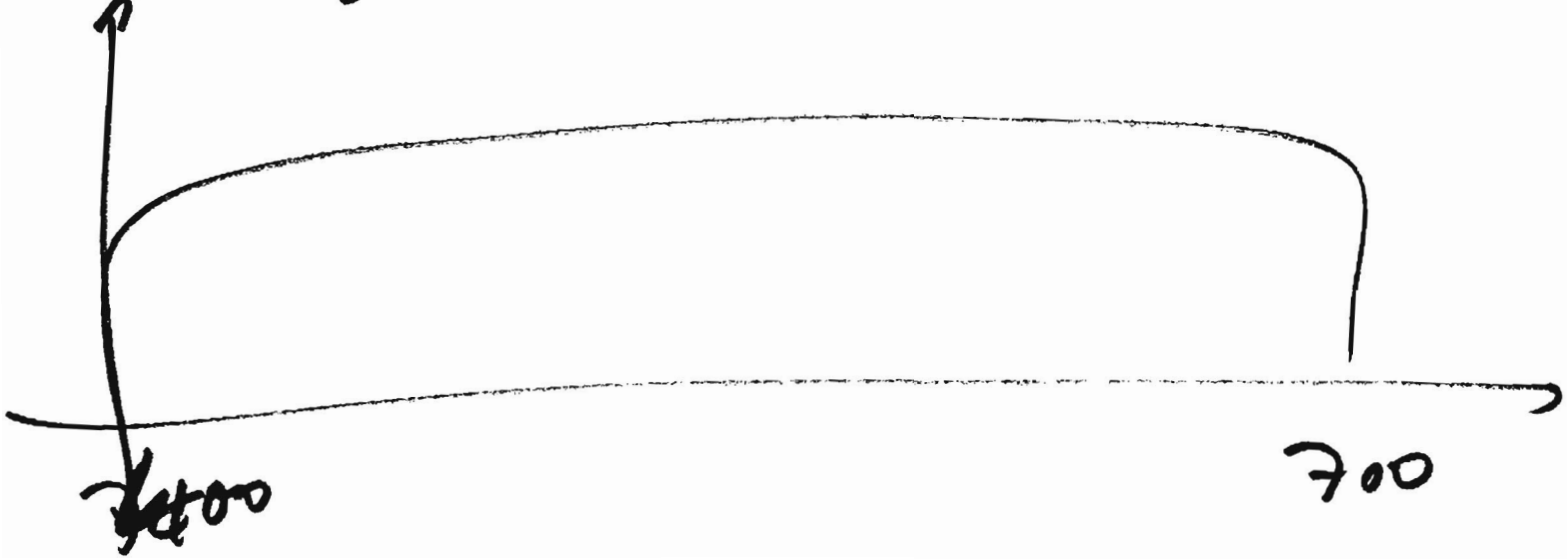
3 primary colors → Red, green, Blue



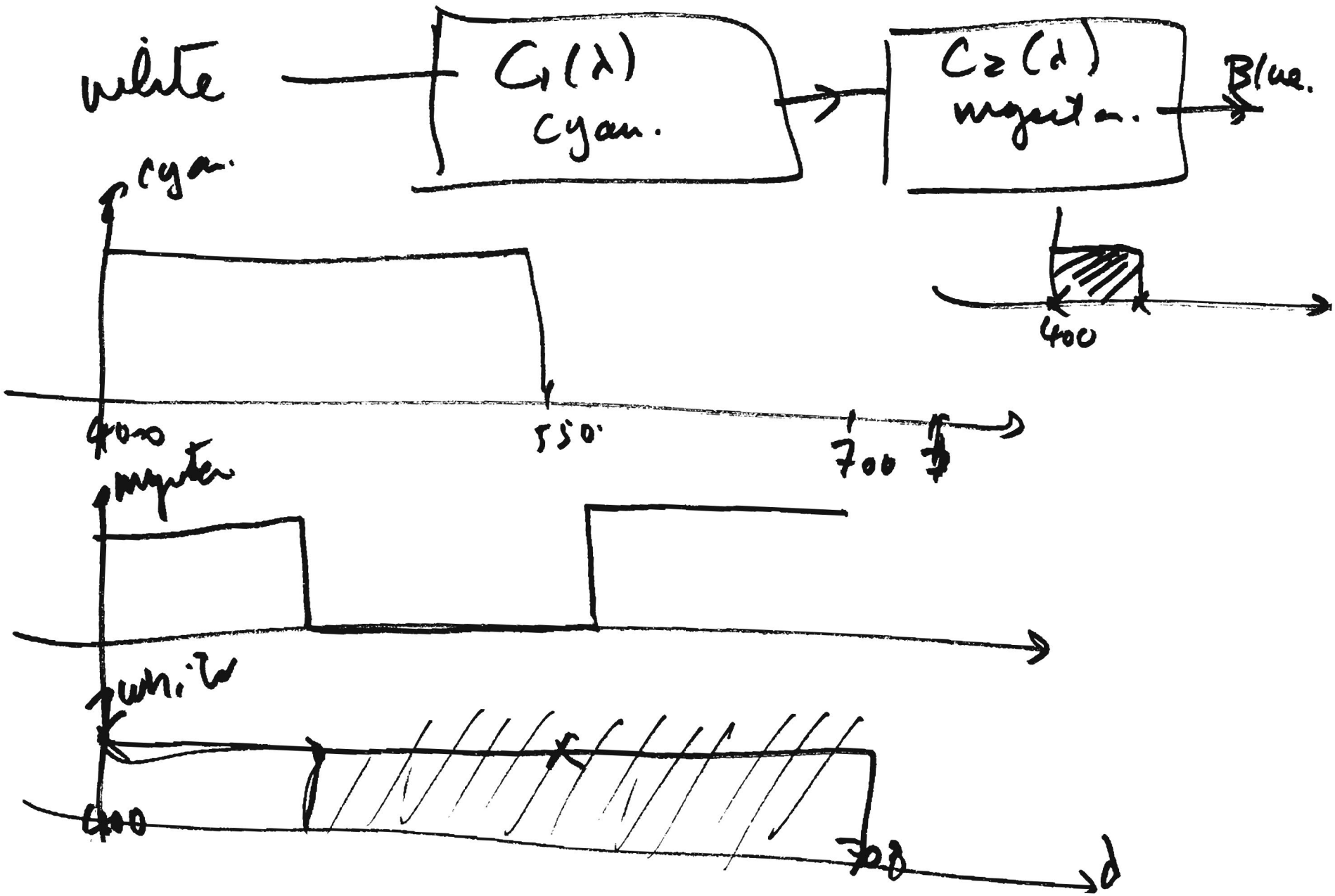

Blue
400nm
green
500
Red
700nm
Red + green = Yellow
no light Blue
$C_1(\lambda)$
$C_2(\lambda)$
+
mix
λ



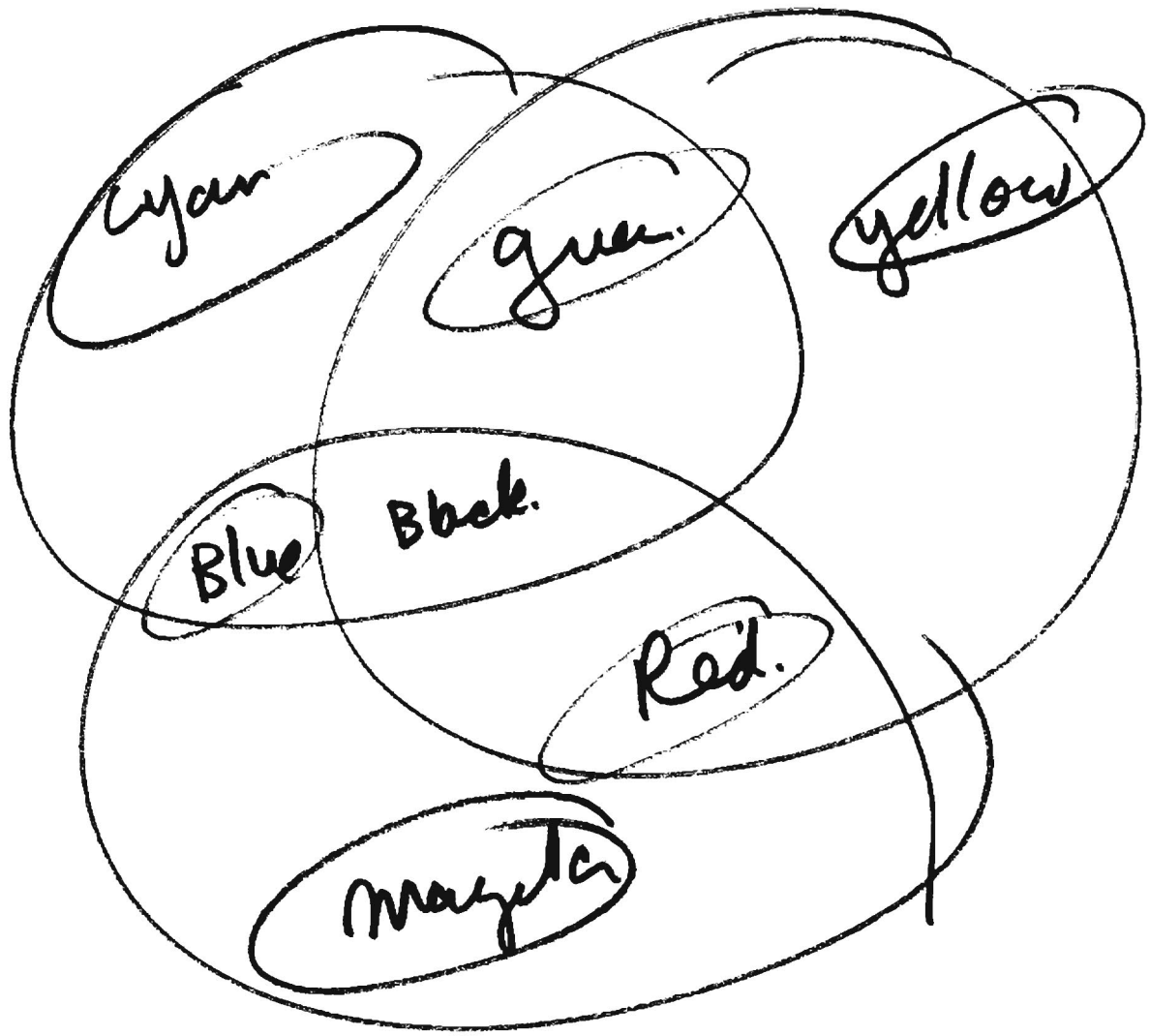
white light Ex: Camera sensor.



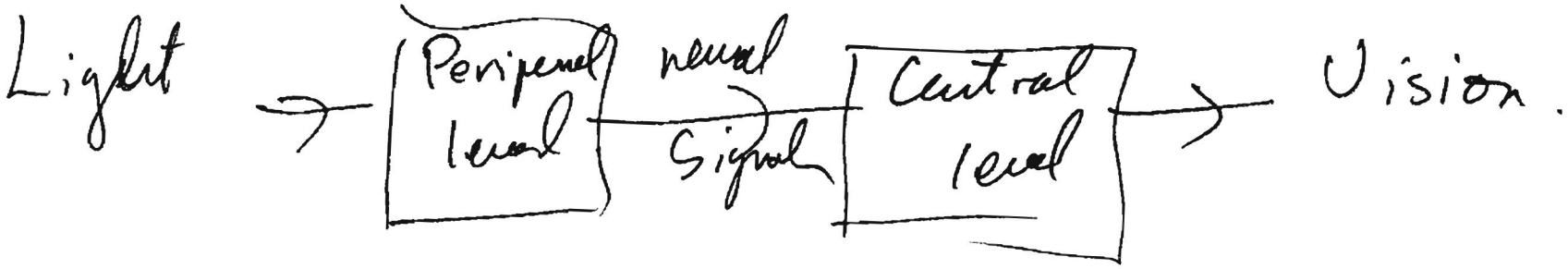
Subtractive Colour system.



3 primary colors of subtraction syn



Human Visual System



Central level ⟶ not well understood.

Peripheral level ⟶ Better understood.

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1. physiological studies
2. psychophysical studies

One simple model for Peripheral level.

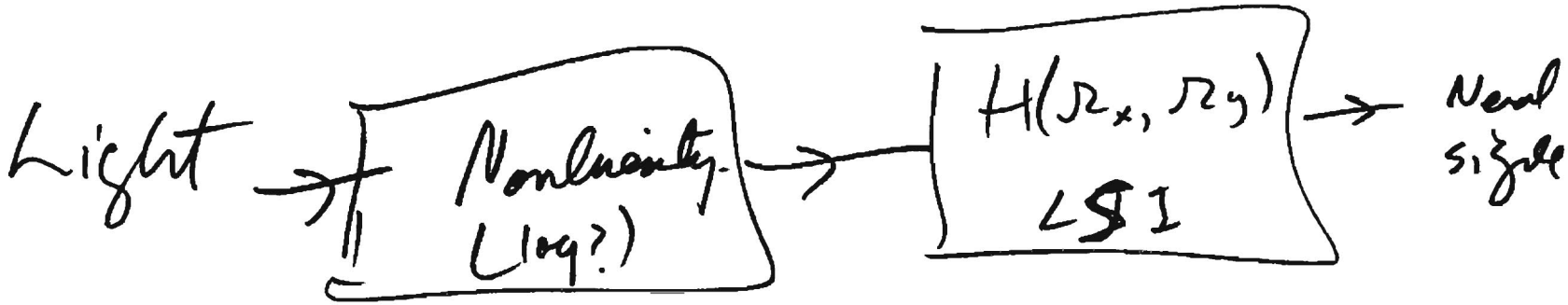


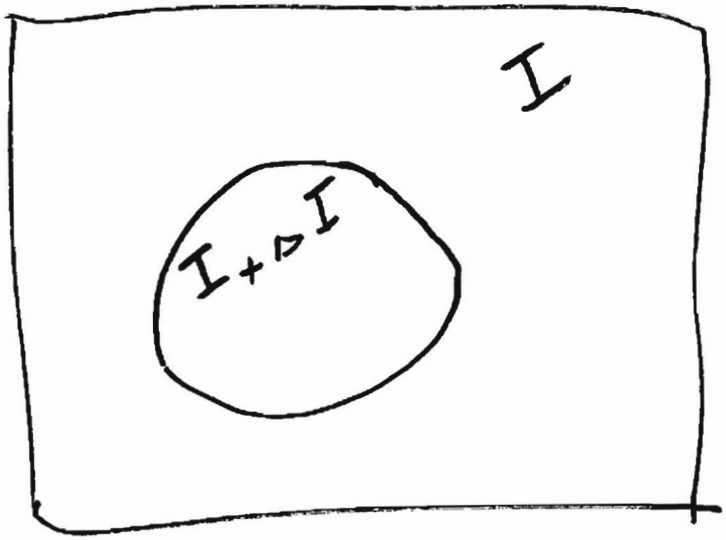
Fig 7.23 J. Lim

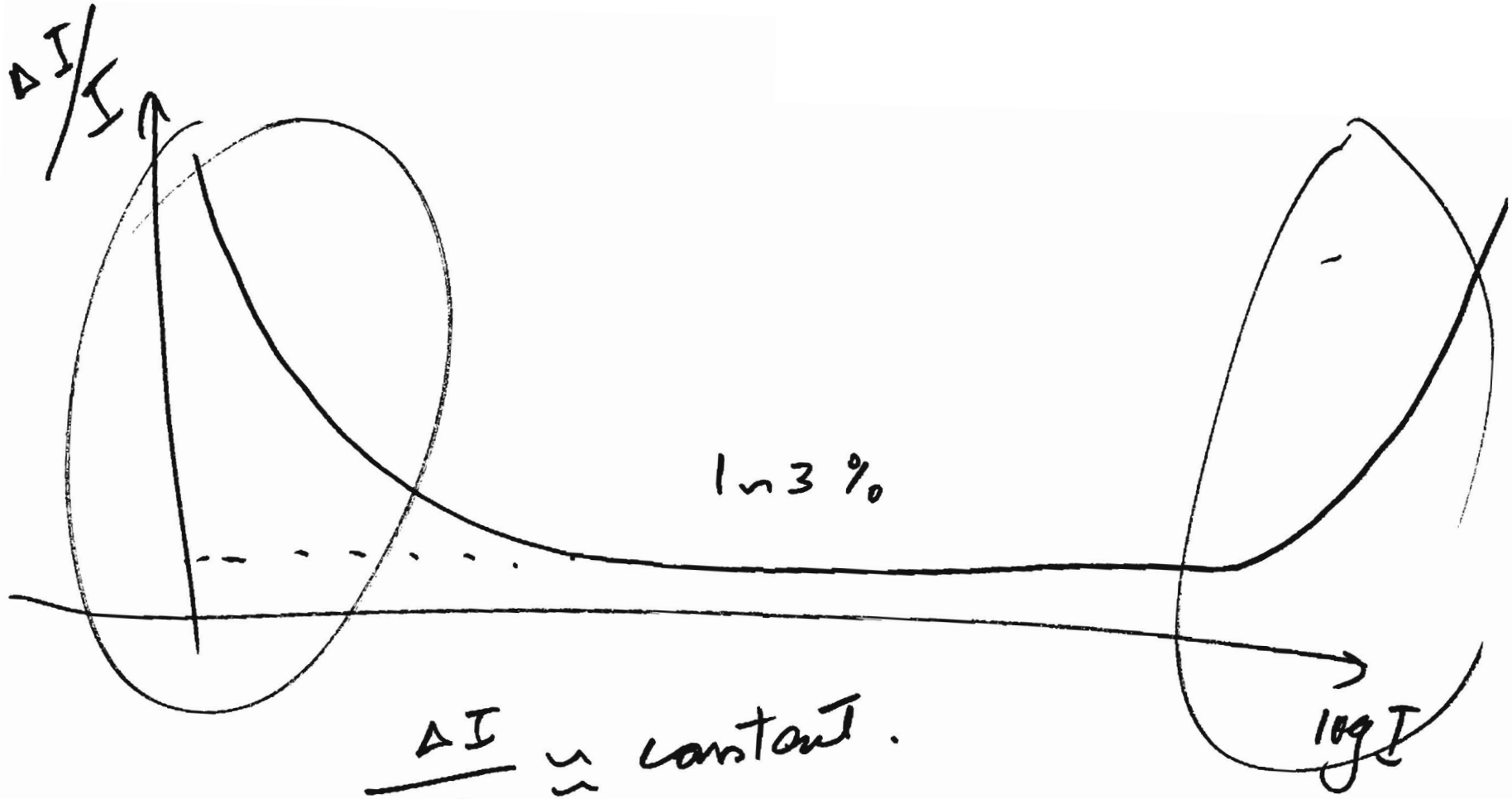
Freq. Response $H(\Omega_x, \Omega_y)$

Visual Phenomena

(1) Weber's Law.

jnd = just noticeable difference.

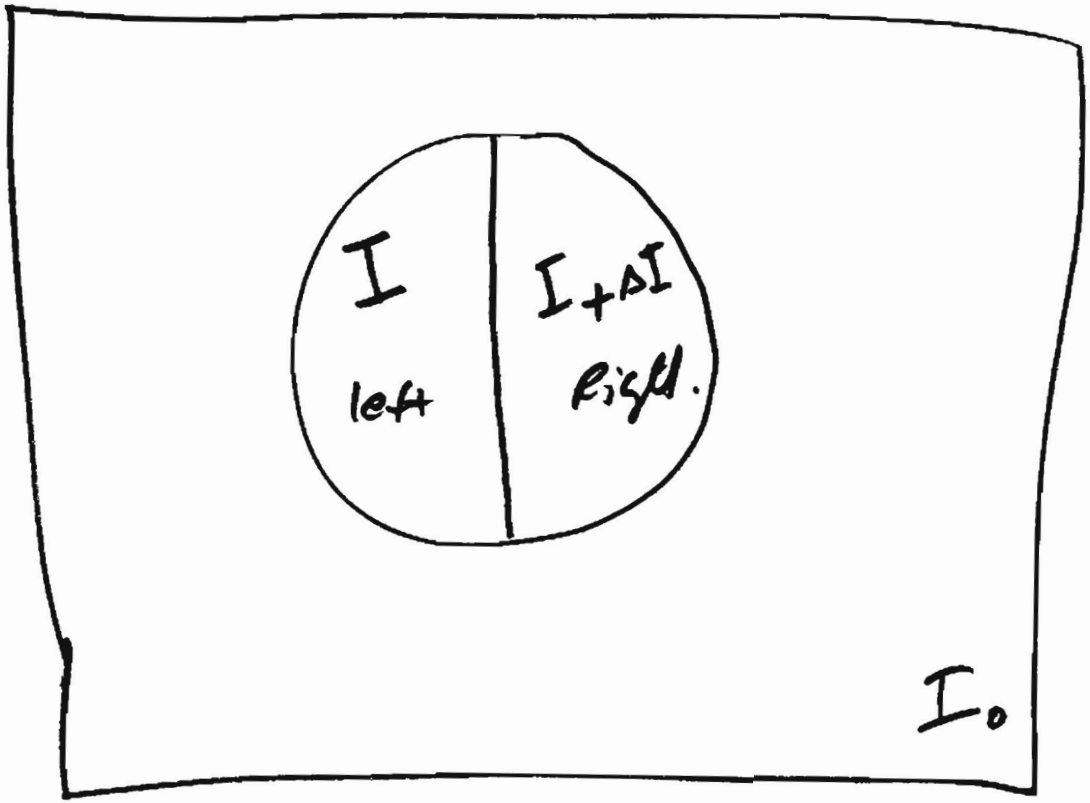


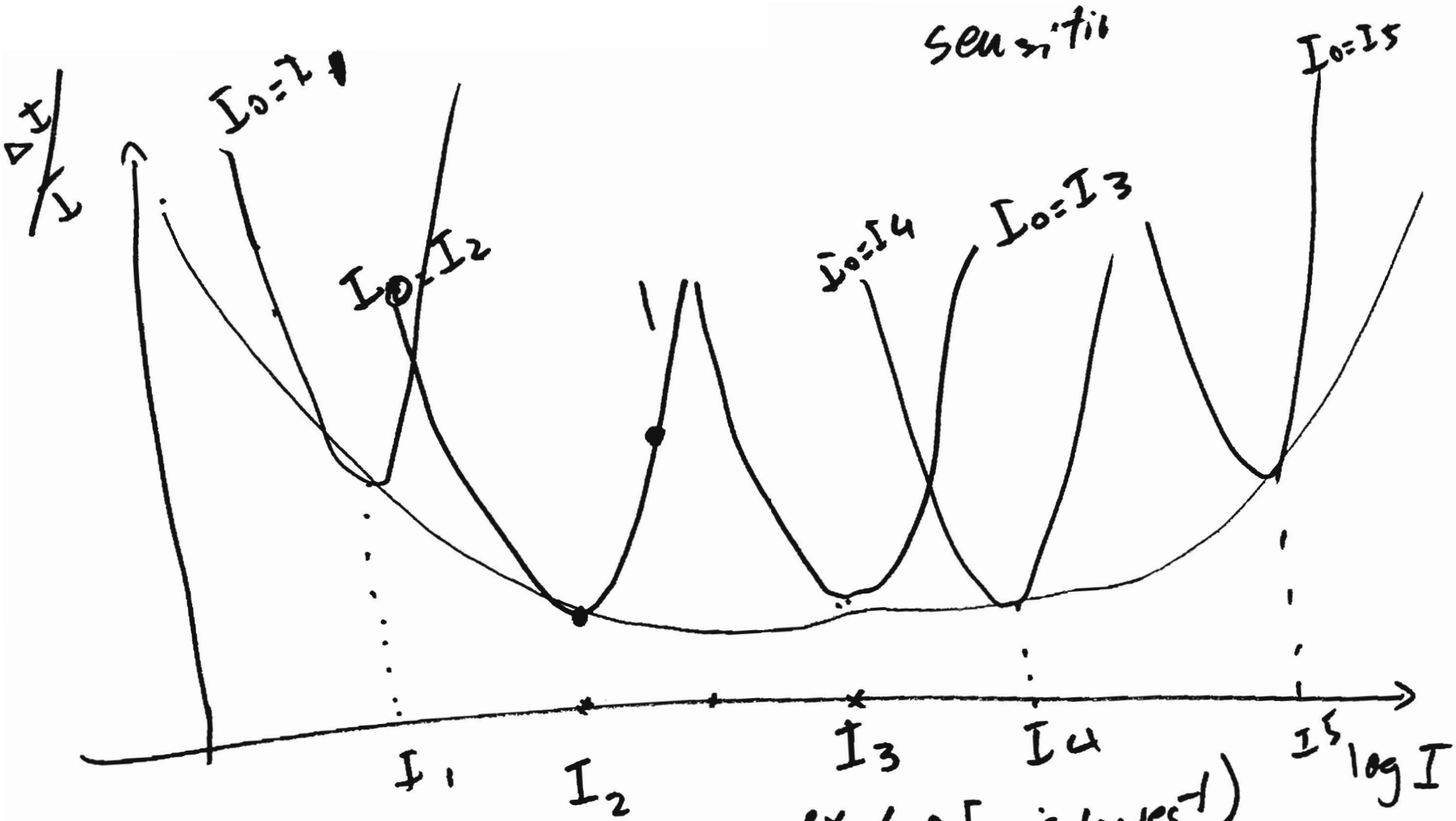


$$\frac{\Delta I}{I} \simeq \text{constant}.$$

$\Delta I \to 0$ $\qquad \frac{dI}{I} \simeq \text{constant} = d(\log I)$

Adaptation Experiment





Sensitivity to intensity is highest ($\frac{\Delta I}{I}$ is lowest) near the level that the observer is adapted to.

Spatial Freq. Response

$$I(x,y) = I_0(y)\cos\left(\omega(x)\, x\right) + \text{constant.}$$

constant $\rightarrow$ ensure I is always positive.

plot $\rightarrow$ 7.22.

Image Sensing Acquisition

All modalities

Illumination source
- infrared
- Xray.
- radar
- visible light.

- Reflection or absorption or Transmittance.

element in Thesaurus

Image formation

Characterized by 2 components.

(a) amount of source illumination incident on scene.

(b) amount that is reflected.

$$\underline{f(x,y)} = i(x,y) \quad r(x,y)$$

sensed img. — illumination — reflectance

$$0 < i(x,y) < \infty$$

show complete words lump 2 pictures

Sunny clear day	90,000	lm/m^2
clear evening	0.1	lm/m^2

$$0 < r(x,y) < 1$$

0.01	black velvet
0.15	stainless steel.
0.80	flat white wall
0.9	silver plated metal.
0.95	snow

Empirical observation
Exploited in Image Processing System

1. Sharper image look better.
2. Same noise in uniform background region is more visible than noise in ~~edge area~~. Textured region.
3. Same noise in dark areas are more noticeable than in bright area.

7.18 J. Lim

4. Some amount of artificial noise looks a lot worse than natural noise
5. Images with unnatural aspect ratio attract viewers attention.

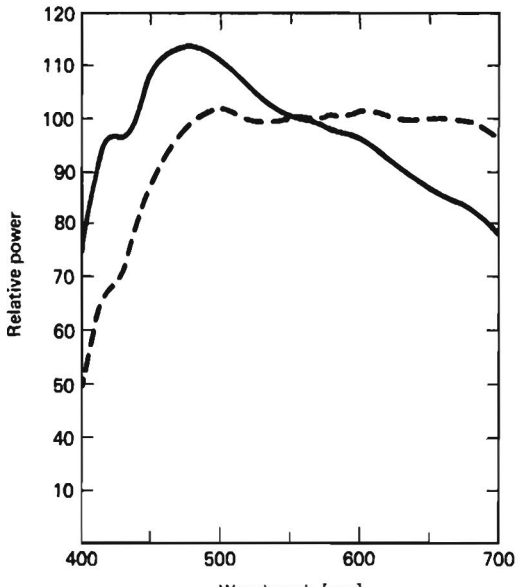


Figure 7.1 Spectral contents of the sun's radiation, above the earth's atmosphere (solid line) and on the ground at noon in Washington (dotted line). After [Hardy].

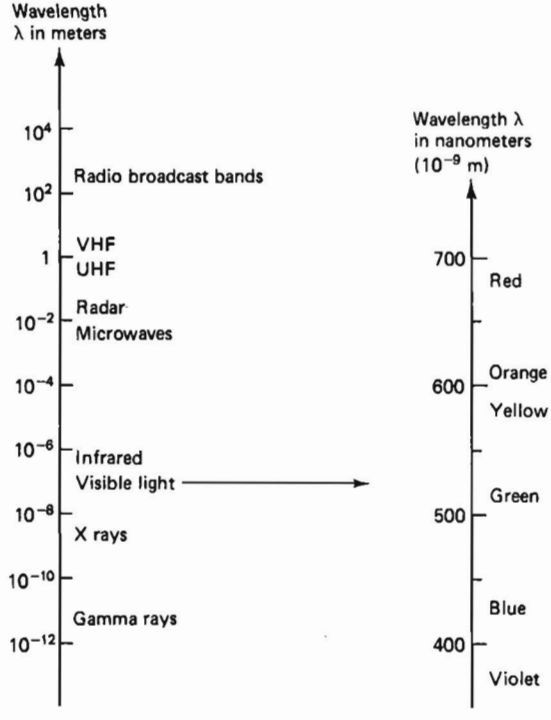


Figure 7.2 Different types of electromagnetic waves as a function of the wavelength λ.

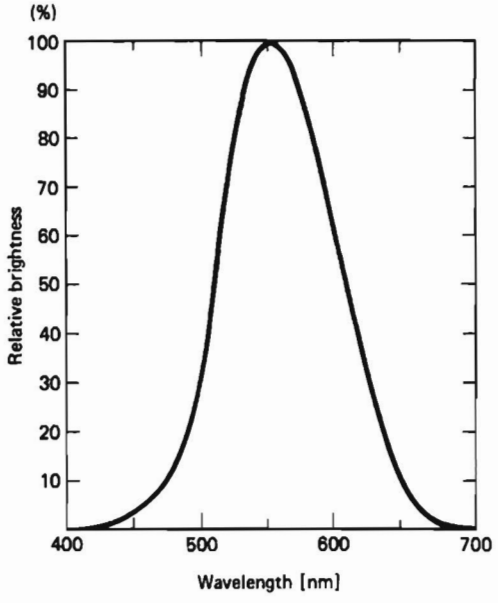


Figure 7.3 C.I.E. relative luminous efficiency function. After [Hardy].

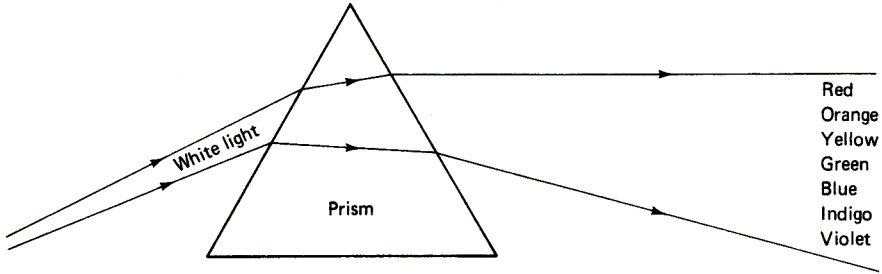


Figure 7.4 White light split into a succession of monochromatic lights by a prism.

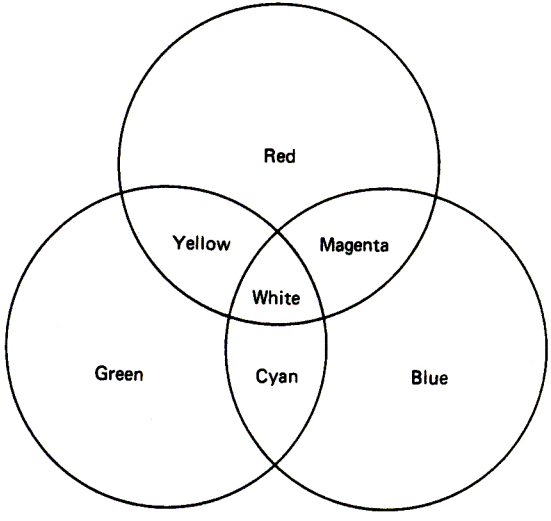


Figure 7.5 Primary colors of the additive color system.

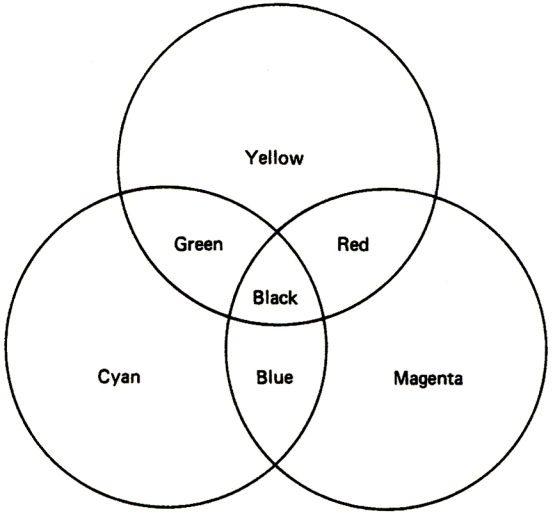


Figure 7.6 Primary colors of the subtractive color system.

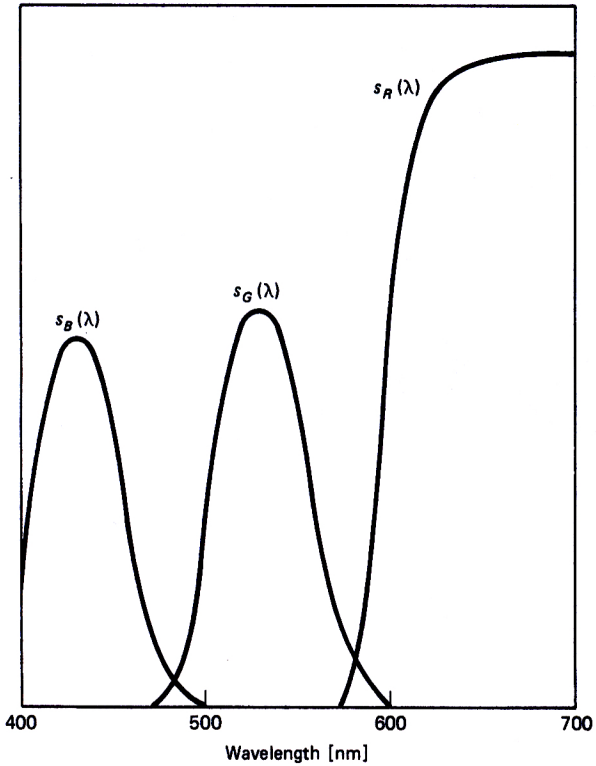


Figure 7.7 Example of spectral characteristics of red, green, and blue color sensors.

(a)

(b)

(c)

Figure 7.8 Red, green, and blue components of a color image. (a) Red component; (b) green component; (c) blue component; (d) color image of 512 × 512 pixels.

(d)

(a)

(b)

(c)

Figure 7.9 Y, I, and Q components of the color image in Figure 7.8(d). (a) Y component; (b) I component; (c) Q component.

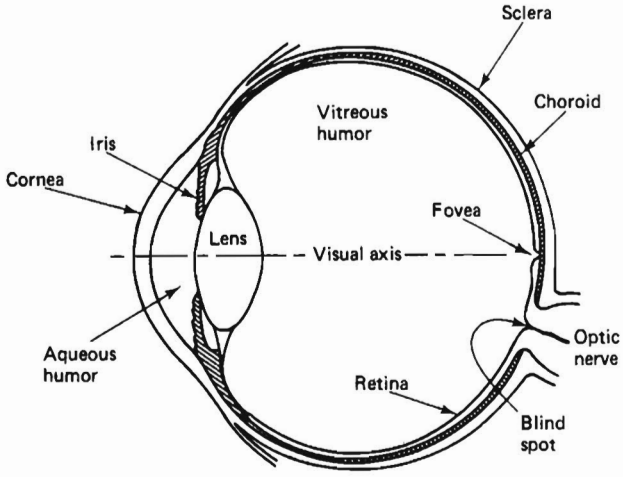


Figure 7.10 Horizontal cross section of a right human eye, seen from above.

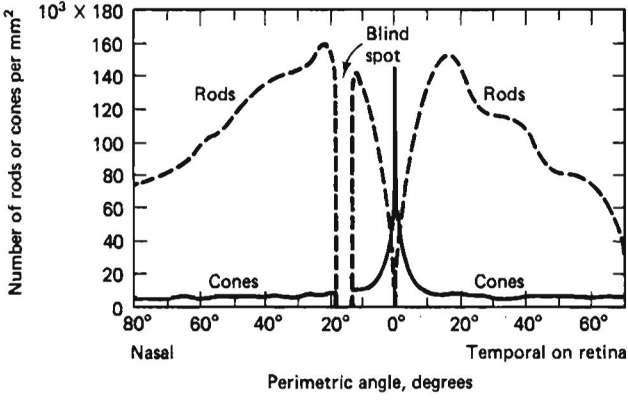


Figure 7.11 Distribution of rods (dotted line) and cones (solid line) on the retina. After [Pirenne].

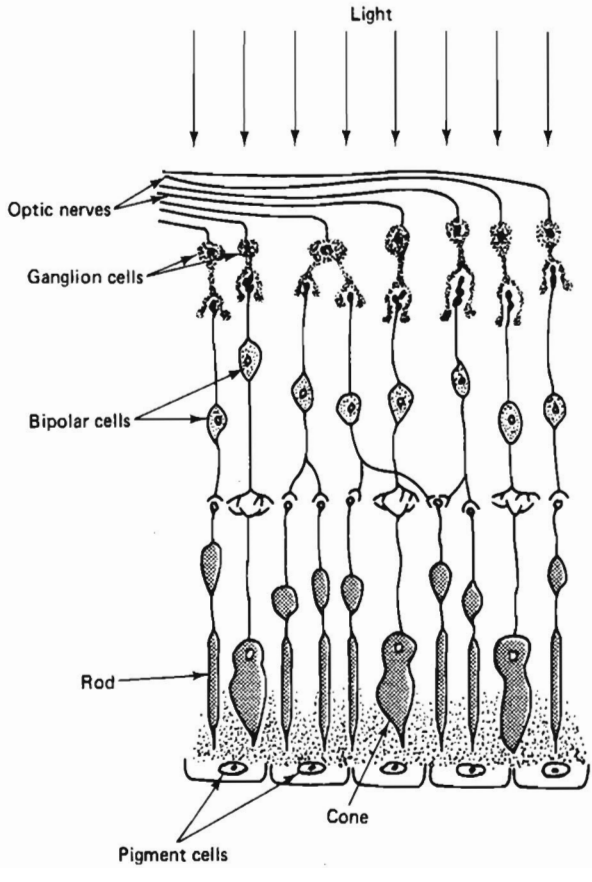


Figure 7.12 Layers in the retina. Note that light has to travel through several layers before it reaches light-sensitive cells.

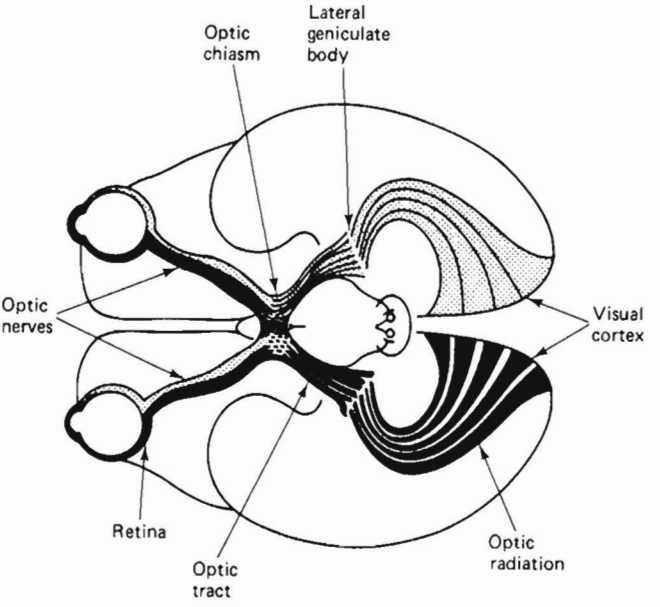


Figure 7.13 Path that neural signals travel from the retina to the visual cortex.

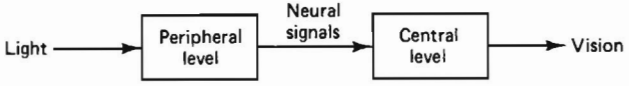


Figure 7.14 Human visual system as a cascade of two systems. The first system represents the peripheral level of the visual system and converts light to neural signals. The second system represents the central level and processes neural signals to extract necessary information.

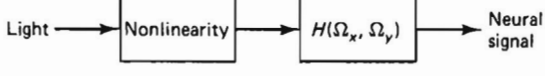


Figure 7.15 Simple model of peripheral level of human visual system.

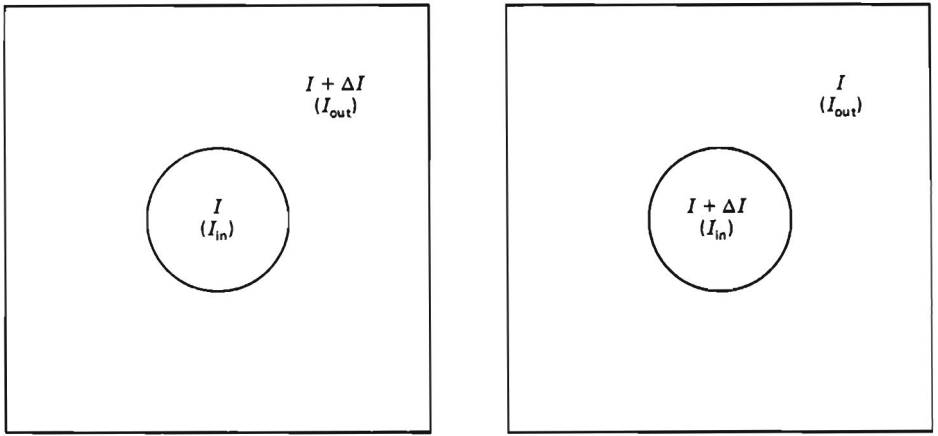


Figure 7.16 Two stimuli used in an intensity discrimination experiment. Each trial consists of showing one of the two stimuli to an observer and asking the observer to make a forced choice of which between I_{in} and I_{out} appears brighter. The stimulus used in a trial is chosen randomly from the two stimuli. Results of this experiment can be used to measure the just noticeable difference ΔI as a function of I.

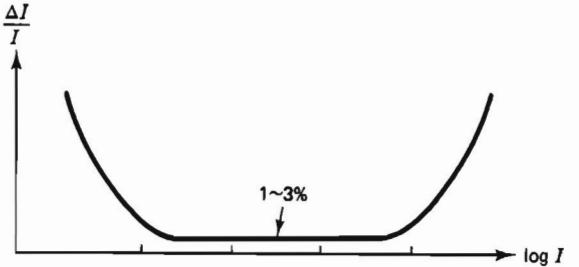


Figure 7.17 Plot of $\Delta I/I$ as a function of I. Incremental intensity ΔI is the just noticeable difference. Over a wide range of I, $\Delta I/I$ is approximately constant. This relationship is called Weber's law.

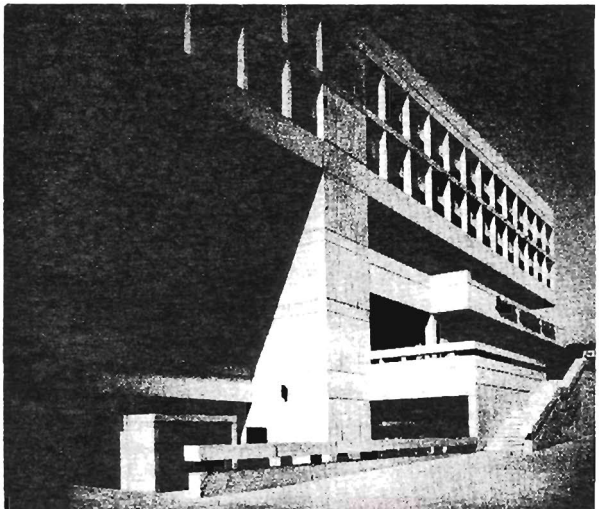


Figure 7.18 Image of 512 × 512 pixels degraded by zero-mean white noise with a uniform probability density function. Same level of noise is more visible in a dark region relative to a bright region. Same level of noise is more visible in a uniform background region than in a region with edges.

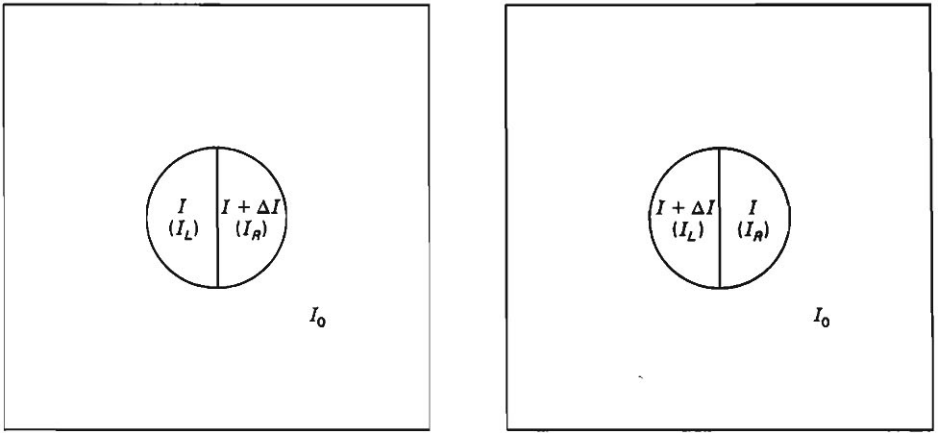


Figure 7.19 Two stimuli used in studying the effect of adaptation on the intensity sensitivity. Each trial consists of showing one of the two stimuli to an observer and asking the observer to make a forced choice of which between I_R or I_L appears brighter. The stimulus used in a trial is chosen randomly from the two stimuli. Results of this experiment can be used to measure the just noticeable difference ΔI as a function of I and I_0.

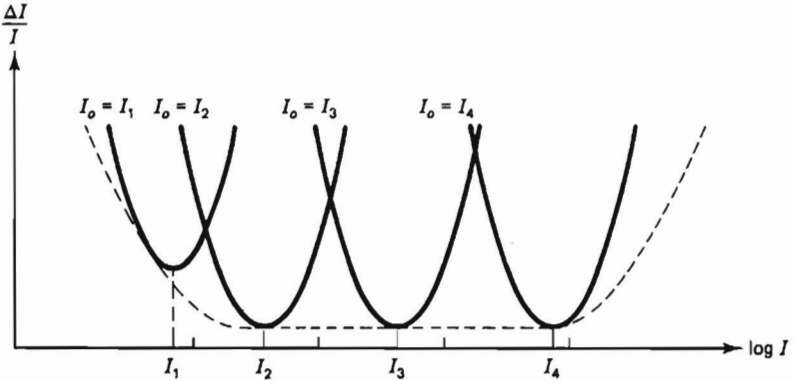
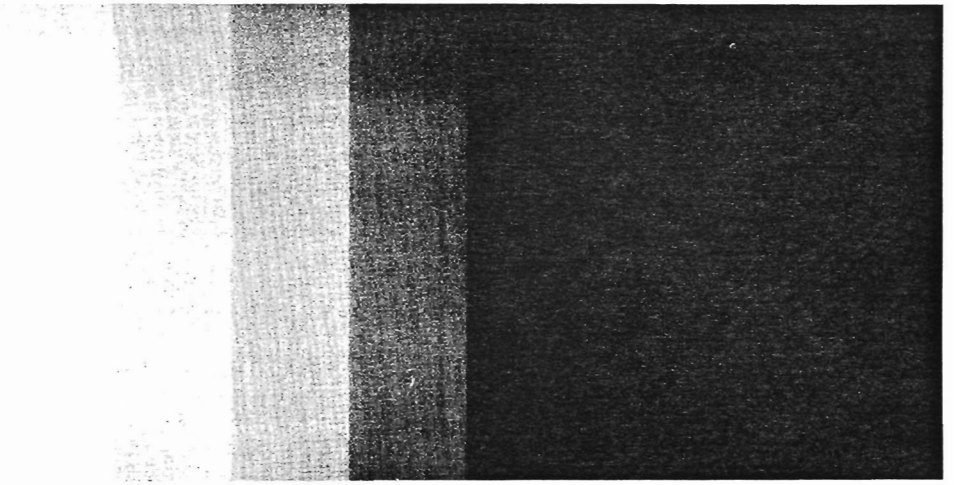
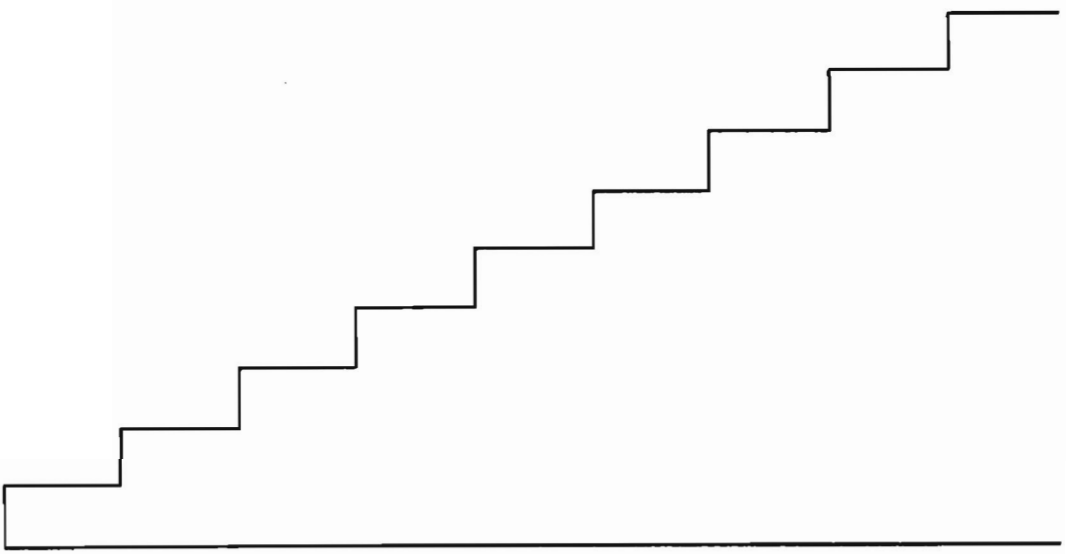


Figure 7.20 Plot of $\Delta I/I$ as a function of I and I_0. When I_0 equals I, $\Delta I/I$ is the same as that in Figure 7.17 (dotted line in this figure). When I_0 is different from I, $\Delta I/I$ increases relative to the case $I_0 = I$. This means that the observer's sensitivity to intensity decreases.



(a)



(b)

Figure 7.21 Illustration of Mach band effect.

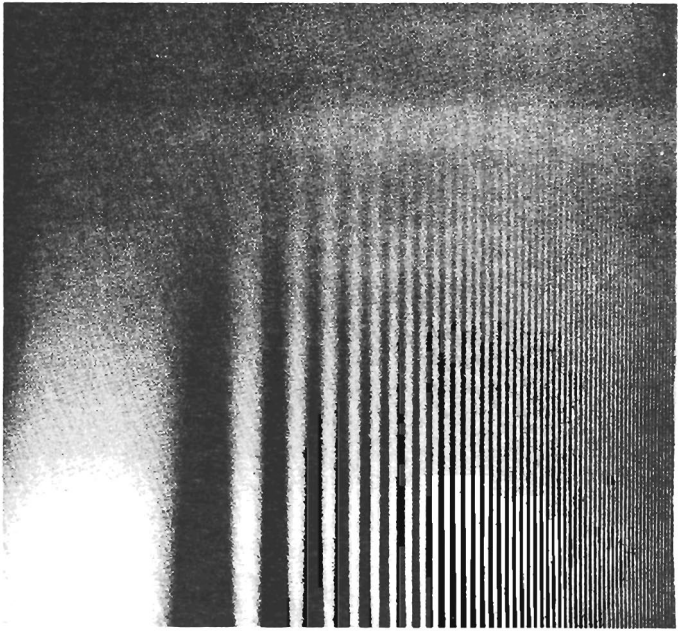


Figure 7.22 Modulated sinewave grating that illustrates the bandpass character of the peripheral level of the human visual system.

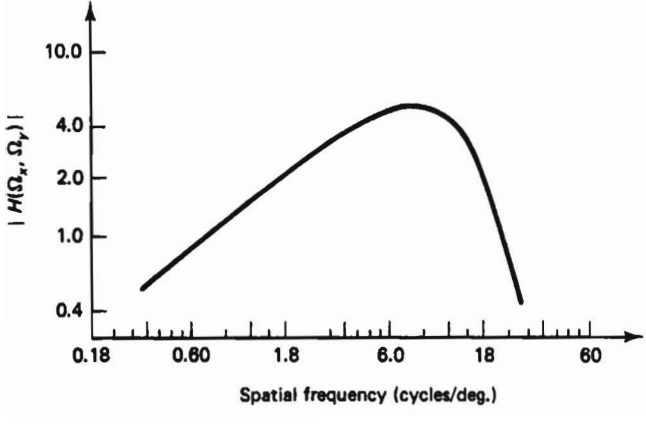


Figure 7.23 Frequency response $H(\Omega_x, \Omega_y)$ in the model in Figure 7.15. After [Davidson].