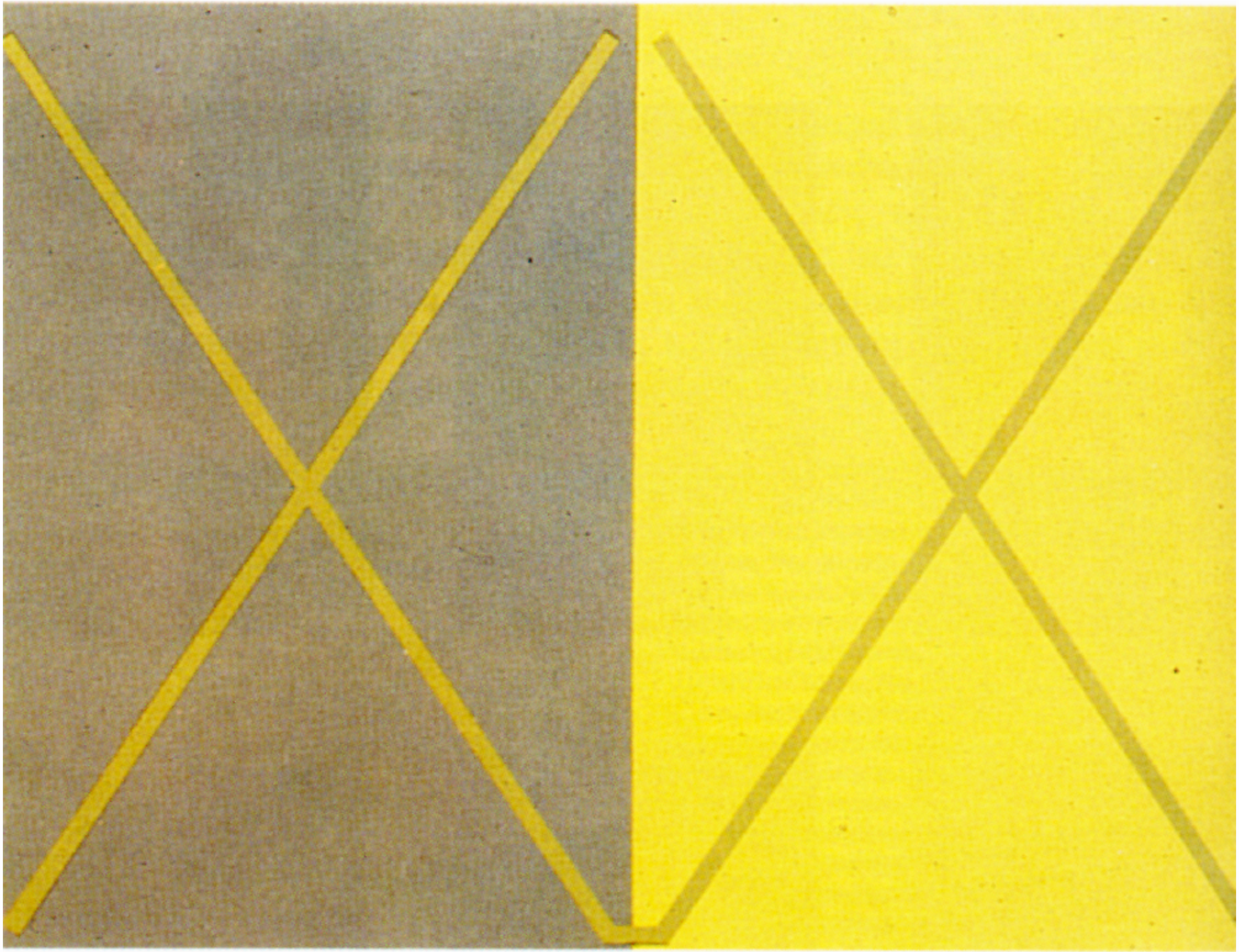
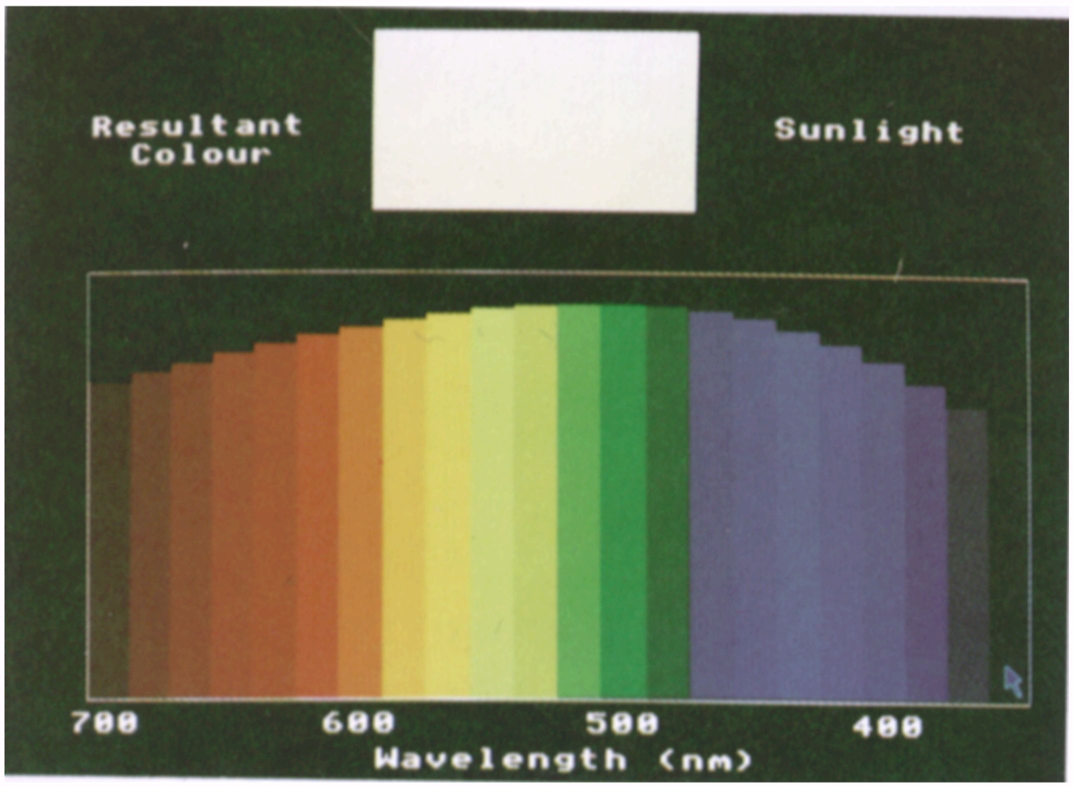
Causes of colour

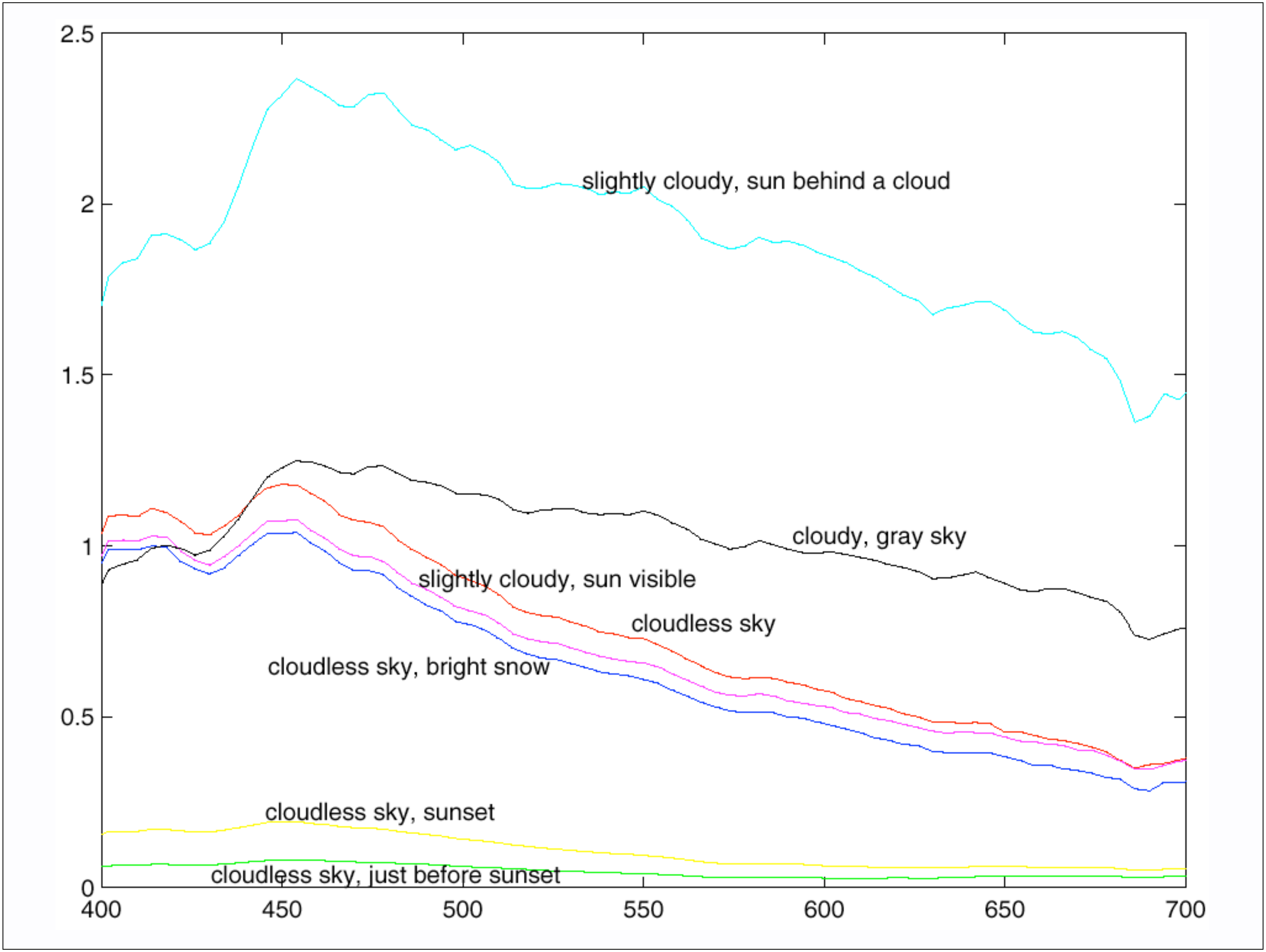
- The sensation of colour is caused by the brain.
- One way to get it is the response of the eye to the presence/absence of light at various wavelengths.
  - Dreaming, hallucination, etc.
  - Pressure on the eyelids
- Light could be
  - emitted with wavelengths absent (flourescent light vs. incandescent light)
  - differentially reflected - e.g. paint on a surface
  - differentially refracted - e.g. Newton's prism
  - subject to wavelength dependent specular reflection (most metals).
  - Flourescence -
    - invisible wavelengths absorbed and reemitted at visible wavelengths.
  - Phosphorescence (ditto, energy, longer timescale)

XXXXX	BLUE	YELLOW
XXXXX	GREEN	BLUE
XXXXX	RED	GREEN
XXXXX	YELLOW	RED
XXXXX	BLUE	YELLOW
XXXXX	RED	GREEN
XXXXX	GREEN	BLUE
XXXXX	BLUE	YELLOW
XXXXX	YELLOW	RED
XXXXX	RED	GREEN

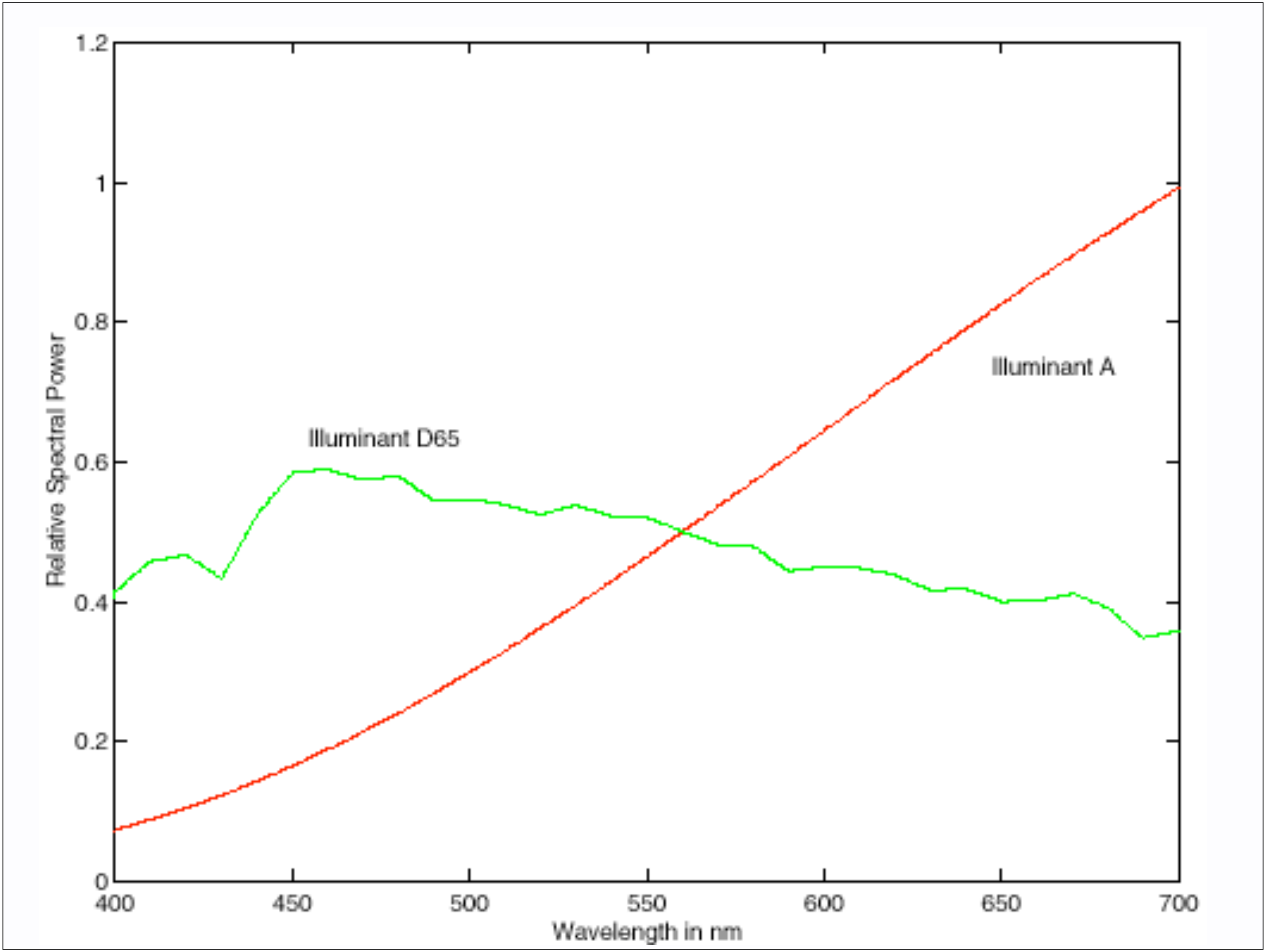


Sunlight

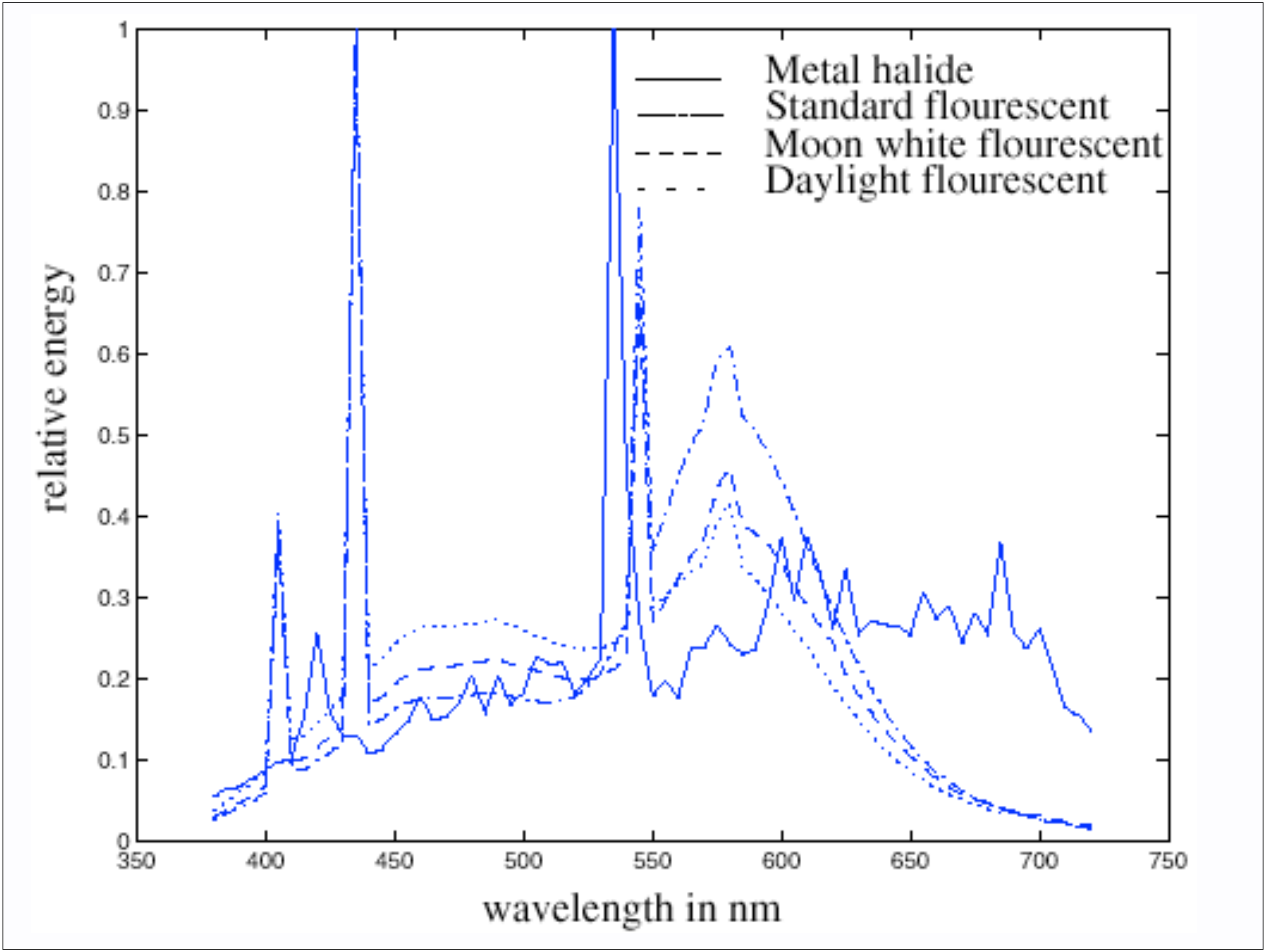




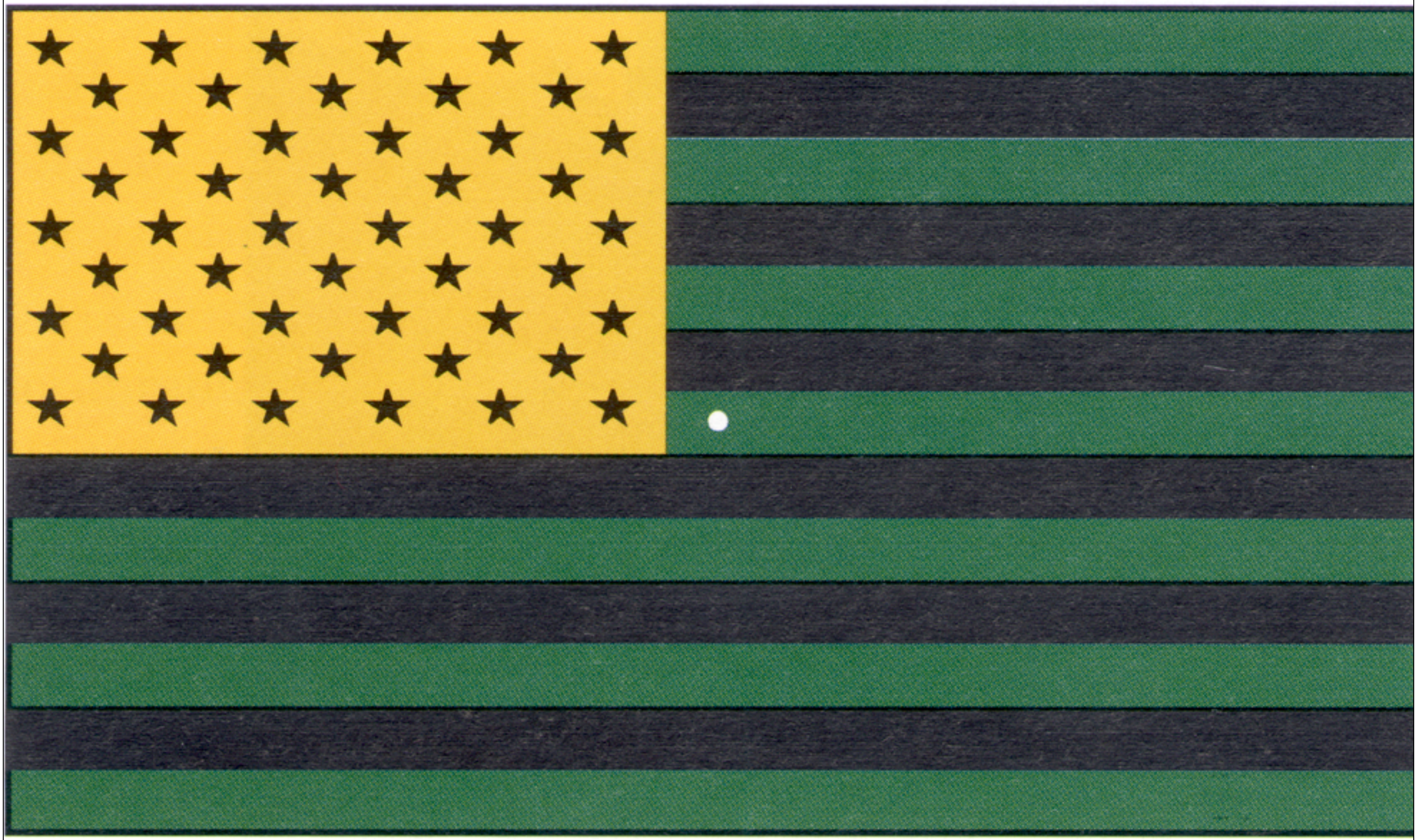
2.5
2
1.5
1
0.5
0
400
450
500
550
600
650
700
slightly cloudy, sun behind a cloud
cloudy, gray sky
slightly cloudy, sun visible
cloudless sky
cloudless sky, bright snow
cloudless sky, sunset
cloudless sky, just before sunset



1.2
1
0.8
0.6
0.4
0.2
0
Relative Spectral Power
Illuminant A
Illuminant D65
400
450
500
550
600
650
700
Wavelength in nm



Metal halide
Standard flourescent
Moon white flourescent
Daylight flourescent
relative energy
wavelength in nm
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
350
400
450
500
550
600
650
700
750



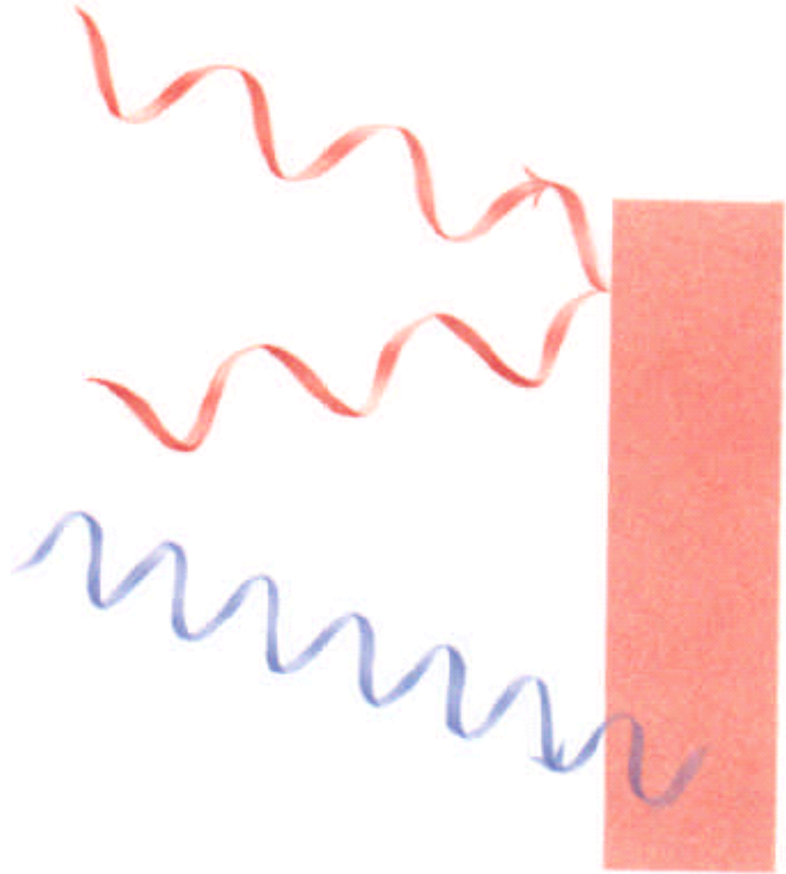


Fig. 1.18 Reflection: red light bounces off an opaque red object, while light of other colours is absorbed.

from "Colour in nature", P. Farrant

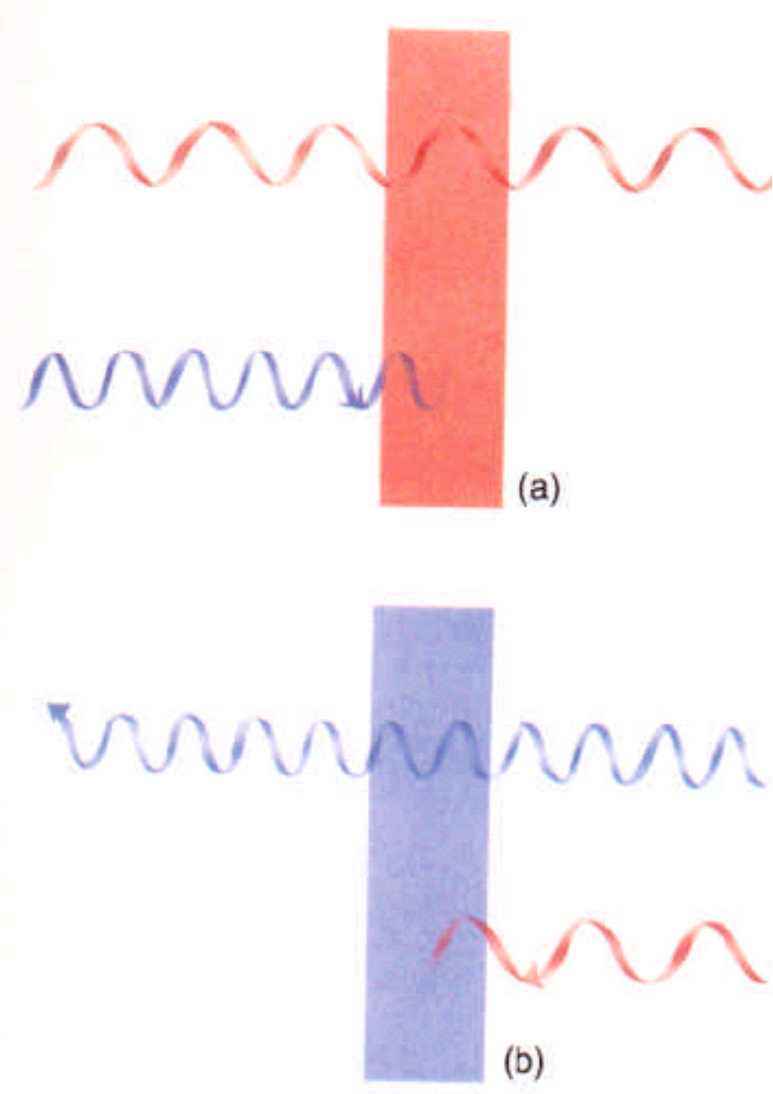


Fig. 1.17 Absorption: a red transparent medium absorbs all wavelengths of light except red (a); a blue transparent medium absorbs all wavelengths except blue (b)

from "Colour in nature", P. Farrant

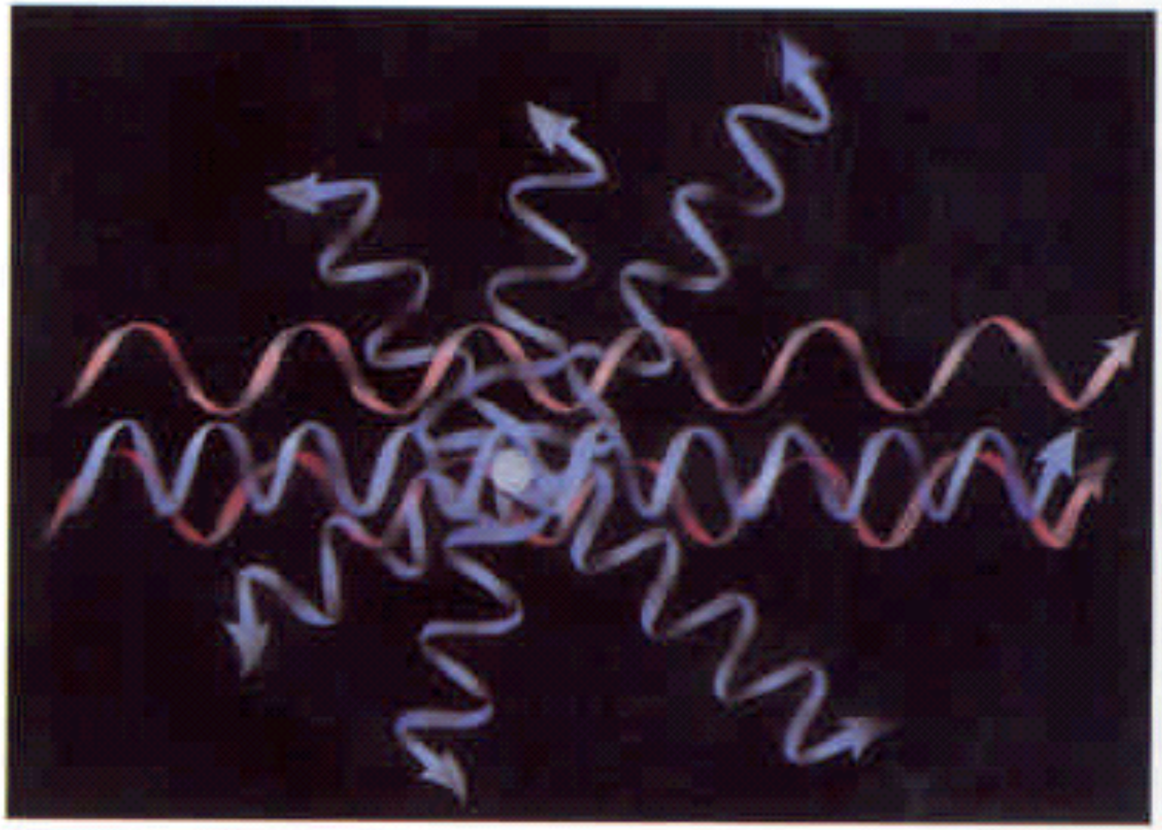
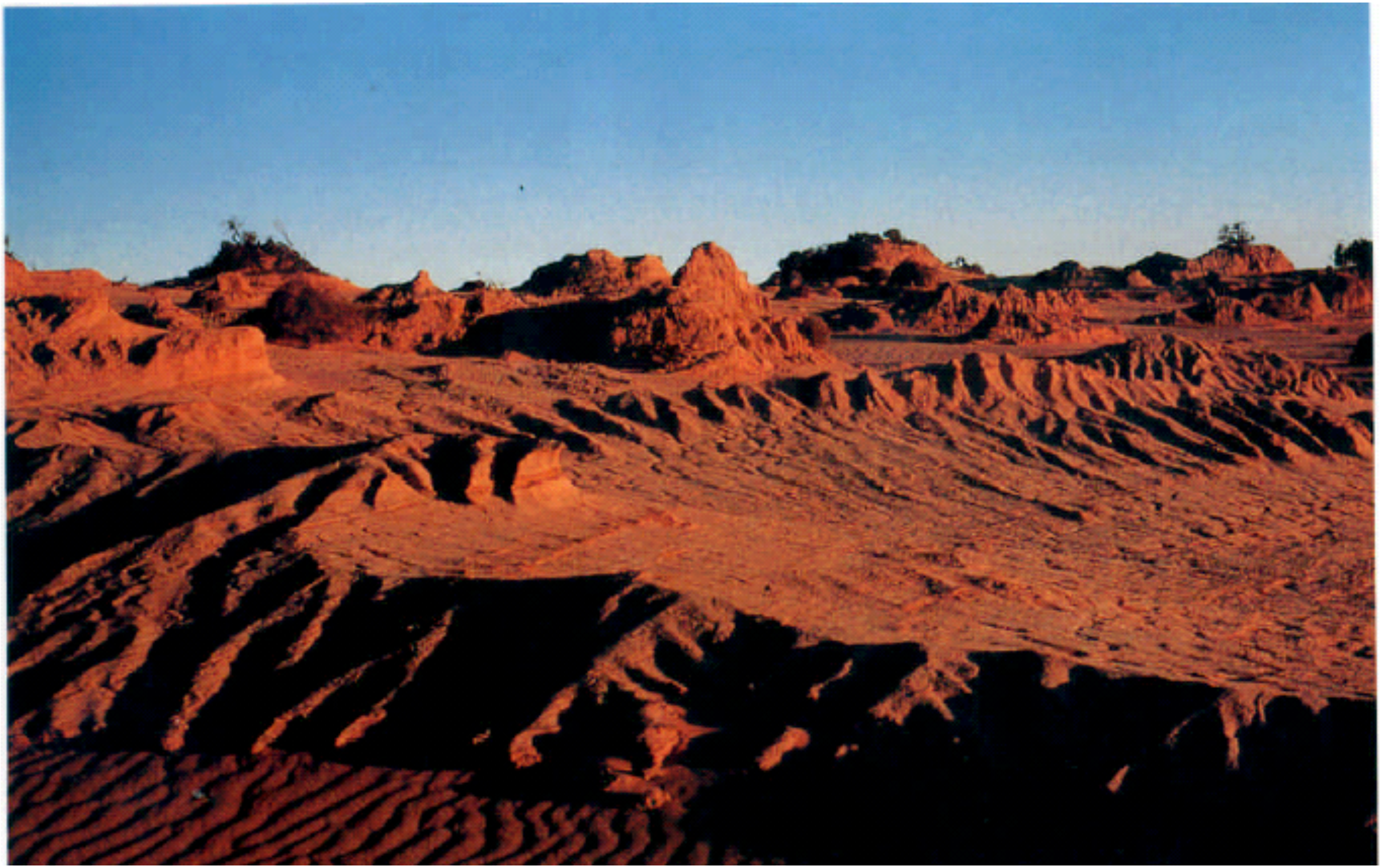


Fig. 1.25 Rayleigh scattering: when particles in air or water are small relative to light wavelength they scatter blue light preferentially.

from "Colour in nature", P. Farrant



from “Colour in nature”, P. Farrant

from “Colour in nature”, P. Farrant

From Lynch and Livingstone, Color and Light in Nature

From Lynch and Livingstone, Color and Light in Nature

From Lynch and Livingstone, Color and Light in Nature

From Lynch and Livingstone, Color and Light in Nature

Big (dust, smoke)

Air molecules

Water drops

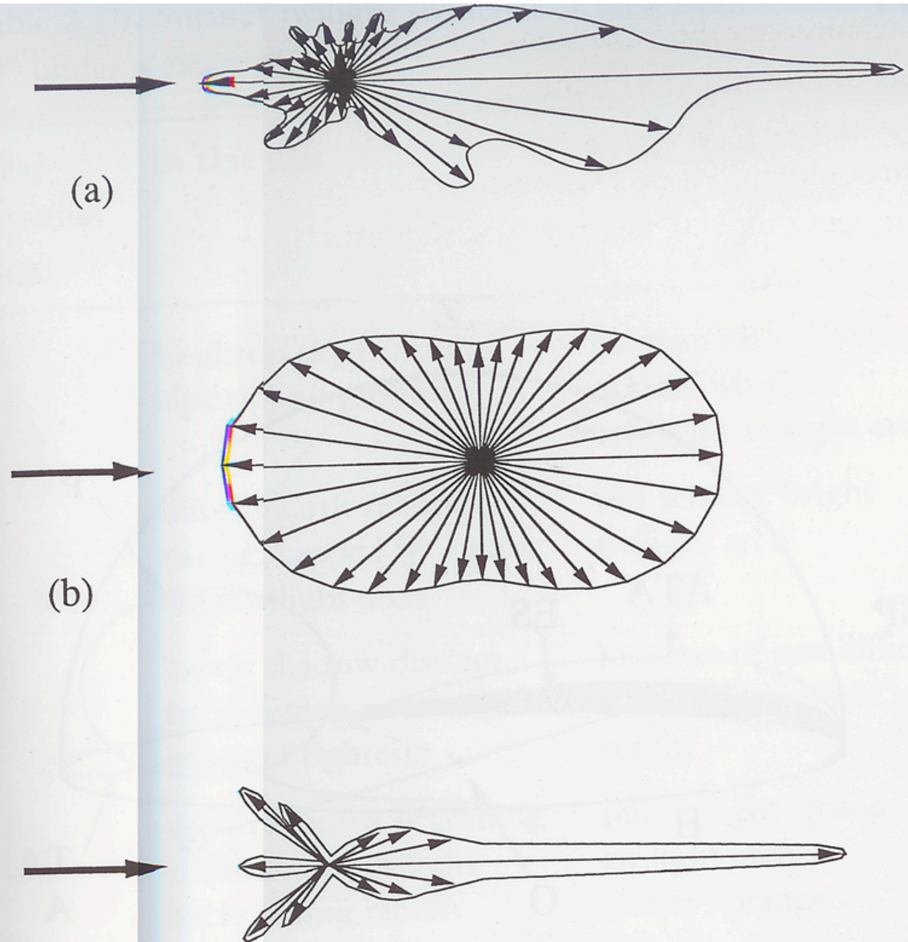


Fig. 2.7C Scattering patterns for different particles. (a) Large irregular particles, like those comprising dust and smoke, are irregular in the sense that they are not symmetric. They do, however, have a strong forward scattering peak and a smaller though still pronounced backscattering peak. (b) Air molecules have a scattering function that is symmetric fore and aft: they scatter the same amount of light in both the forward and backward directions but lack both the forward and backscattering peak. (c) Large water drops have a strong forward and backscattering peak and also show strong enhancements at the primary and secondary rainbow angles.

From Lynch and Livingstone, Color and Light in Nature

Fig. 2.7A (LEFT) Aureole around the sun. The sun is hidden by a street lamp. To the eye, the sky appeared clear.

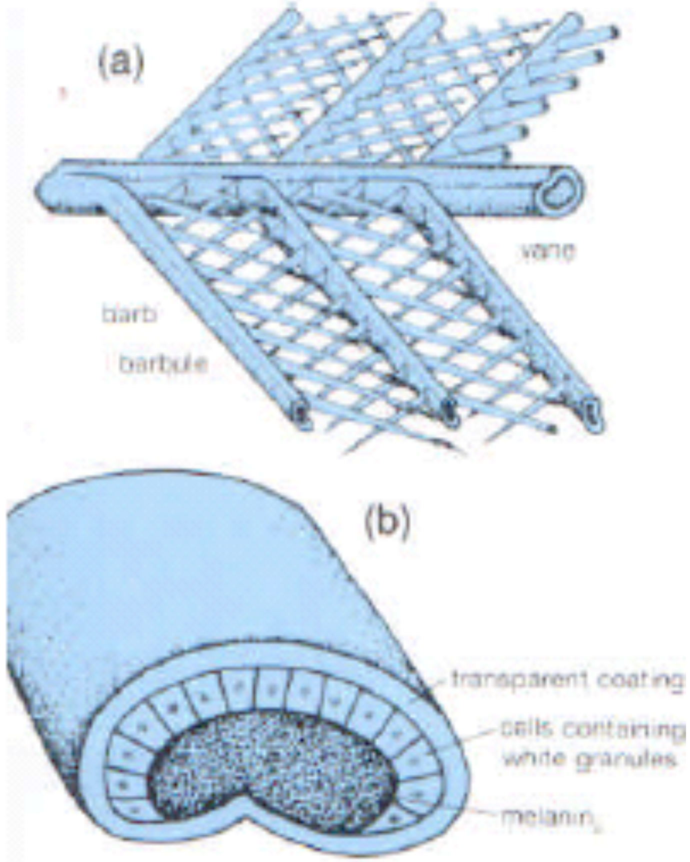
Fig. 2.7B (RIGHT) The next day the sky was exceptionally clear and there was no aureole.

From Lynch and Livingstone, Color and Light in Nature

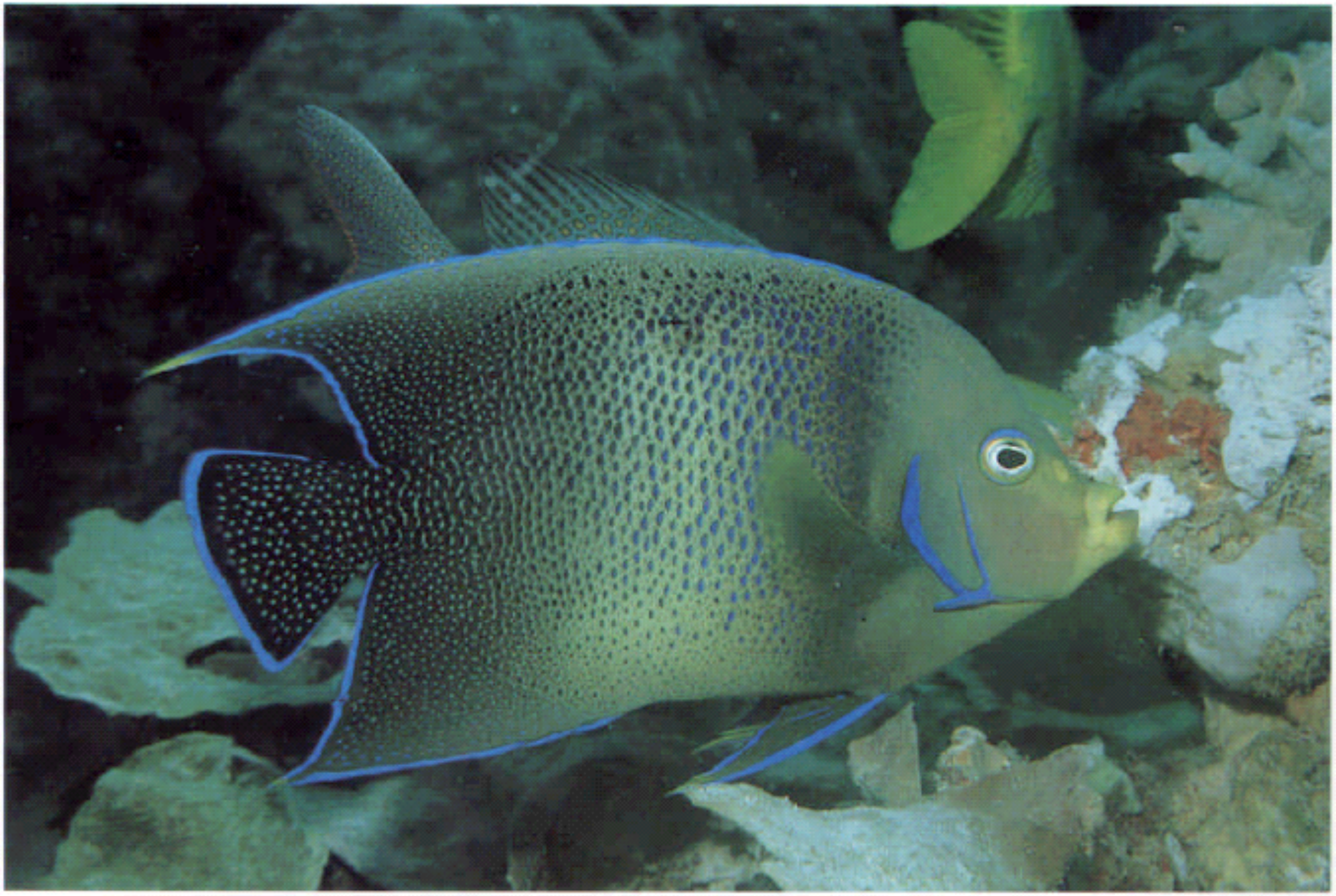
From Lynch and Livingstone, Color and Light in Nature

Scattering (again)
causing Tyndall
Blue

(notice because scattering
occurs at an interface,
all media could be translucent
e.g. fresh snow)



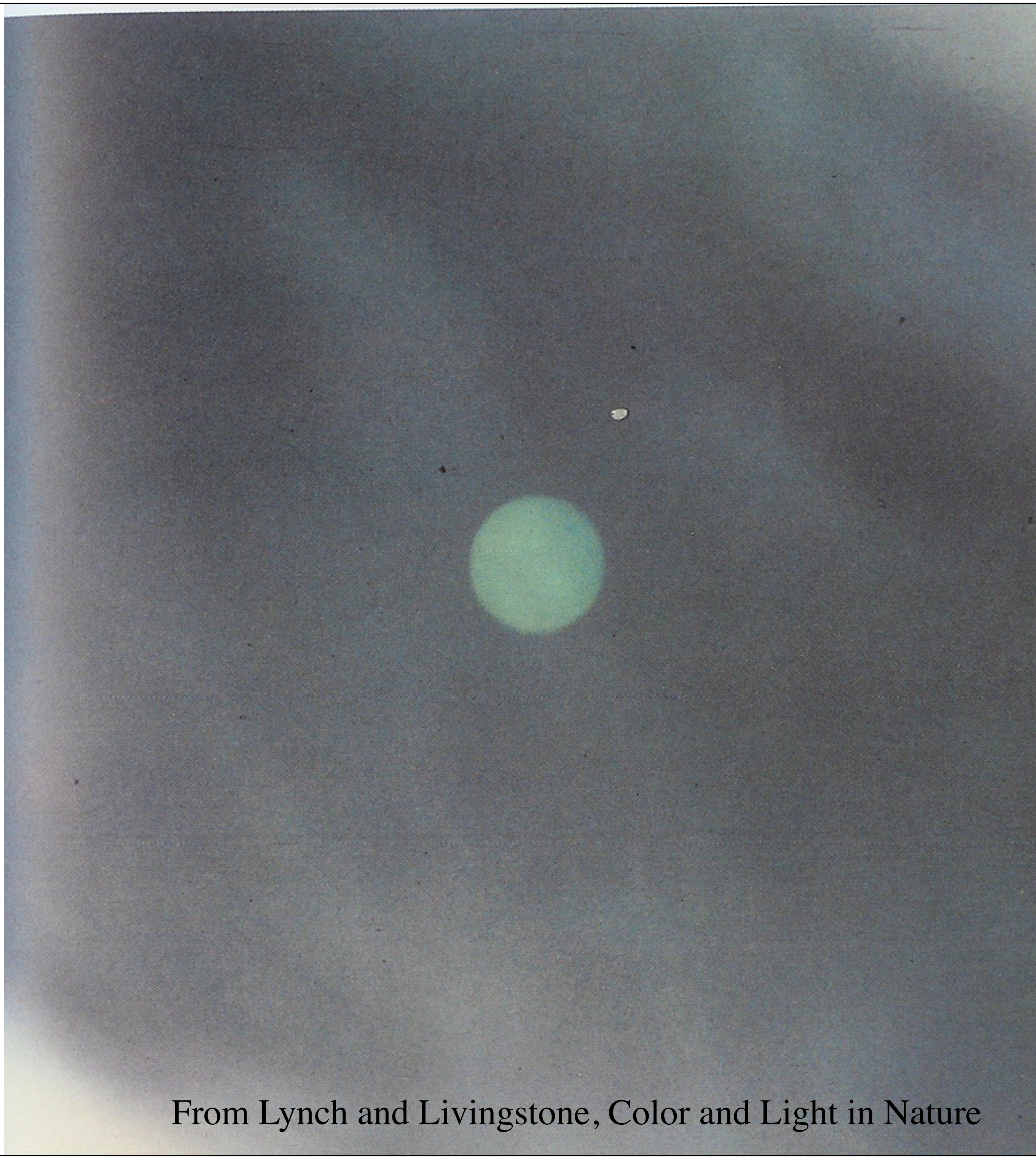
ig. 10.4 (a) Feather structure of
blue bird.
b) Section through blue
arbule: Tyndall blue is a
tructural colour caused by
cattering of blue wavelengths
y microscopic particles in the
uter layer of cells. Inside the
eather there is a dark melanin
acking.



from “Colour in nature”, P. Farrant

from “Colour in nature”, P. Farrant

PL. 10.21 Green snakes and lizards have a yellow pigment in combination with structural Tyndall blue and a melanin backing.
Photo: P. Farrant


From Lynch and Livingstone, Color and Light in Nature

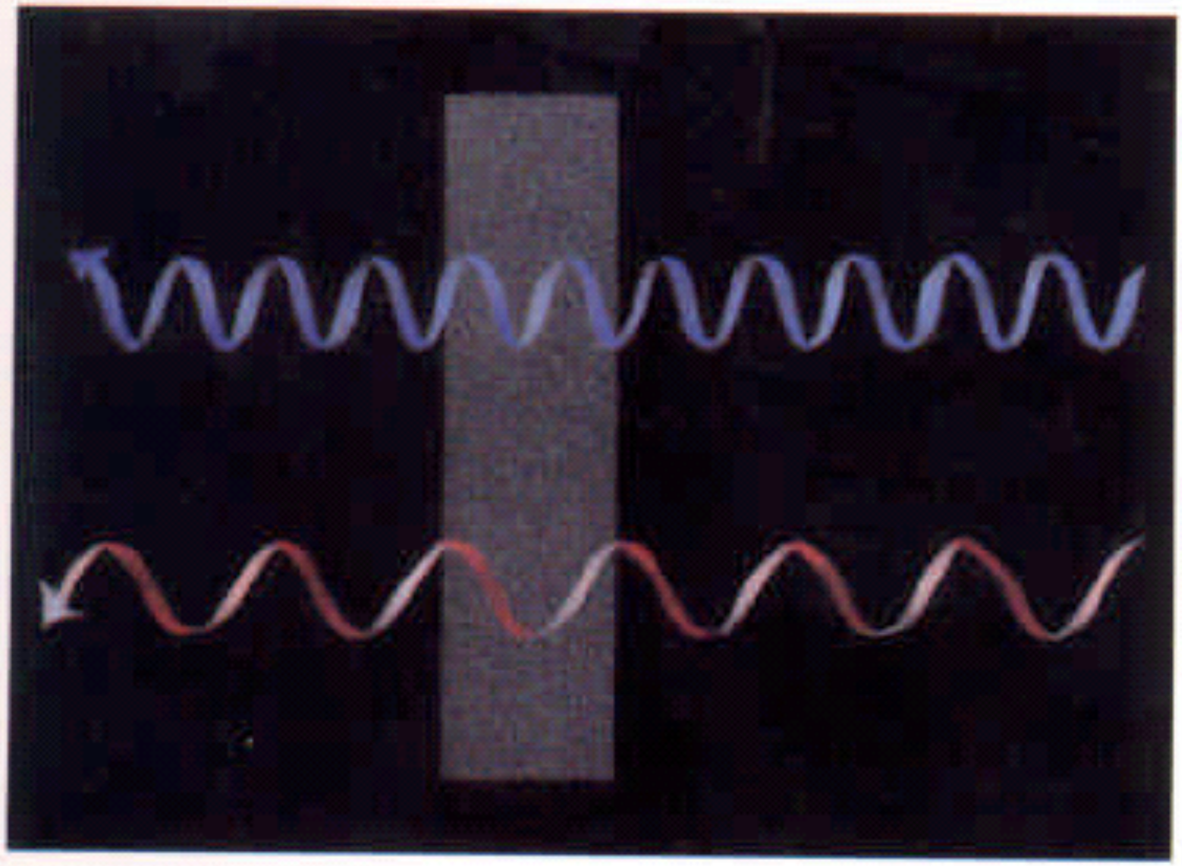


Fig. 1.16 Transmission: light waves of all colours pass through a colourless transparent medium.

from “Colour in nature”, P. Farrant

from “Colour in nature”, P. Farrant

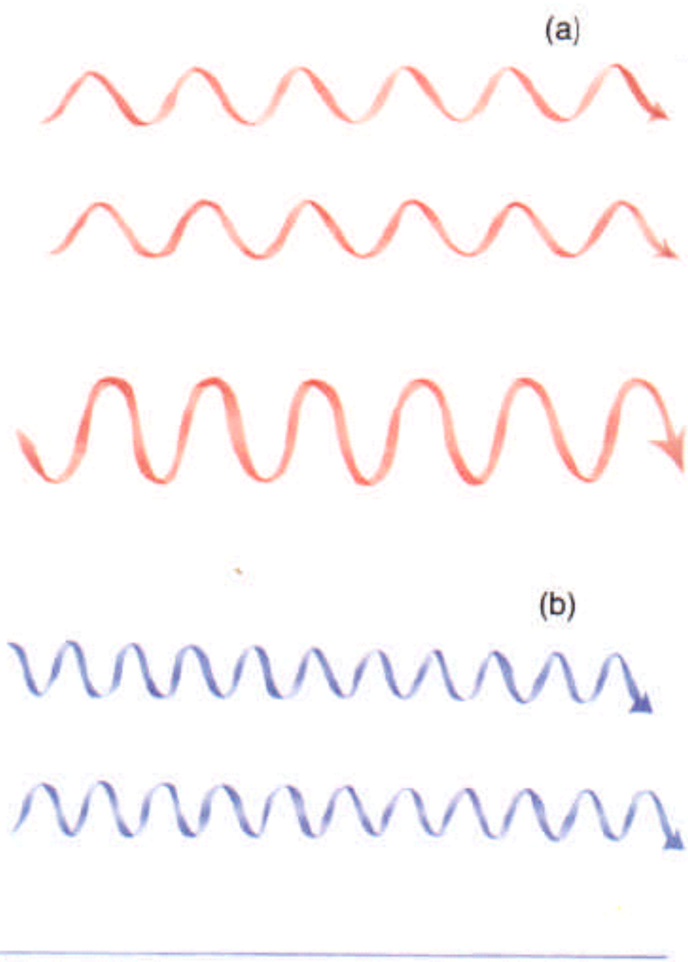


Fig. 1.20 Interference: when two light waves are in phase, they interfere positively to reinforce each other and produce a wave with double the intensity of colour (a). When two waves are out of phase they cancel each other and no colour is seen (b).

from "Colour in nature", P. Farrant

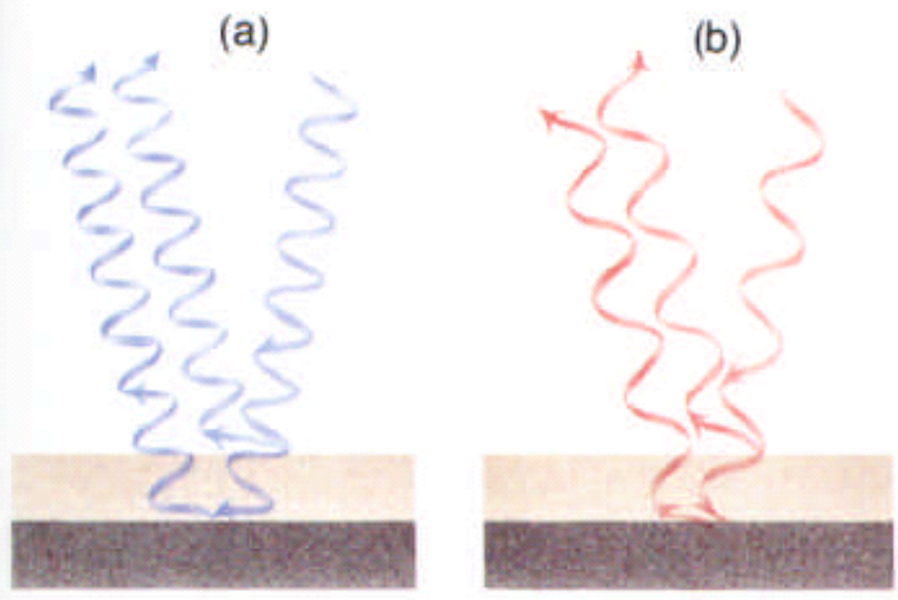
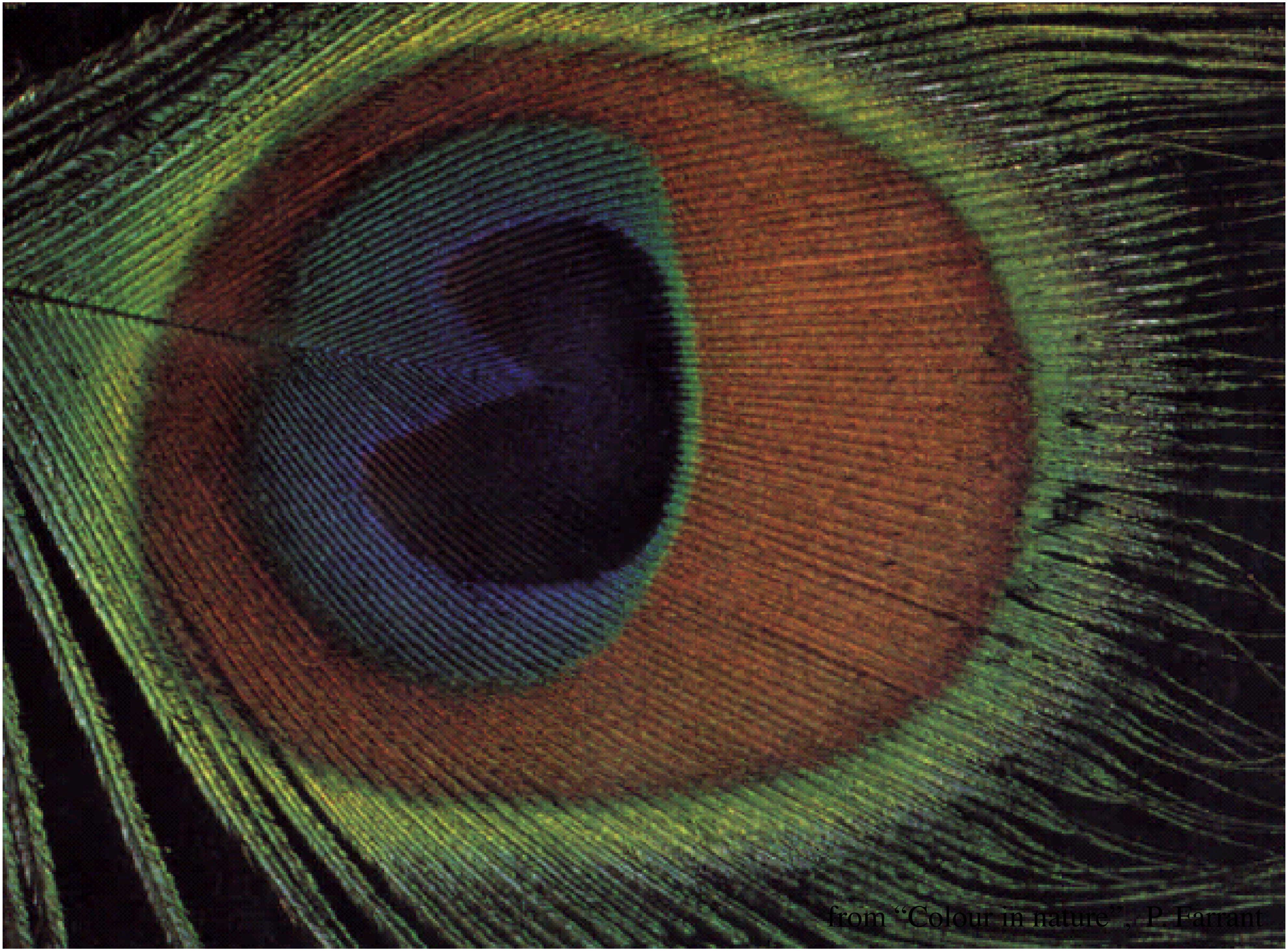


Fig. 1.22 Iridescence: when a light wave is partially reflected and partially transmitted at the surface of a thin layer of transparent material (e.g. a bubble), the two parts of the original wave may interfere with each other when the transmitted wave is reflected from a lower layer and re-emerges at the surface. In this case the blue waves are in phase and their colour is reinforced (a) but the red waves are out of phase and their colour is cancelled (b).

from "Colour in nature", P. Farrant

from “Colour in nature”, P. Farrant


from “Colour in nature”, P. Farrant

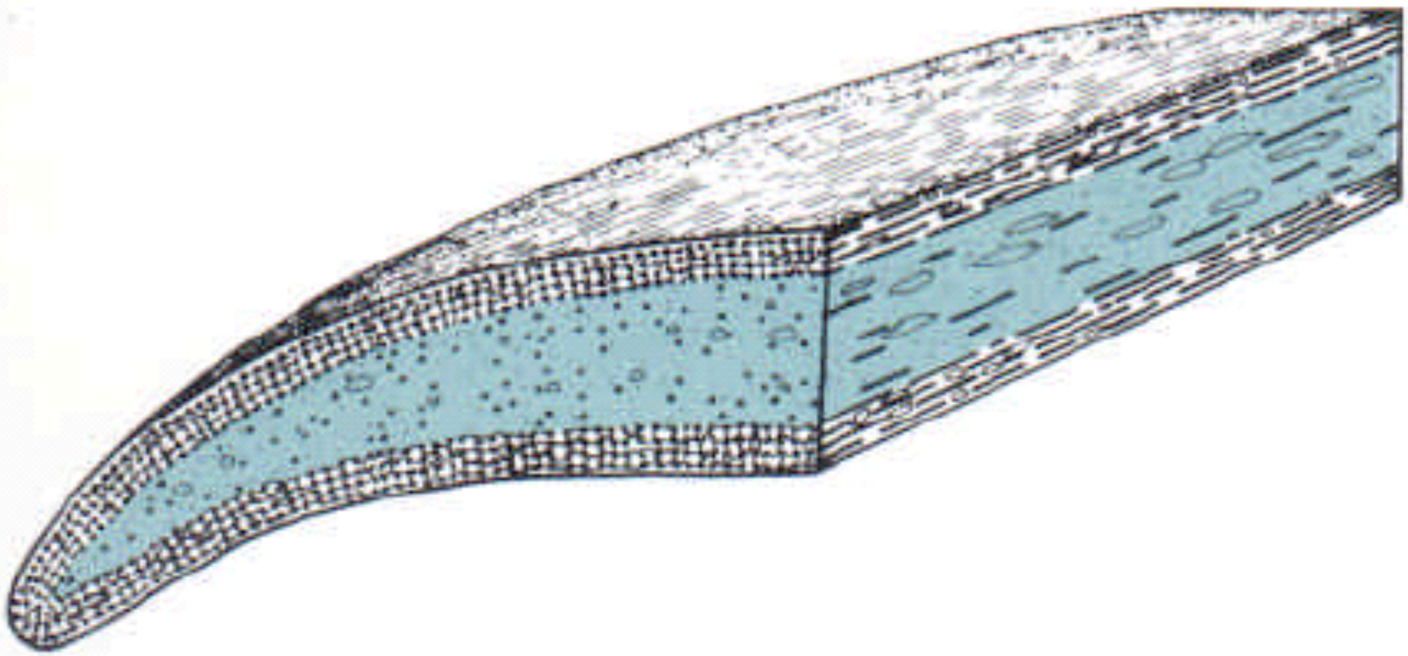


Fig. 10.1 The iridescence-producing structure of peacock feathers comprises evenly spaced melanin rods and air spaces, embedded in keratin.

from "Colour in nature", P. Farrant

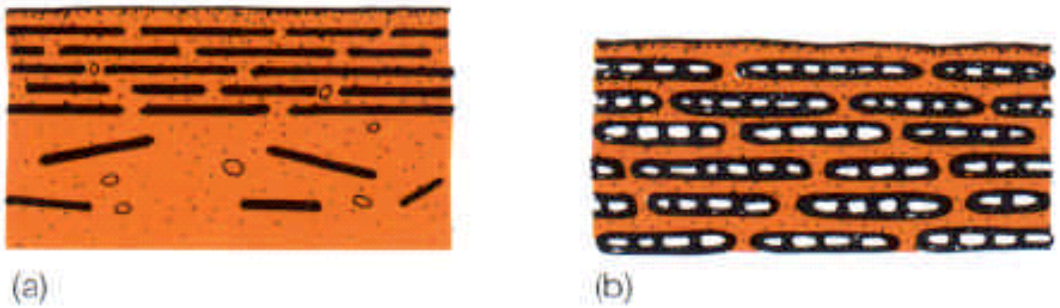


Fig. 10.2 The iridescence-producing structure of (a) sunbirds' feathers comprises layers of solid melanin platelet embedded in keratin, whereas that of (b) hummingbirds' consists of hollow melanin-line flat discs, also embedded in keratin.

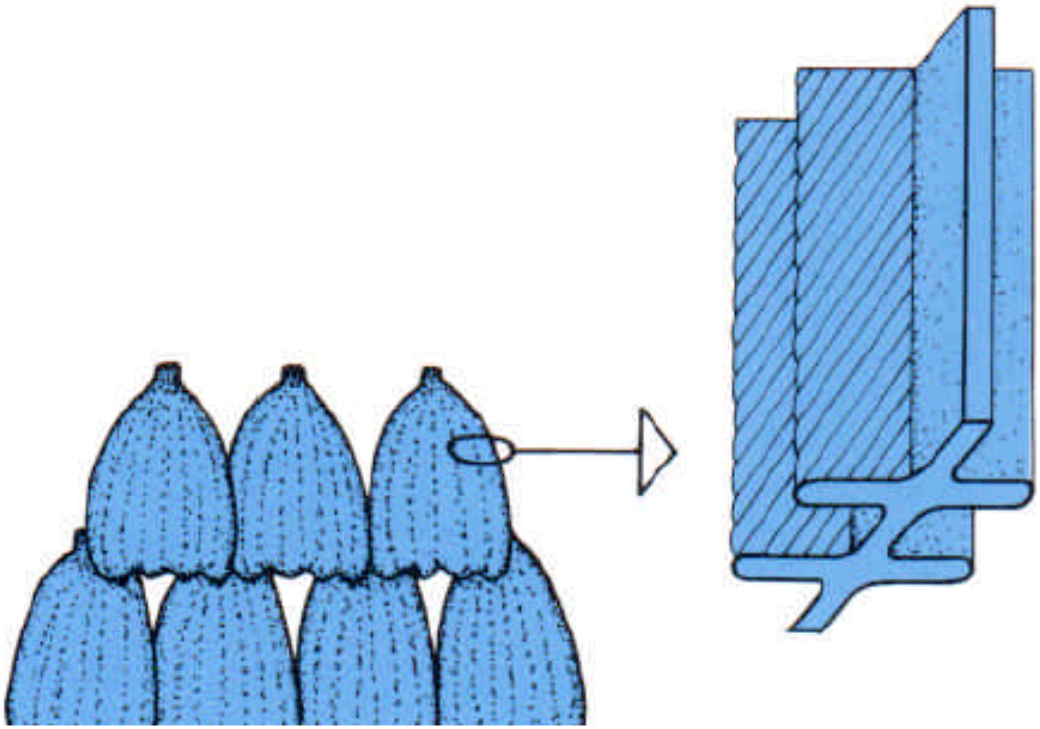
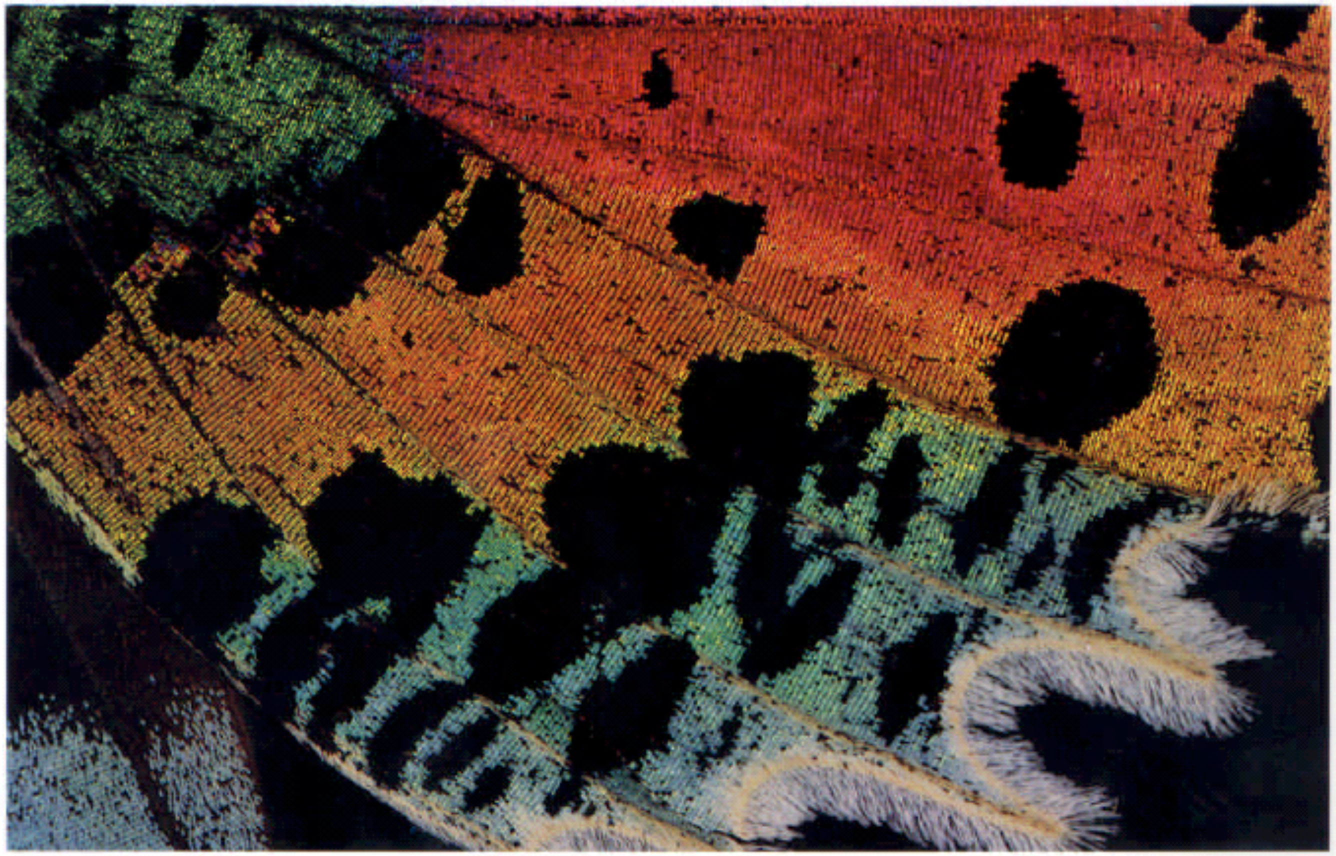


Fig. 10.3 Iridescence in morph butterflies is due to sloping layers within ridges on the win

from "Colour in nature", P. Farrant



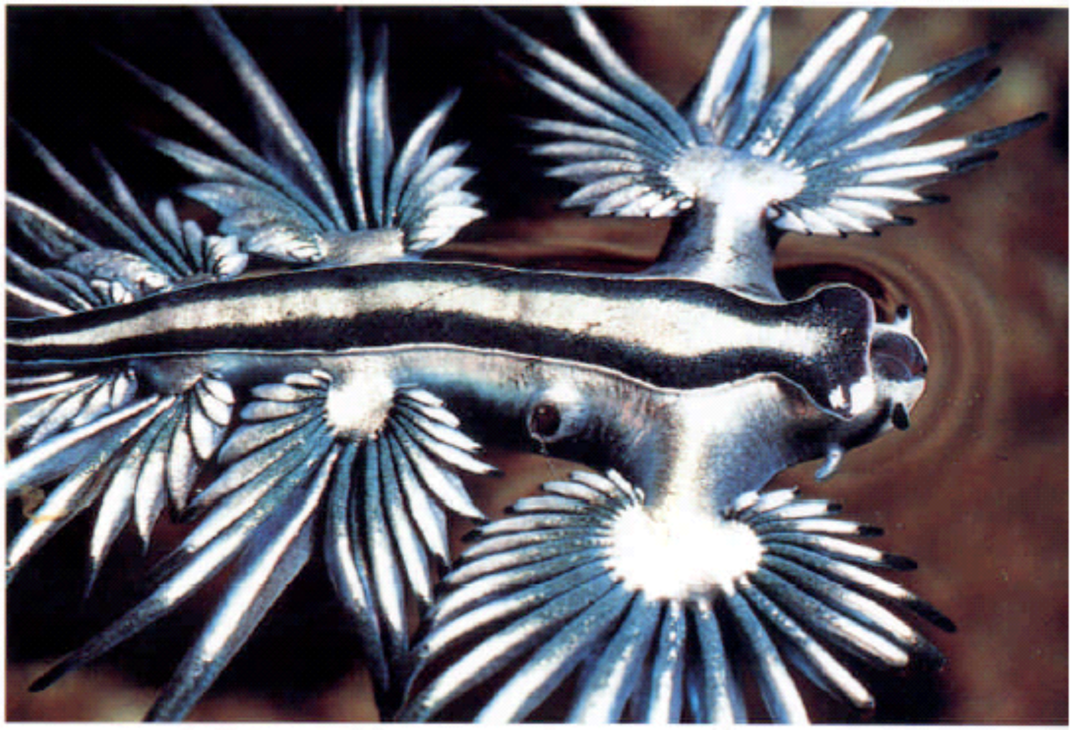
PL. 10.9 Urania moths have iridescent scales containing layers of chitin, air spaces and a backing of melanin. *Photo: P. Farrant*

PL. 10.5 In pigeons, relatively large granules of melanin produce some interference colours. *Photo: P. Farrant.*

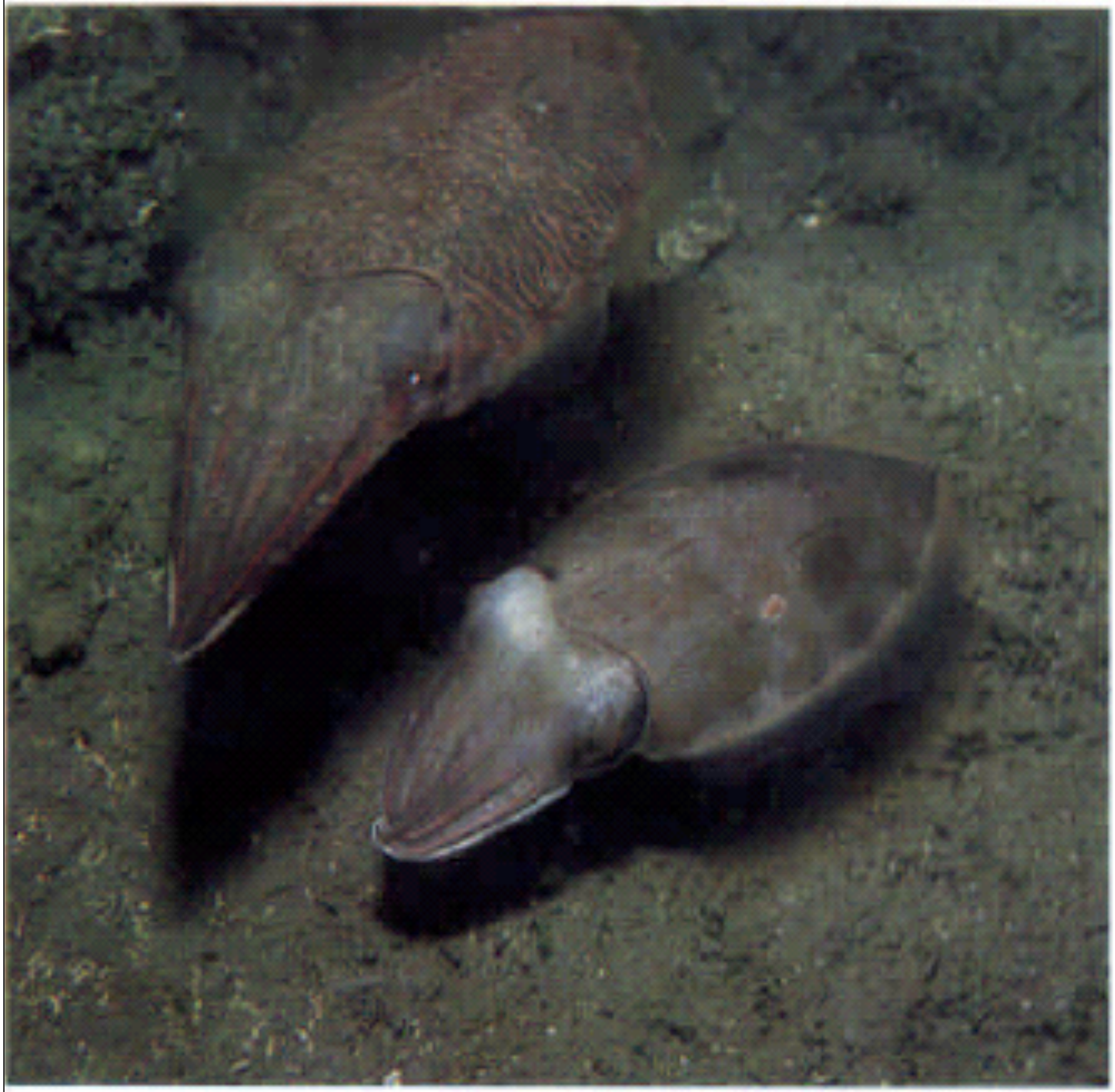
from “Colour in nature”, P. Farrant

PL. 10.2 Goatfish with iridescent eyes; light is reflected from regular layers of guanine particles.

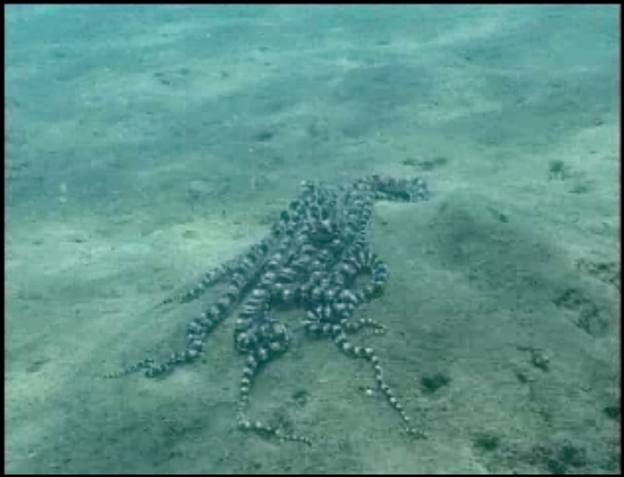
from "Colour in nature", P. Farrant

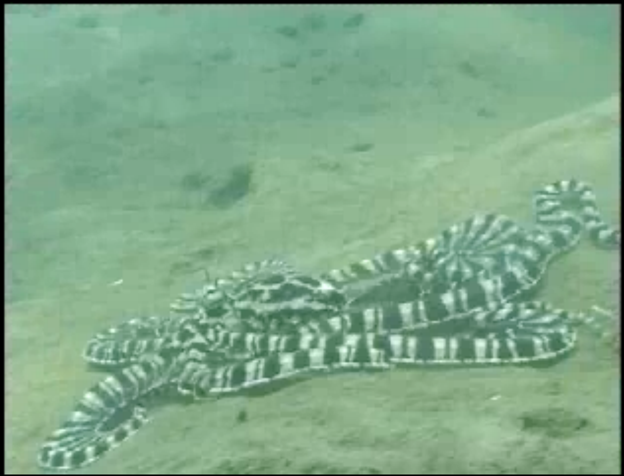


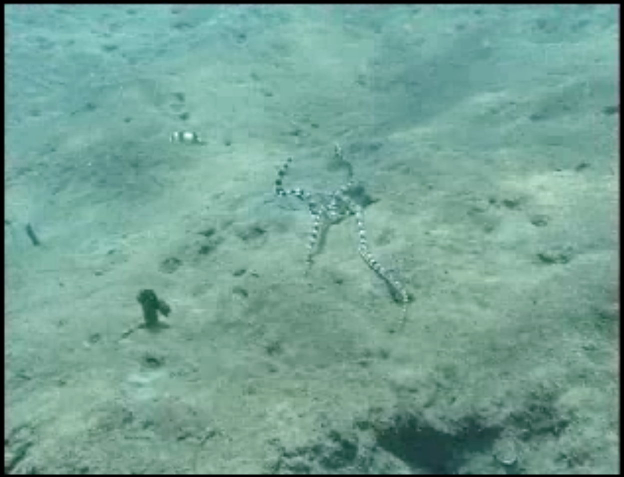
Layers of guanine + other phenomena



upper colour reflecting layer
+ lower white layer
+ chromatophores

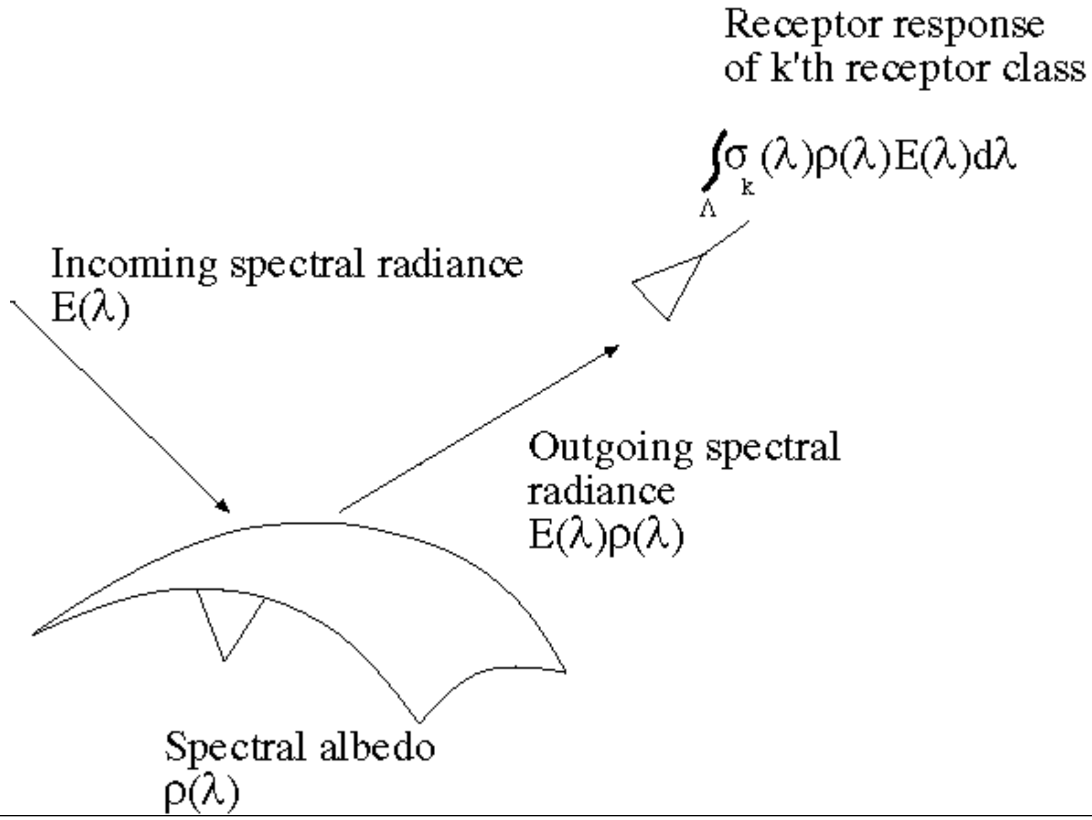






The color of objects

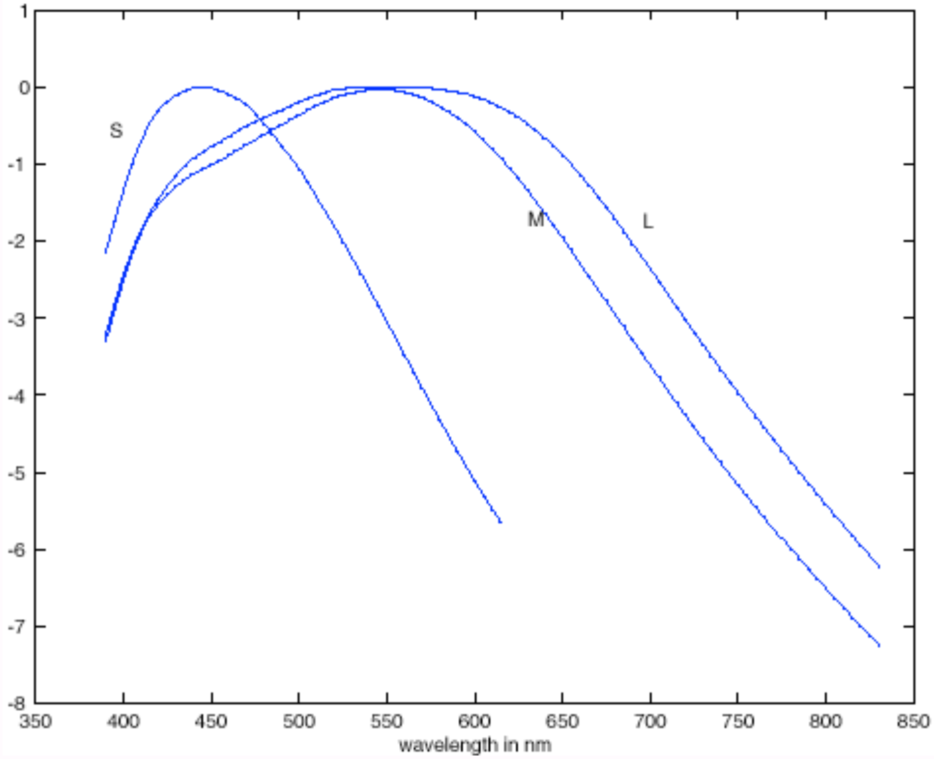
- Colored light arriving at the camera involves two effects
  - The color of the light source
  - The color of the surface
  - Changes caused by different colored light sources can be large



Color receptors and color deficiency

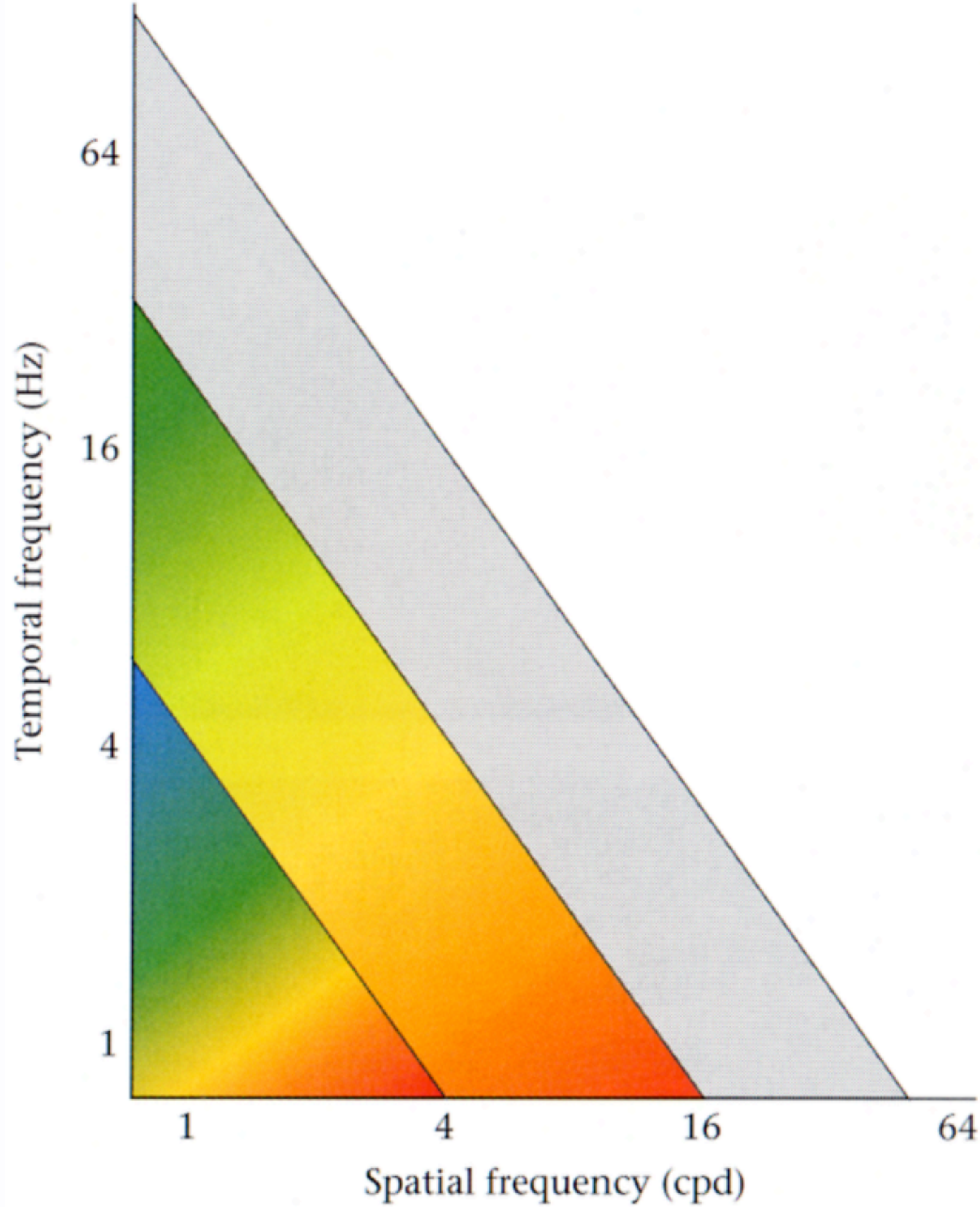
- Trichromacy is justified -
  - in color normal people, there are three types of color receptor (shown by molecular biologists).
- Some people have fewer;
  - most common deficiency is red-green color blindness in men. Red and green receptor genes are carried on the X chromosome. Most red-green color blind men have two red genes or two green genes. Yields an evolutionary story.
- Deficiency
  - can be caused by CNS, by optical problems in the eye, or by absent receptors
- Other color deficiencies:
  - Anomalous trichromacy
  - Achromatopsia
  - Macular degeneration

Color receptors

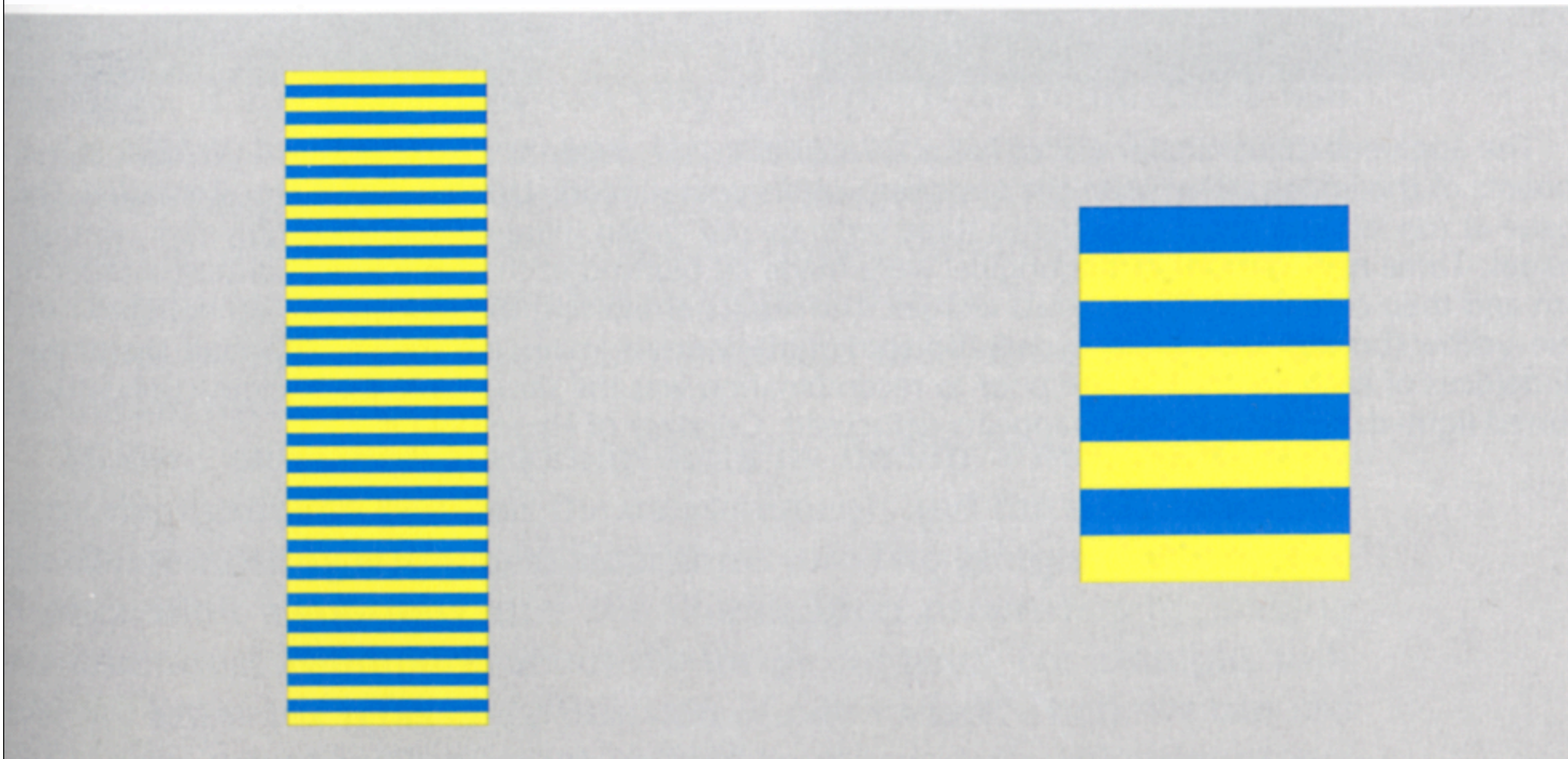


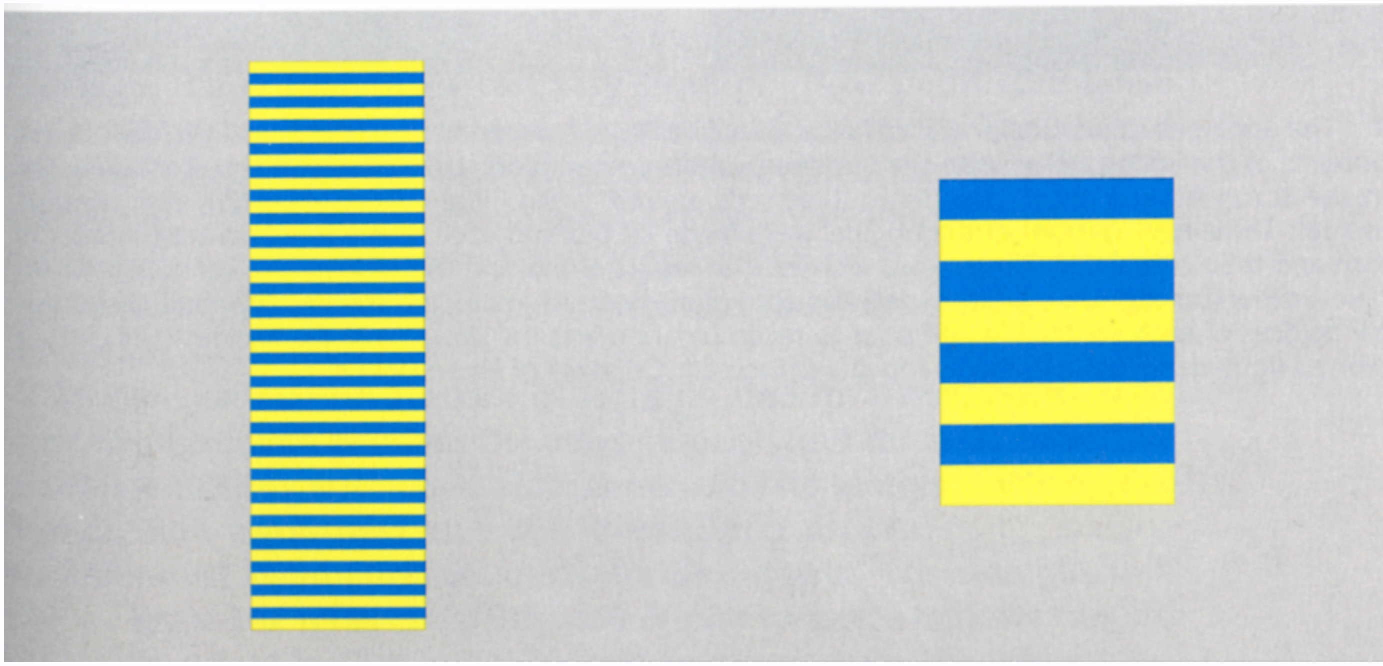
Principle of univariance: cones give the same kind of response, in different amounts, to different wavelengths. Output of cone is obtained by summing over wavelengths.

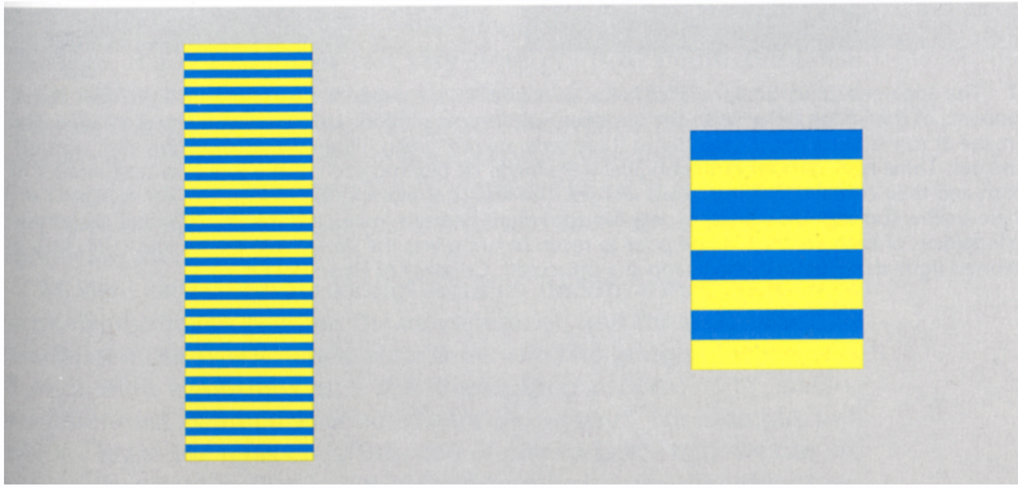
Responses measured in a variety of ways

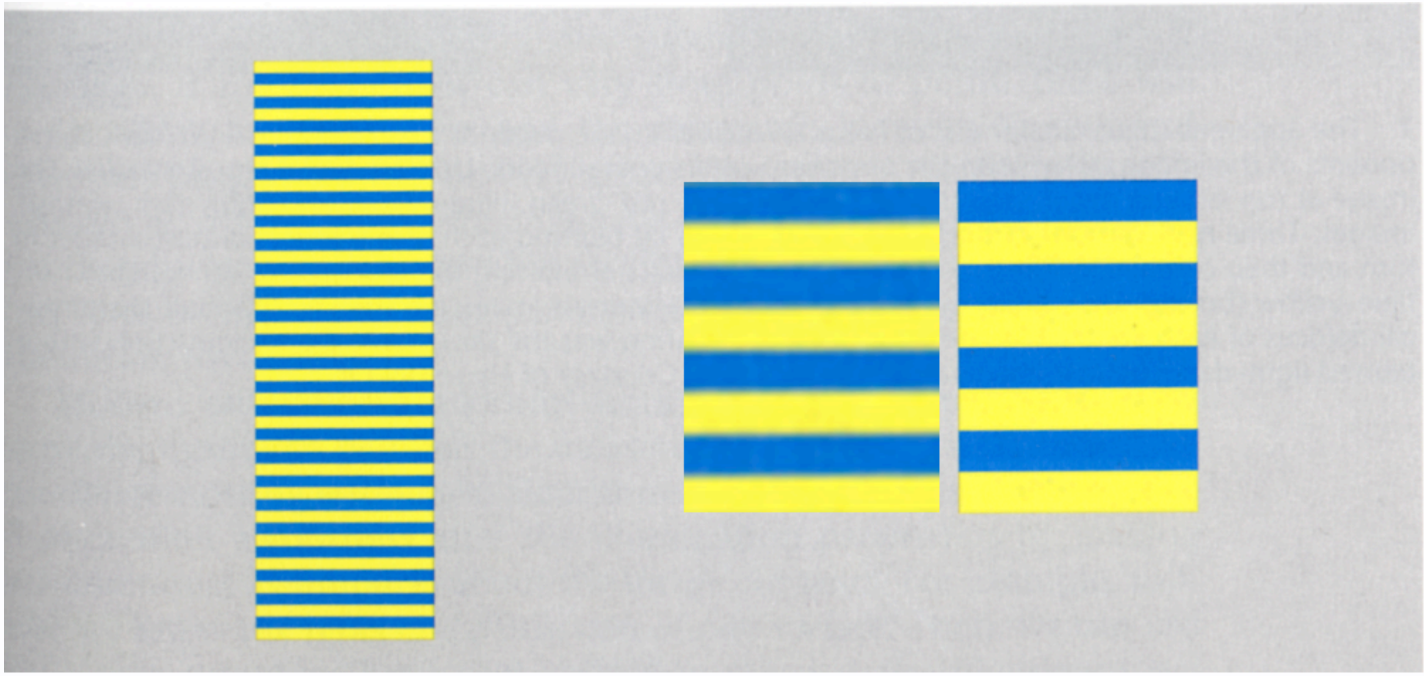


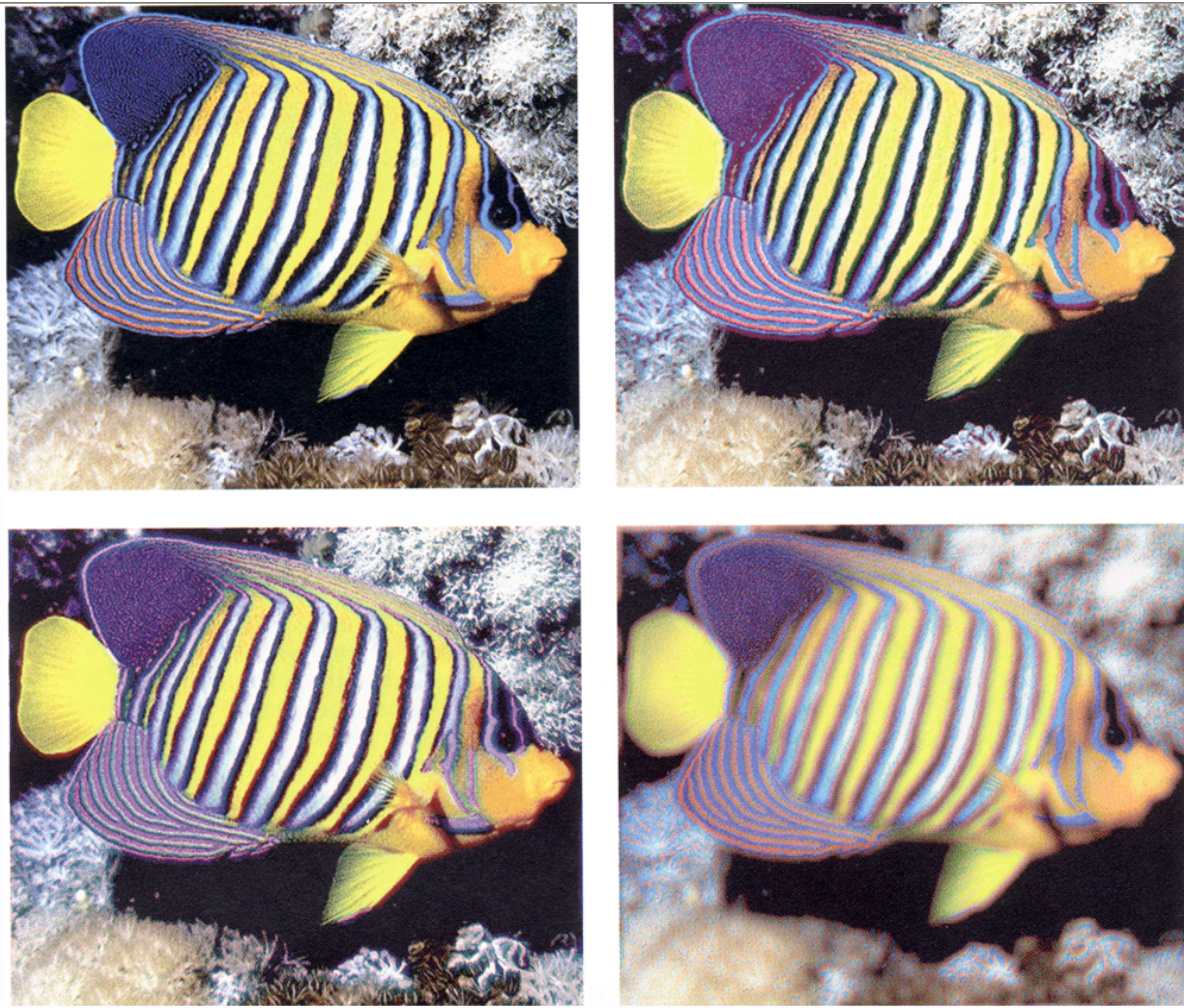
64
16
4
1
Temporal frequency (Hz)
1
4
16
64
Spatial frequency (cpd)









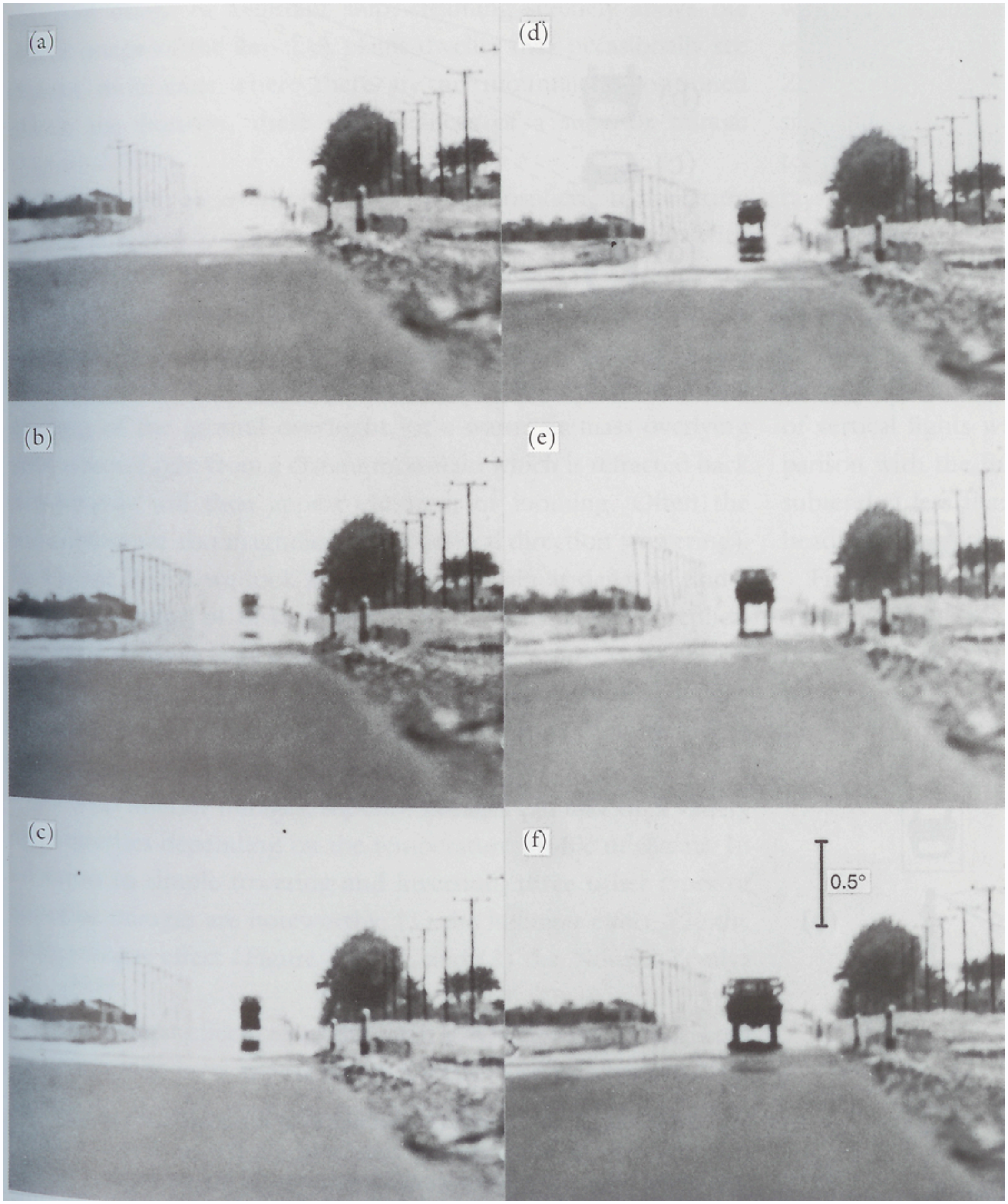


Geometric phenomena

From Lynch and Livingstone, Color and Light in Nature

From Lynch and Livingstone, Color and Light in Nature

From Lynch and Livingstone, Color and Light in Nature

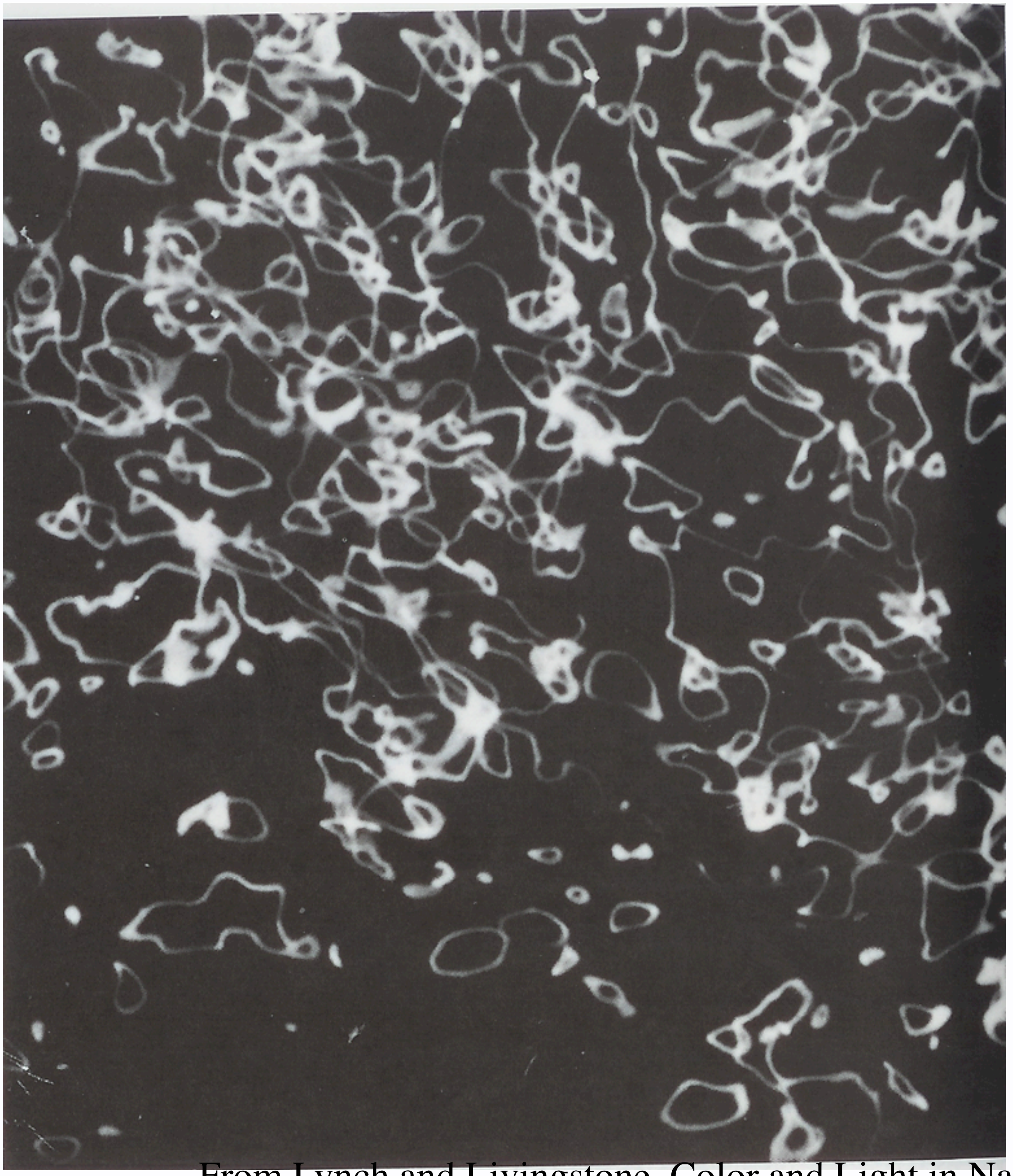


Mirage at base of truck

From Lynch and Livingstone, Color and Light in Nature

Minnaert, Light and Color in the outdoors

Notice flattened sun,
sparkles



From Lynch and Livingstone, Color and Light in Nature

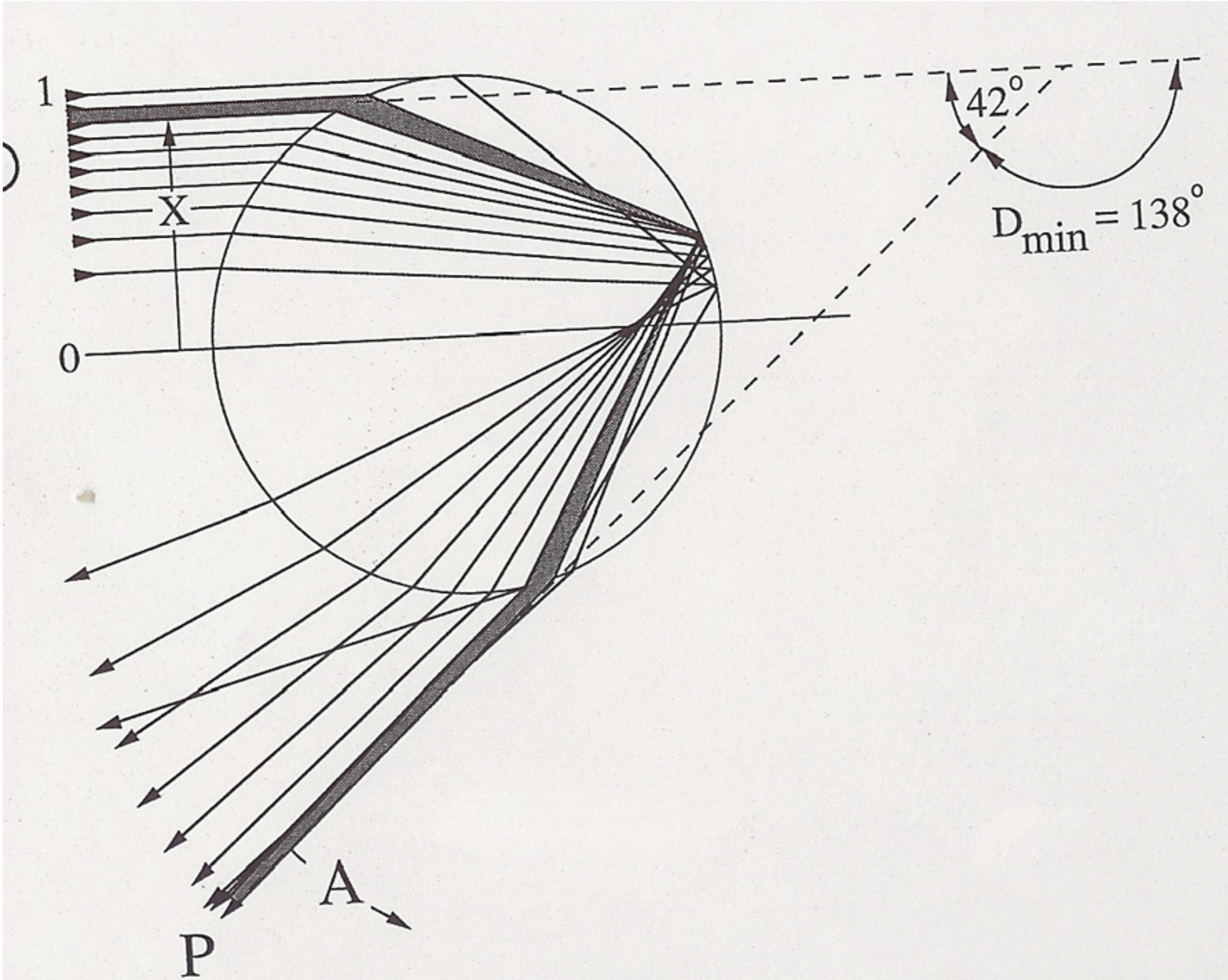
From Lynch and Livingstone, Color and Light in Nature

From Lynch and Livingstone, Color and Light in Nature

From Lynch and Livingstone, Color and Light in Nature

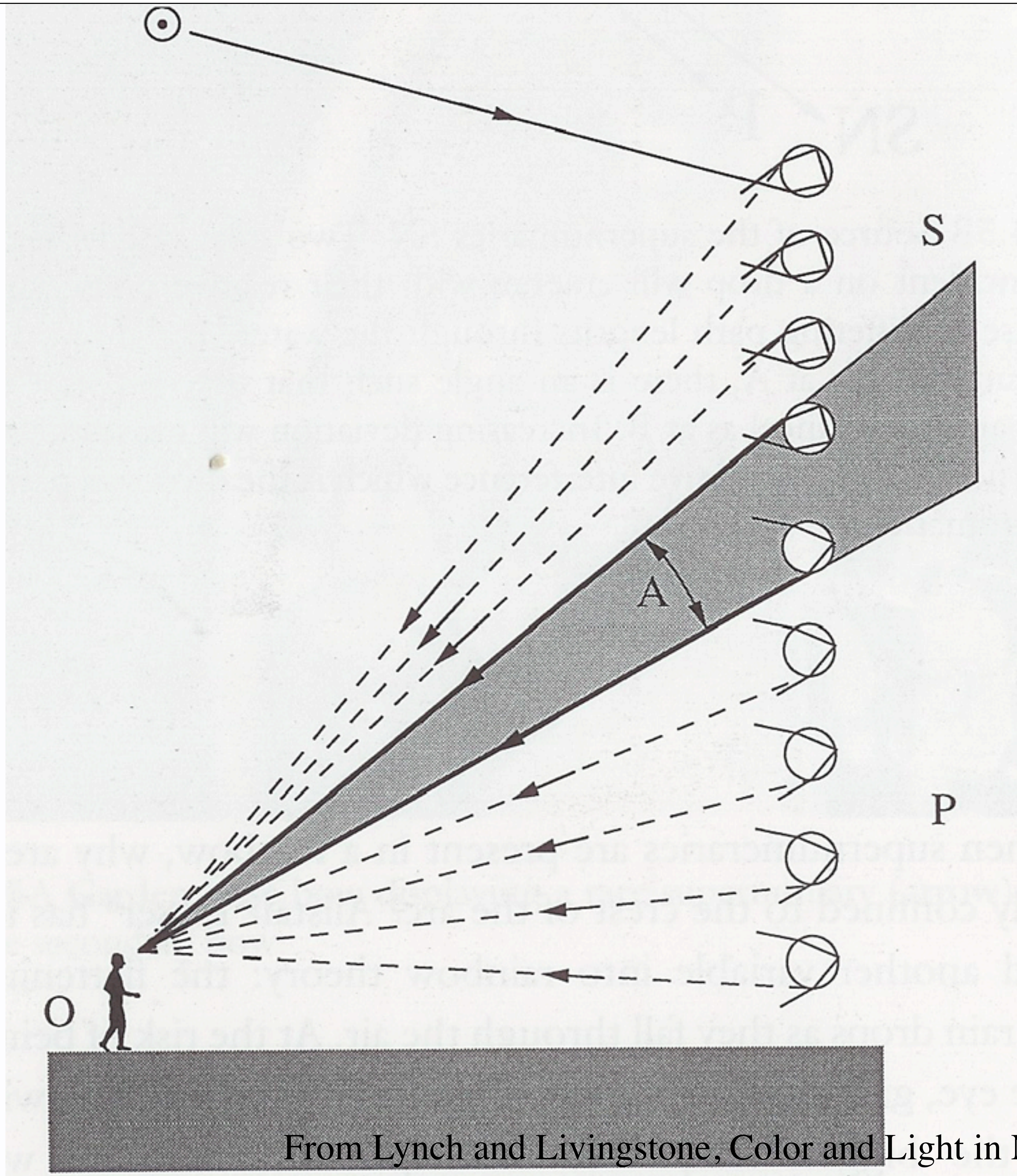
From Lynch and Livingstone, Color and Light in Nature

From Lynch and Livingstone, Color and Light in Nature



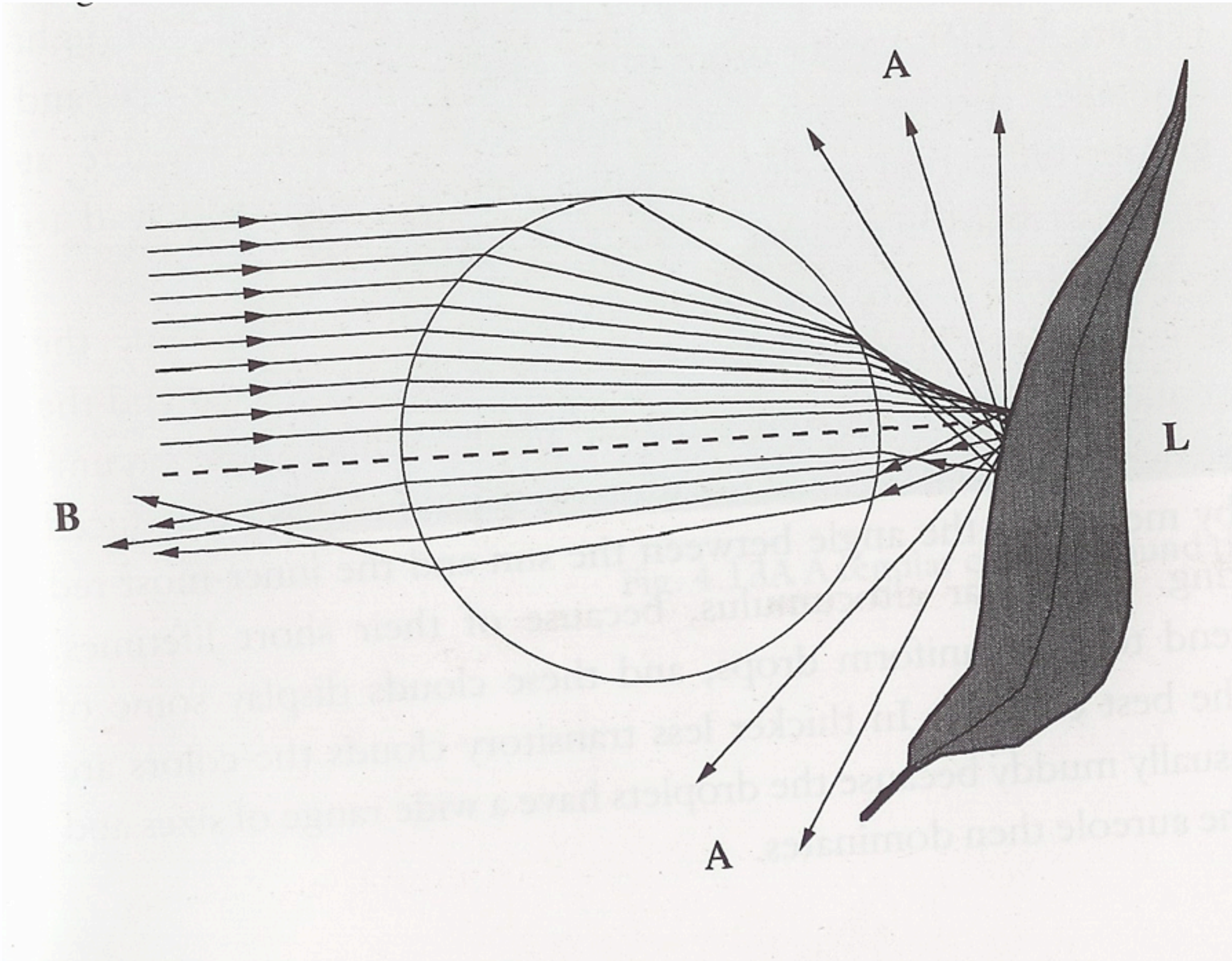
From Lynch and Livingstone, Color and Light in Nature

From Lynch and Livingstone, Color and Light in Nature

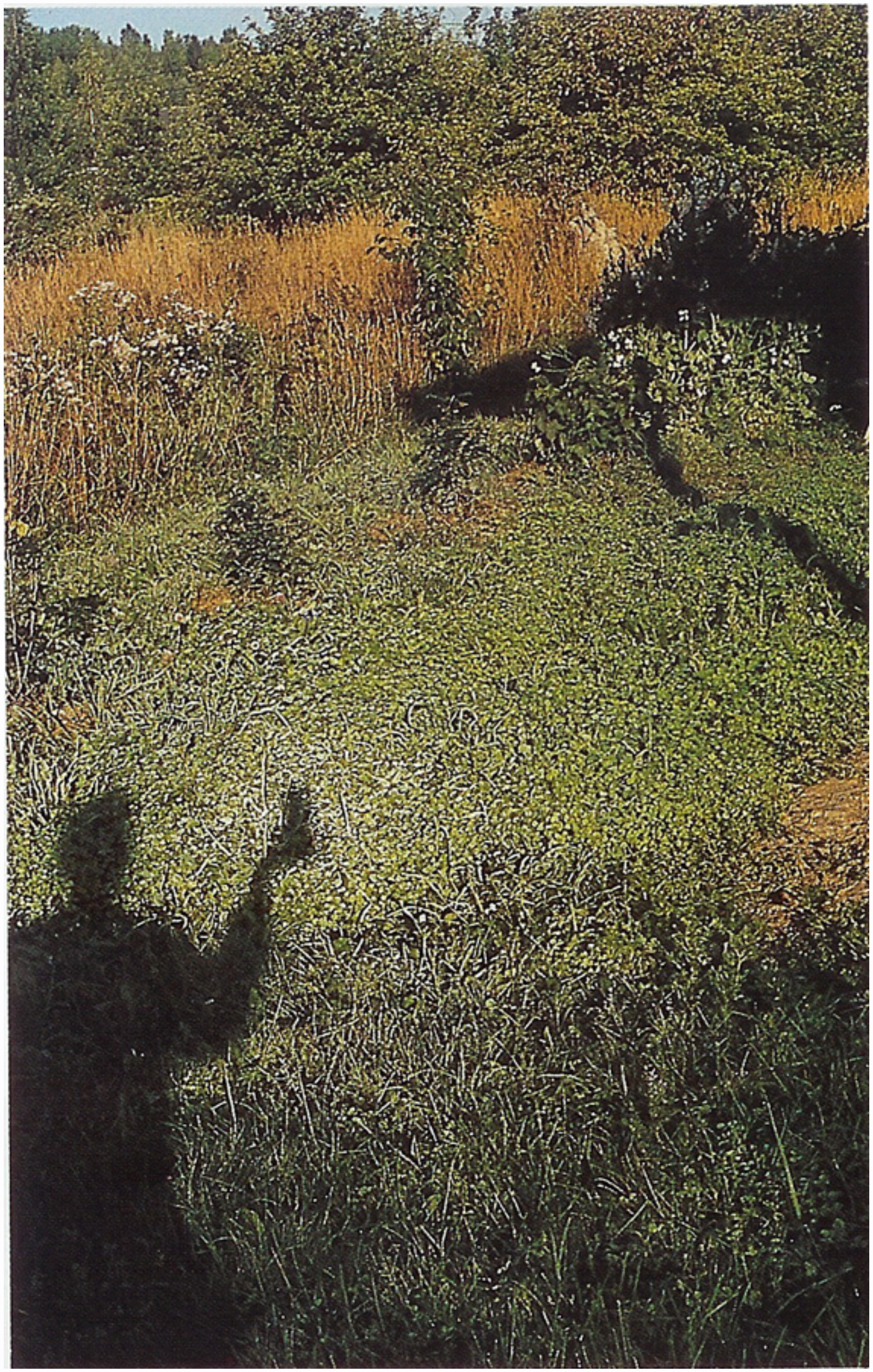


From Lynch and Livingstone, Color and Light in Nature

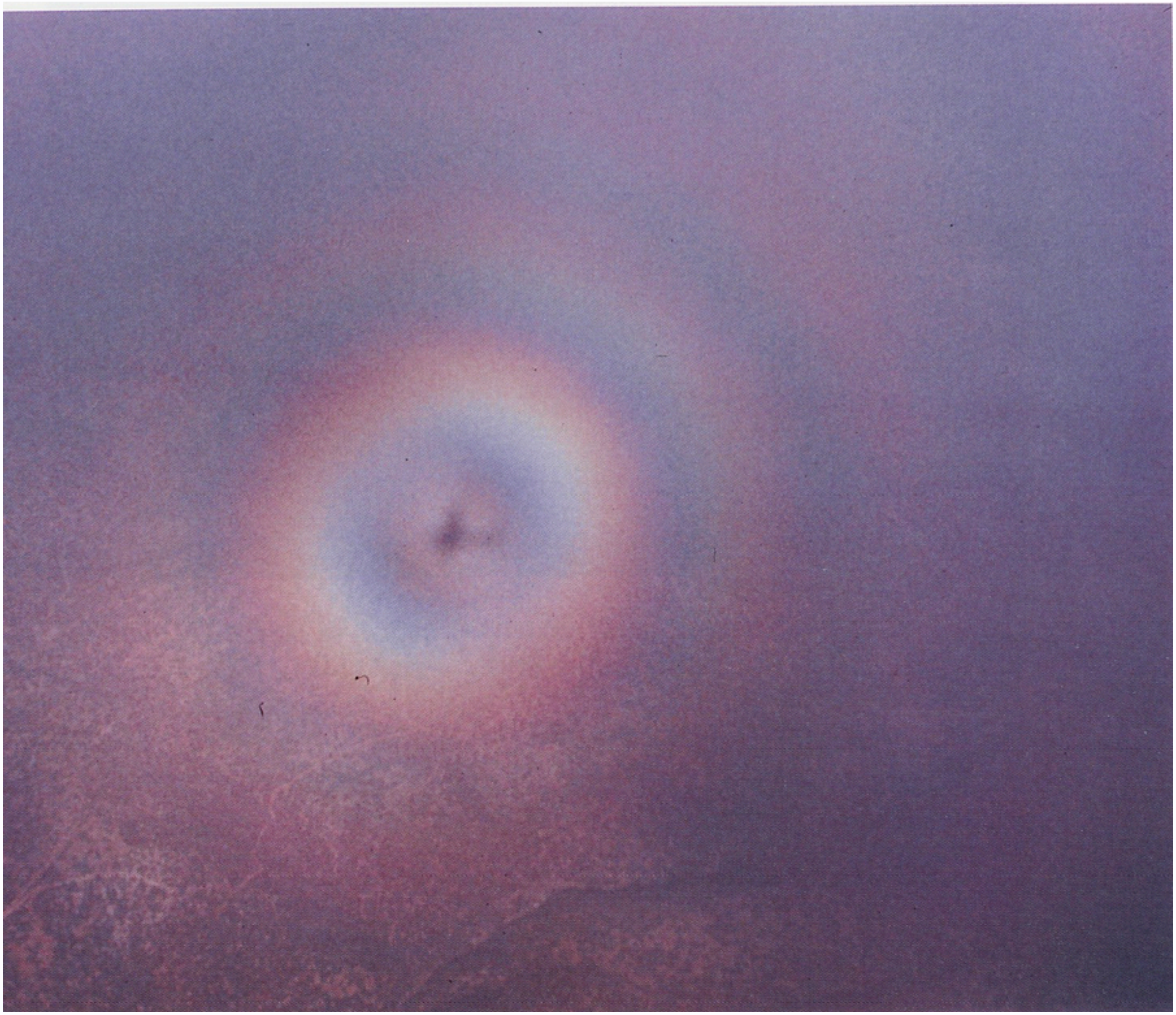
From Lynch and Livingstone, Color and Light in Nature



From Lynch and Livingstone, Color and Light in Nature



Minnaert, Light and Color in the outdoors
Heiligenschein



From Lynch and Livingstone, Color and Light in Nature

From Lynch and Livingstone, Color and Light in Nature