Chapter 2

Principles of Photography and Imaging

Elements of Photogrammetry with Applications in GIS

1. Introduction

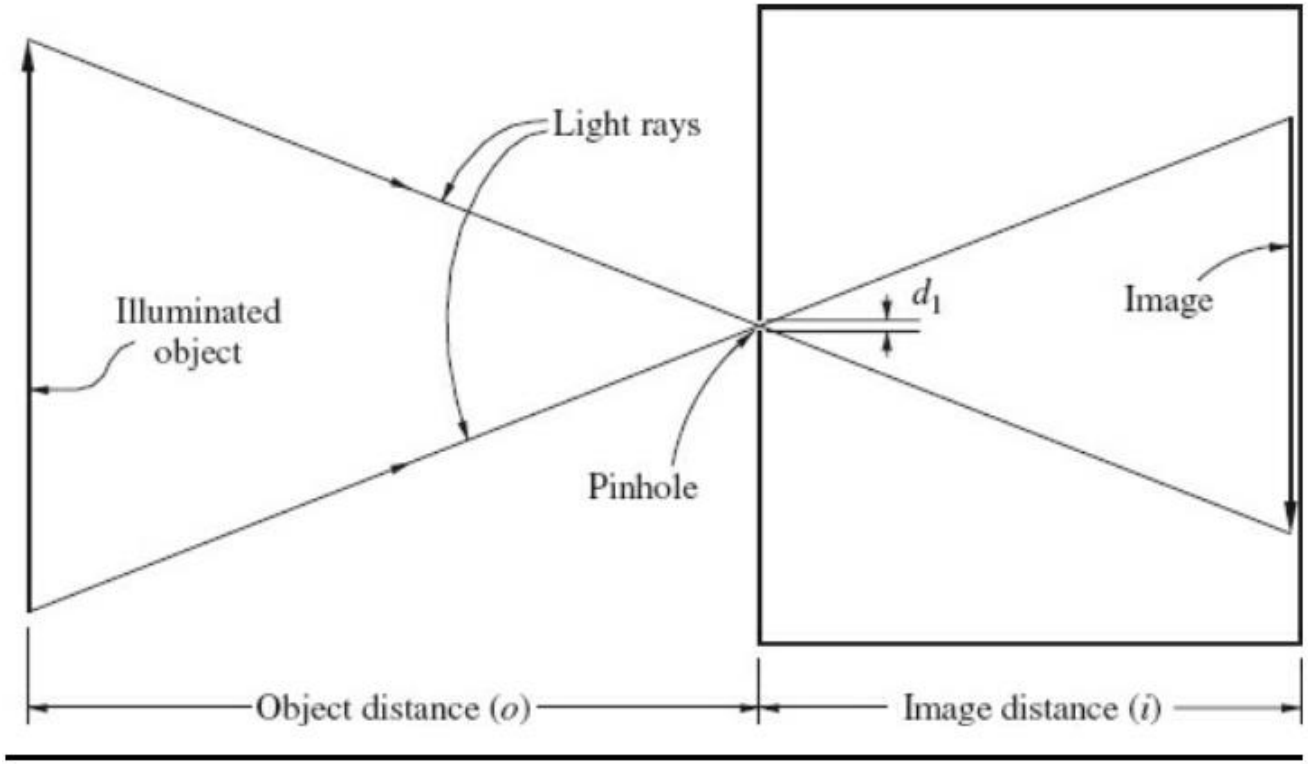


Figure 2-1 Principle of the pinhole camera.

- Photography
  - Meaning: drawing with light
- Pinhole camera
  - Ancient Arabs discovered inverted images inside a dart tent.
  - French artists (1700s) drew perspective views of illuminated objects.
  - Louis Daguerre developed a photographic film

2. Fundamental Optics

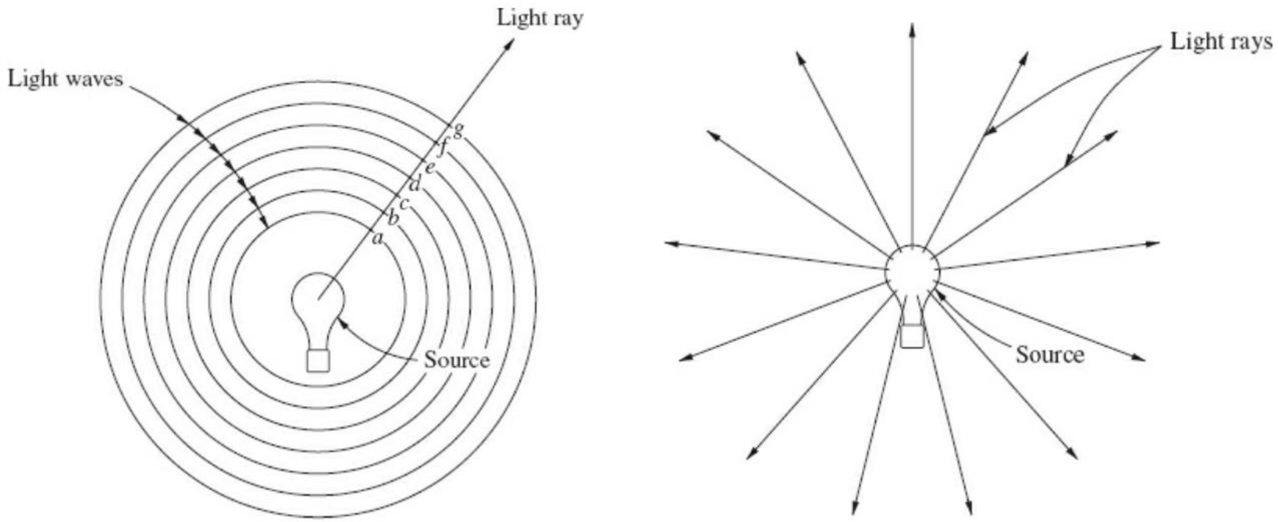


Figure 2.2 & 2.3 Concepts of light waves in physical optics and bundle of rays in geometric optics

➢ Physical optics

- Electromagnetic waves with own frequency, amplitude, & wavelength

$$V = f\lambda$$

$V = 2.99792458 \times 10^8\ m/s$ in a vacuum

➢ Geometric optics

- Light rays of straight lines
- Useful for understanding of the science of photogrammetry

2. Fundamental Optics

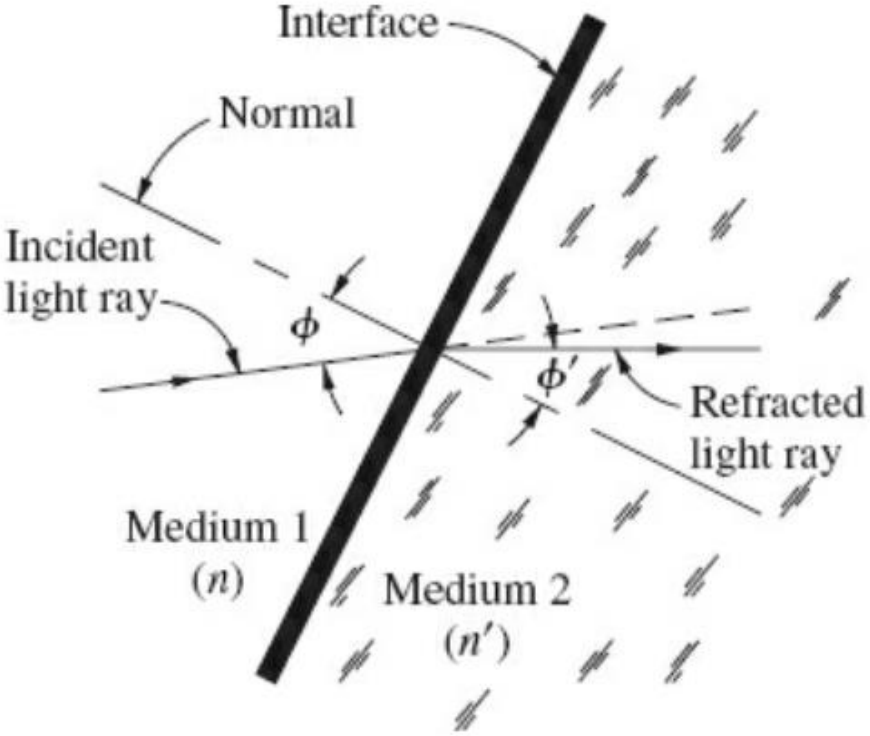


FIGURE 2-4 Refraction of light rays.

- Refractive index

$$n = \frac{c}{V}$$

- c: light velocity in a vacuum, V: velocity in the substance

- Depends on the wavelength of the light
−1.0:vacuum, 1.0003: air, 1.33: water, glass: 1.5~2.0

- Snell's law

$$n \sin \varphi = n' \sin \varphi'$$

2. Fundamental Optics

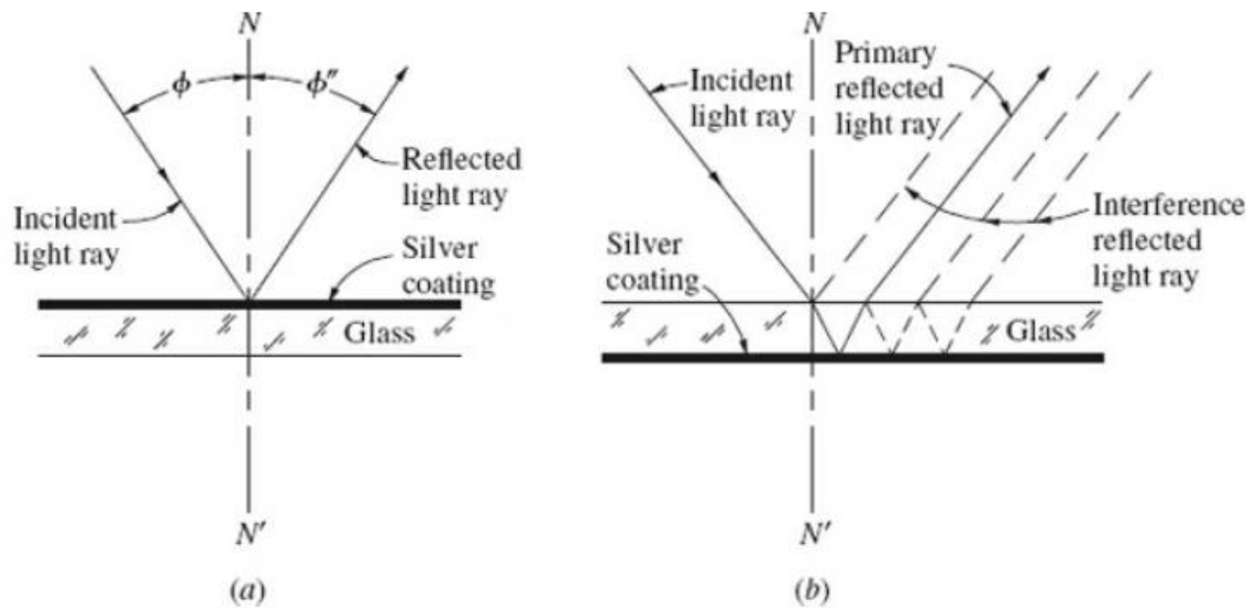


FIGURE 2-5 (*a*) First-surface mirror demonstrating the angle of incidence φ and angle of refection φ''; (*b*) back-surfaced mirror.

- Reflection

  - Angle of reflection is equal to the incidence angle

- First–surface mirror is adopted for scientic purpose.
- Back-surfaced mirror creates multiple reflection which is optically undesirable.

3. Lenses

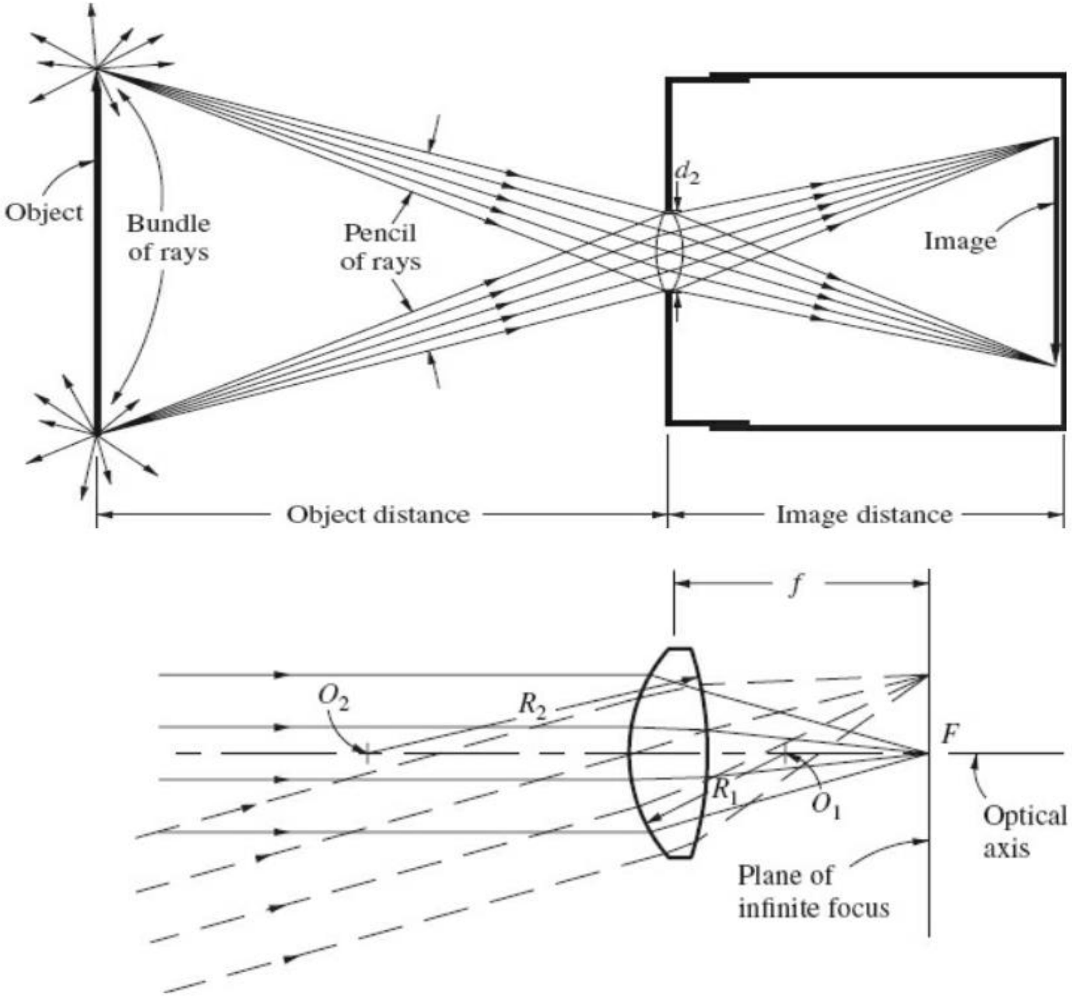


Figure 2.6 & 2.7 Image formation in a single-lens camera (above); optical axis and focus related terms

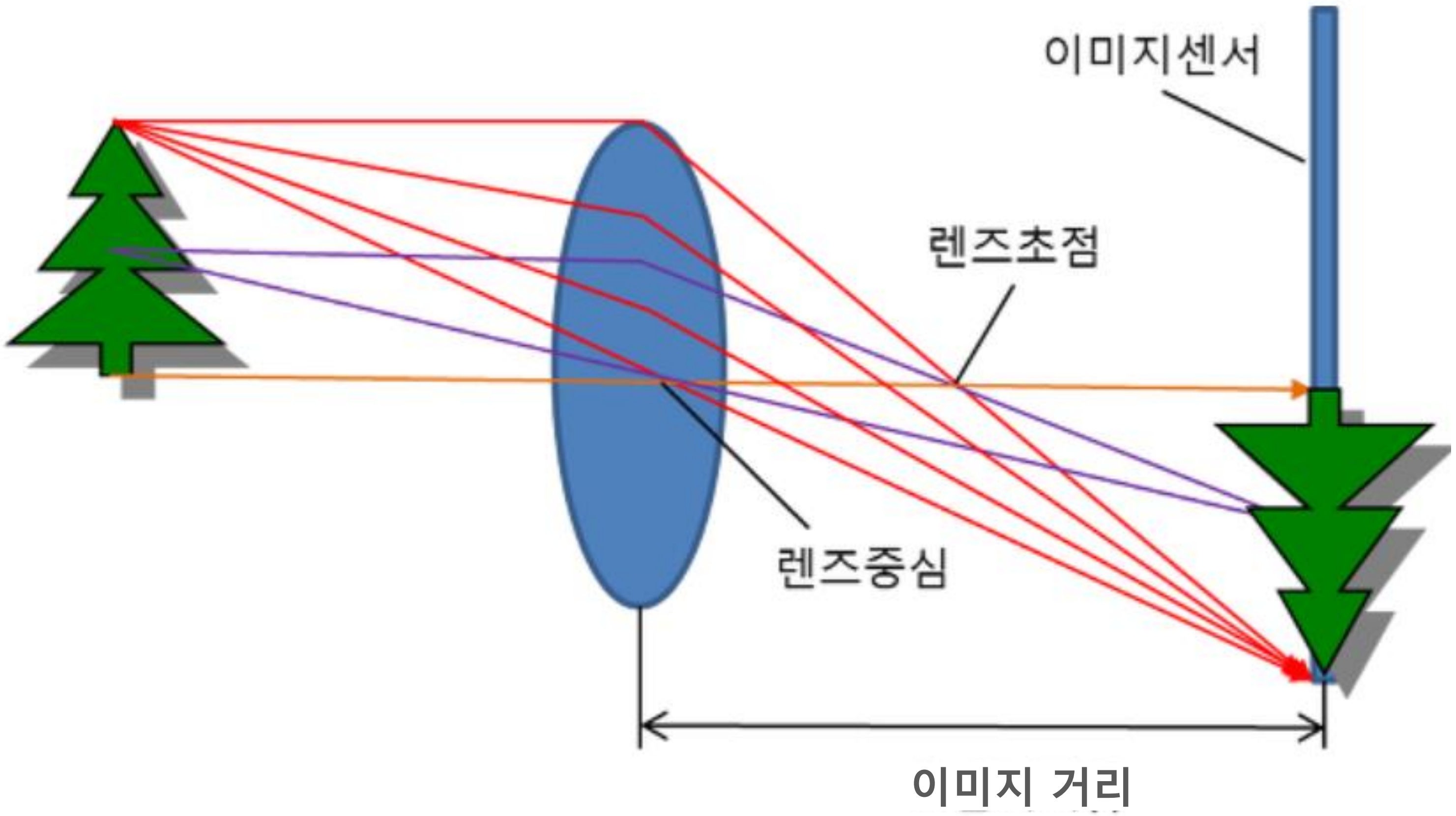
- Lens vs pinhole

  - Increased amount of light is passed

- Terms & formula

- Optical axis: a line joining the curvature centers (O_1 & O_2)
- Focal point: a point to which light rays parallel to the optical axis converges
- Focal length (*f*): distance between a focal point to the center of a lens
- Focal plane: a plane perpendicular to the optical axis passing through the focal point
- Lens formula

$$\frac{1}{O}+\frac{1}{i}=\frac{1}{f}$$



Example of image formation

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3. Lenses

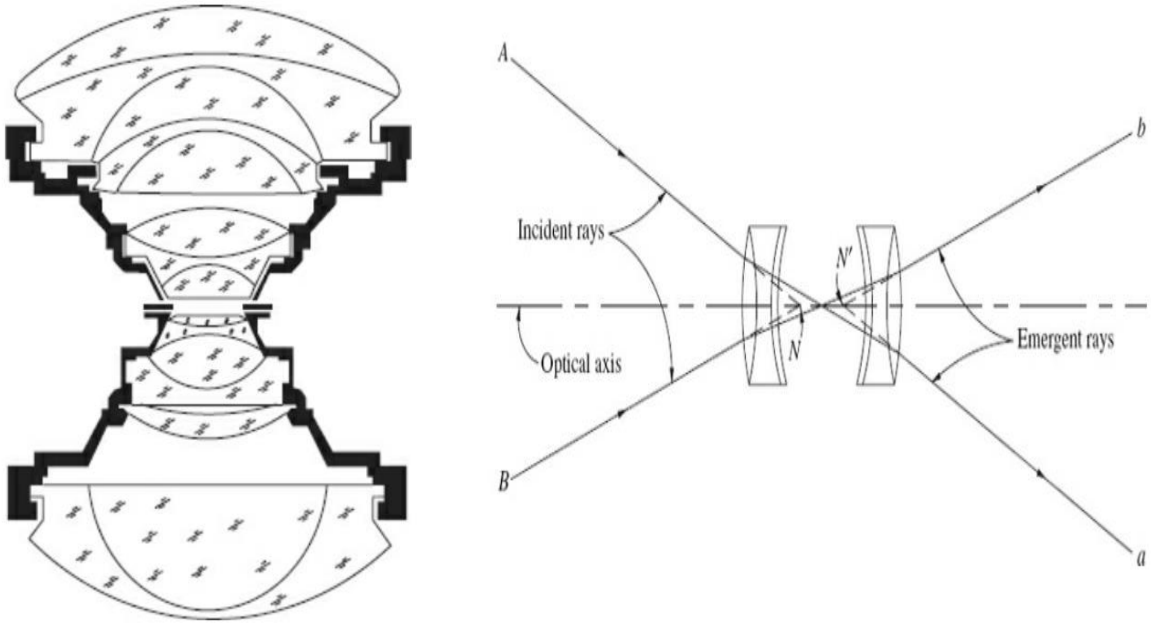


Figure 2.9 & 2.10 Cross section (SAGA-Flens) and nodal points of a thick lens

- Thick lens

  - A single lens is somewhat blurred and geometrically distorted.

  - Aberrations (收差): degrade of sharpness

- Lens distortion

- Deteriorate the geometric quality (positional accuracy)
- Symmetric radial distortion: distorted along radial lines
- Decentering distortion: off-center distortion (tangential/asymmetric radial)

3. Lenses

- Resolution

  - Ability to show detail normally measured by the number of line pairs within 1 mm width or by modulation transfer function (MTF) of image density

- Depth of field

  - "Range in object distance that can be accommodated by a lens without introducing significant image deterioration"

  - Extremely critical for close-range photography

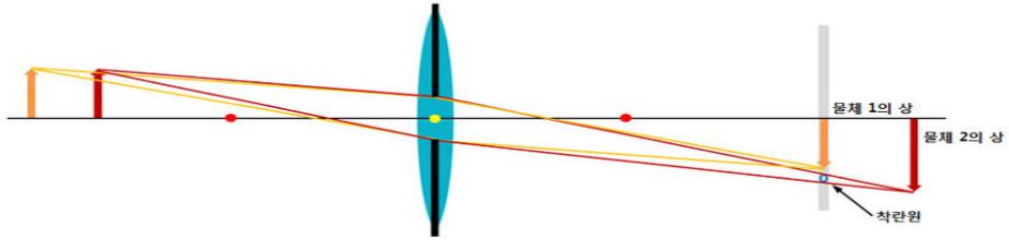
  - Affected by aperture, focal length, & object distance

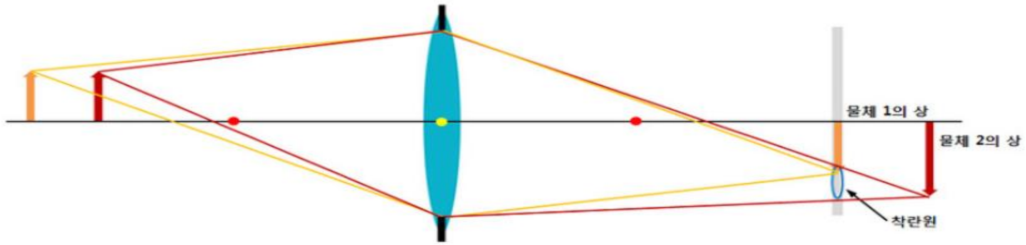
- Vignetting and falloff

  - "Lens characteristics which cause resultant images to appear brighter in the center than around the edges"

Factors affecting the depth of field

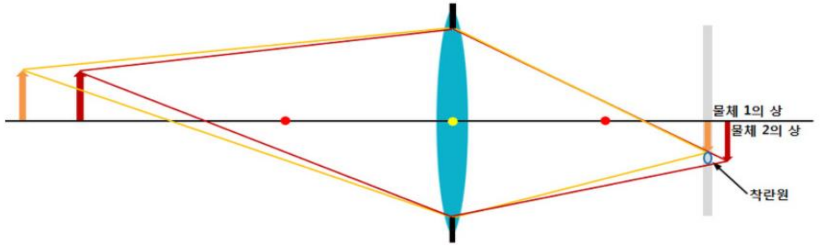
- Aperture: small opening → large depth; large opening → small depth





- Focal length: small length → large depth; large length → small depth

Circle of confusion (착란원)



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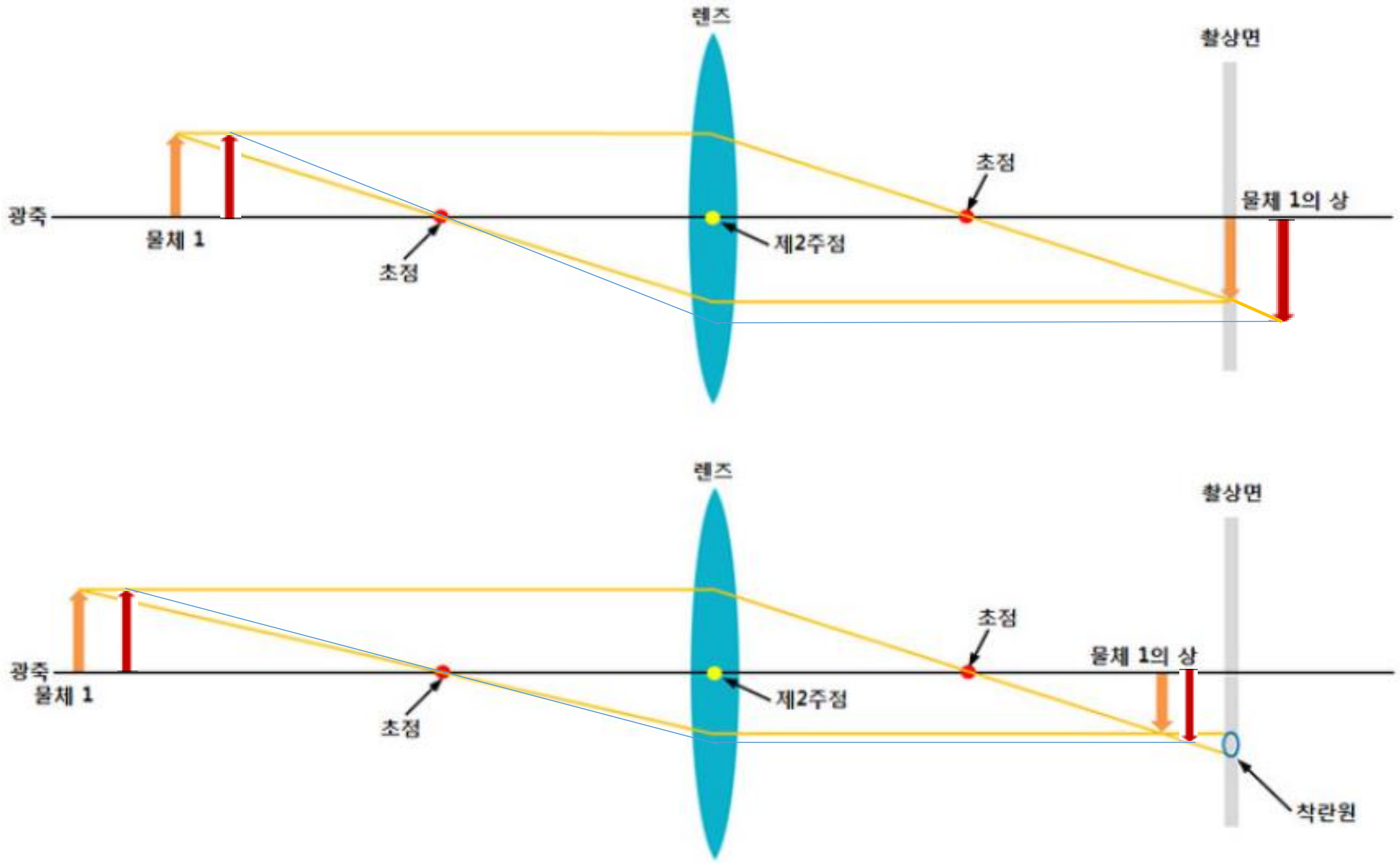
- Object distance: small distance → small depth; large distance → large depth



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4. Single-Lens Camera

- Lens formula for symmetric single lens

- For aerial photography the object distance approaches infinity considering a focal length

$$\frac{1}{o}+\frac{1}{i}=\frac{1}{f} \quad \rightarrow \frac{1}{i}=\frac{1}{f}$$

※ Lens formula for non-symmetric single lens

$$\frac{1}{f_i o}+\frac{1}{f_o i}=\frac{1}{f_i f_o}$$

5. Illuminance

- Common unit of illuminance is the meter-candle (1 m·cd is produced by a candle at a 1 m of distance)

- Illuminance is proportional to lens opening area and inversely proportional to distance^2.

$$Illuminance \approx \frac{d^2}{i^2} \approx \frac{d^2}{f^2} \text{ (for far object)}$$

- Brightness factor

$$\sqrt{\frac{d^2}{f^2}} = \frac{d}{f}$$

- f-stop = $\frac{f}{d}$

6. Relationship of Aperture and Shutter Speed

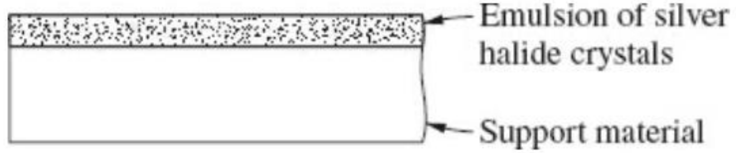
- Total exposure = illuminance × time of exposure (meter-candle-seconds)

- Normal f-stop settings are 1, 1.4, 2.0, 2.8, 4.0, 5.6, 8.0, 11, 16, 22, 32 in which successive nominal f-stop halves the aperture area of the previous one.

- Exposure of f-4 with 1/500 s is same with f-2.8 with 1/1000 s.

7. Characteristics of Photographic Emulsions

- Photographic film consists of emulsion containing silver halide crystals and support of paper, plastic film or glass.



- The silver halide crystal bonding is weakened to form a latent image when it is exposed to light → when the latent image is developed the exposed area of emulsion become black.

- Degree of darkness of a developed emulsion is called its density and defined as *D:*

$$D = \log\left(\frac{\text{incident intensity}}{\text{transmitted intensity}}\right)$$

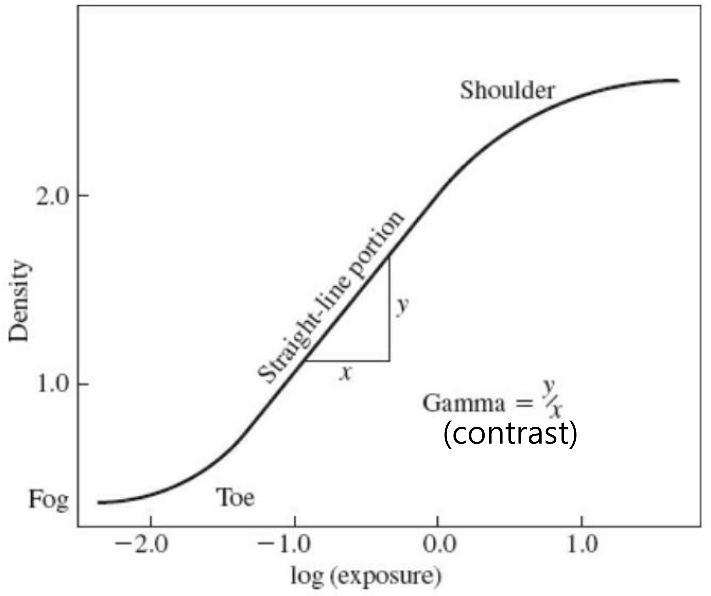


Figure 2-13 Typical "characteristic curve" of a photographic emulsion.

7. Characteristics of Photographic Emulsions

- As grain size of emulsion increases the film becomes more sensitive while the resulting image becomes coarse and resolution is reduced.
- ISO (International Standards Organization) number assigned to a film is roughly equal to the inverse of shutter speed for pure sunlight with a lens opening of *f*-16.

(If film is properly exposed in pure sunlight at *f*-16 and 1/200 sec. it is classified ISO 200)

- In aerial photography the sensitivity of films is expressed as aerial film speed (AFS) which is determined at 0.3 of density above the fog density.

8. Processing Black-And-White Emulsions

- Five-step darkroom procedure for processing an exposed b/w emulsion

1) Developing

The emulsion is placed in a chemical solution (developer) for 1~15 min. upon the film and developer to cause silver halide grains to be reduced to free black silver. Contrast can be changed by development time and developer temperature.

2) Stop bath

The emulsion is immersed in the stop bath of an acidic solution for a few seconds to neutralize the developer solution.

3) The Fixing

The undeveloped silver halide grains are dissolved out and the emulsion is hardened in the fixing solution after 10 to 20 min. of immersion.

8. Processing Black-And-White Emulsions

4) Washing
The emulsion is washed in clean running water to remove any remaining chemicals (detergent may be added) for 10 to 20 minuits.

5) Drying

The emulsion and backing material are dried to remove water by air drying or heated dryers.

A positive is obtained from the negative by repeating the photographic process: a printing paper covered with a layer of emulsion is exposed by passing light through the negative.

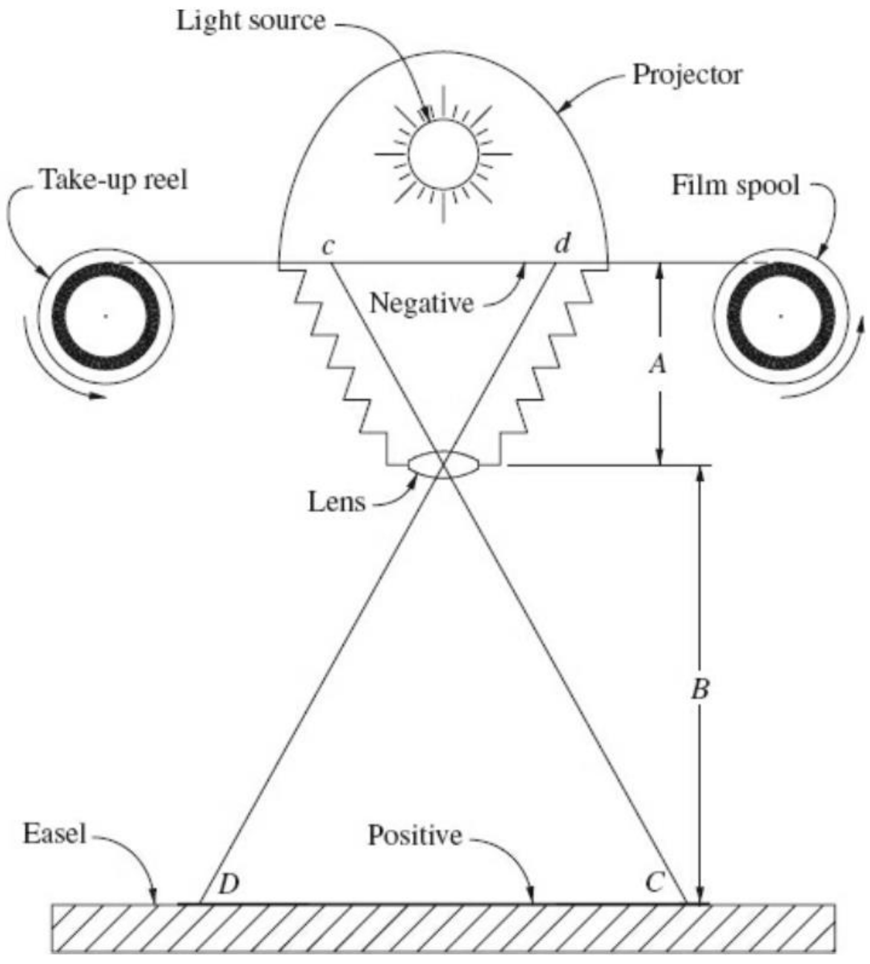


FIGURE 2-15 Geometry of enlargement with a projection printer.

9. Spectral Sensitivity of Emulsions

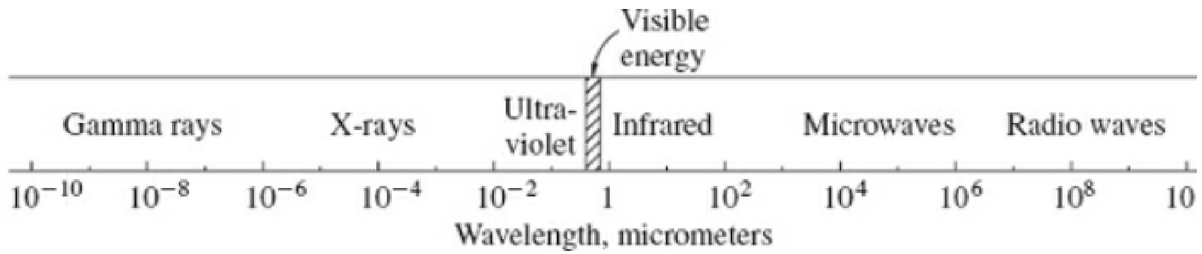


FIGURE 2-16 Classification of the electromagnetic spectrum by wavelength

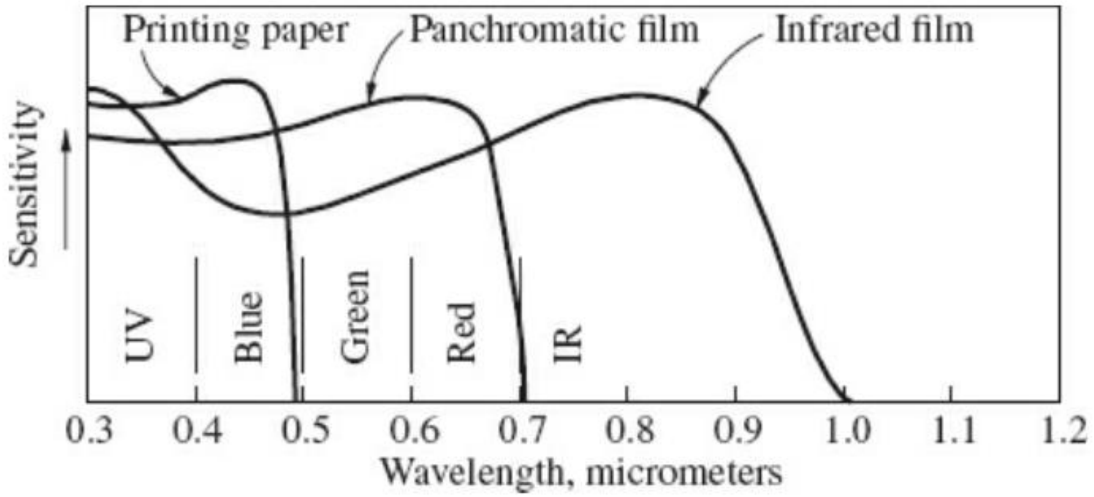


FIGURE 2-18 Typical sensitivities of various black-and-white emulsions.

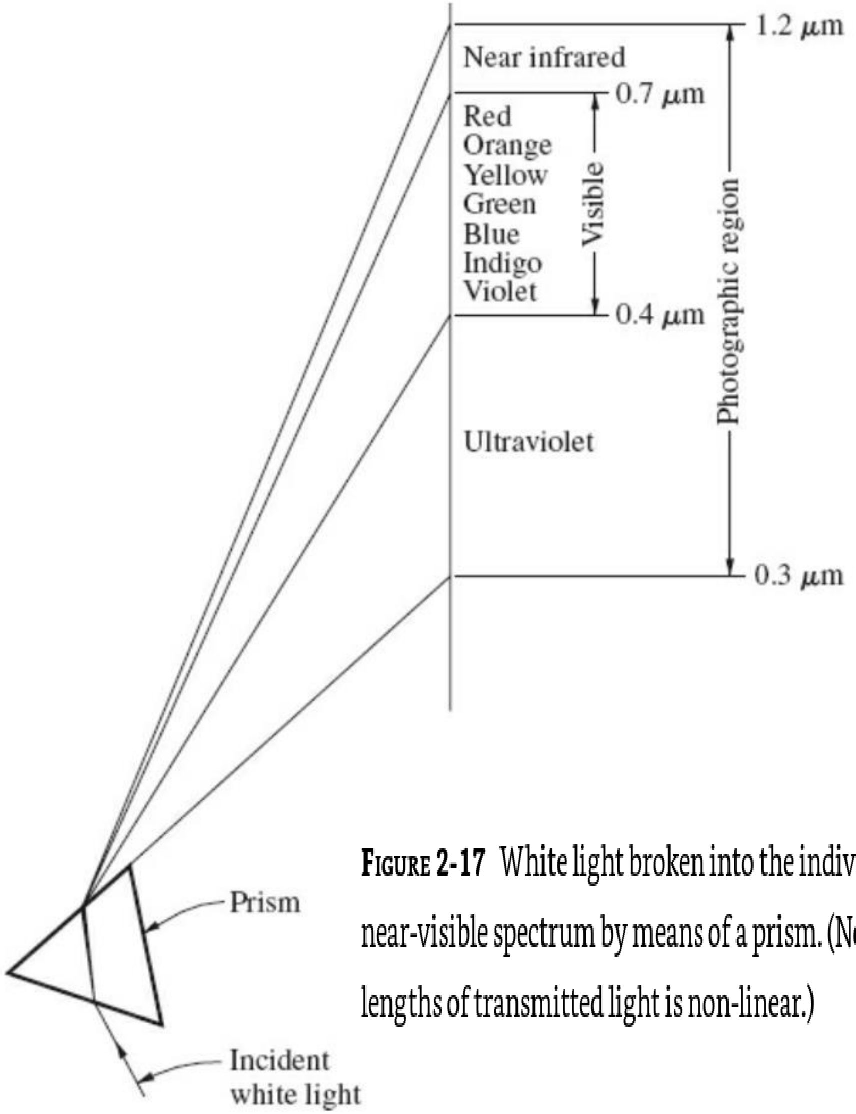


FIGURE 2-17 White light broken into the individual colors of the visible and near-visible spectrum by means of a prism. (Note that the range of wave-lengths of transmitted light is non-linear.)

10. Filters

- Filters in front of camera lenses allow only certain range of wavelengths to pass through the lens.
- Haze filters block ultraviolet and short blue wavelengths which produce haze, and therefore they are almost always used on aerial cameras.
- Filters can cause distortions that a camera should be calibrated with the filter in place and, after calibration, the filter should not be removed.

11. Color Film

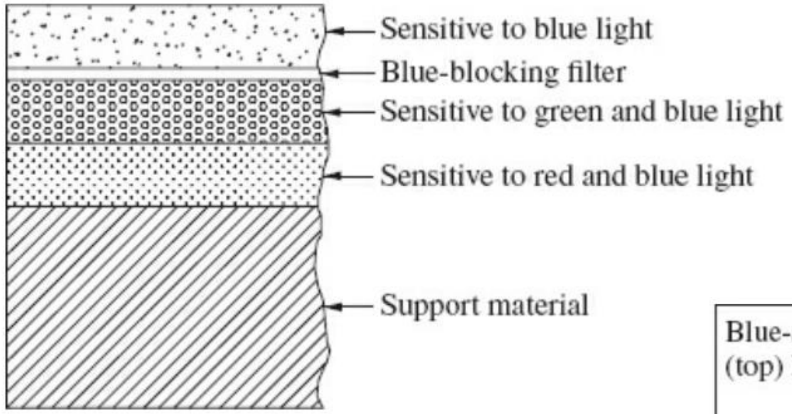


FIGURE 2-19 Cross section of normal color film.

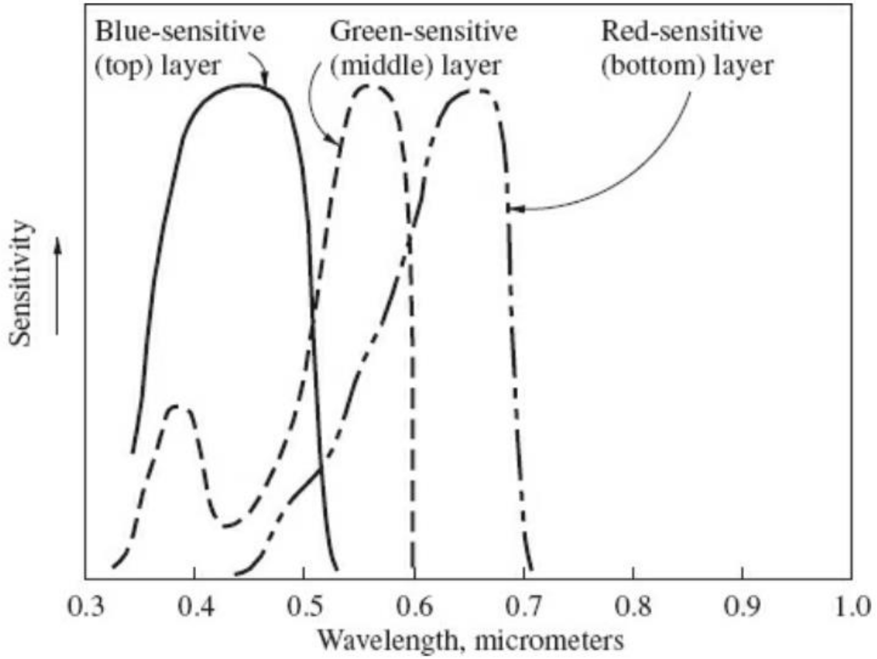


FIGURE 2-20 Typical color sensitivity of three layers of normal color film.

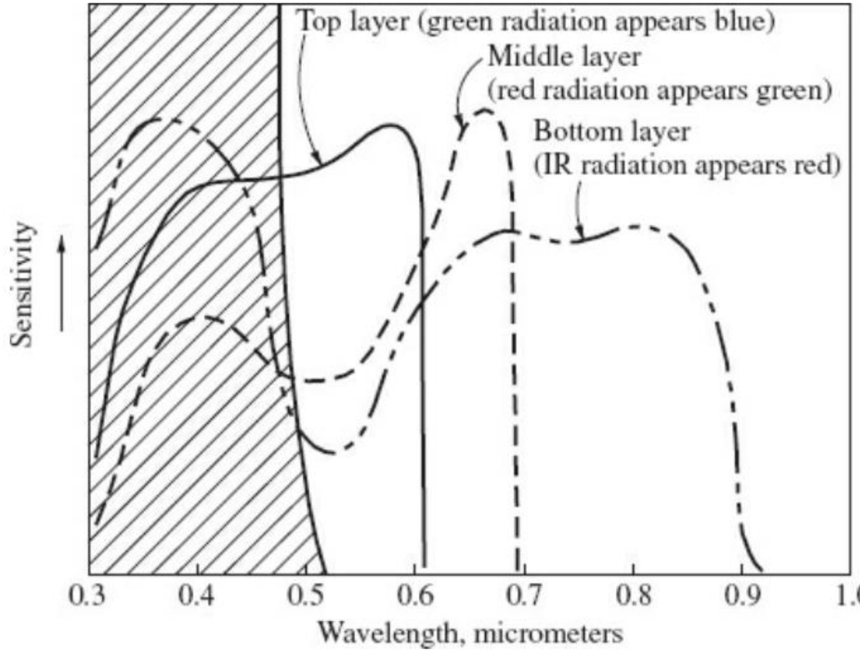
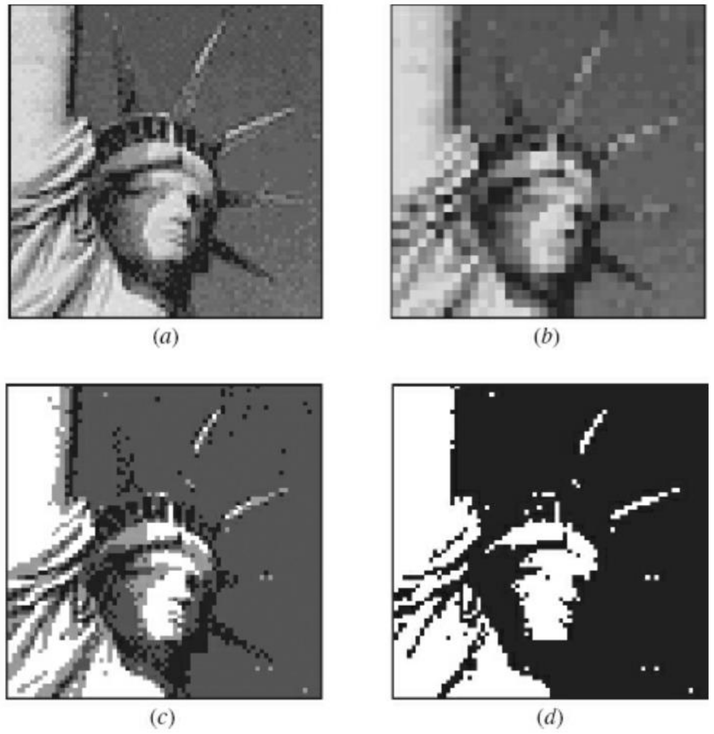


FIGURE 2-22 Typical sensitivity of color infrared (false-color) film.

12. Digital Images

Discrete sampling of an image has two fundamental characteristics – geometric & radiometric resolution

- ➢ Geometric resolution
  - Refers to physical size of individual pixel: smaller pixel → higher resolution
- ➢ Radiometric resolution
  - Quantization: conversion of analog signal amplitude into discrete levels (digital signal)
  - Spectral resolution: spectral resolution of color film is normally divided into three bands (RGB)



(a) 72x72 pixels (b) 36x36 pixels
(c) 4 gray levels (d) 2 b/w levels

13. Color Image Representation

- RGB system can be represented with color cube.
- Intensity-hue-saturation (IHS) system is more readily understood by humans. It can be defined as a set of cylindrical coordinates: HIS → angle, height, & radius
- Intensity represents brightness, hue does color, and saturation does boldness of the color.

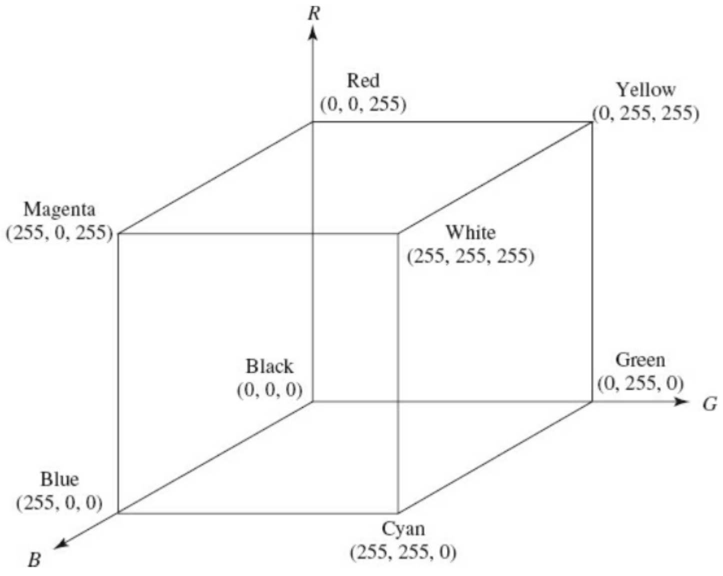


Figure 2-26 Blue-green-red color cube.

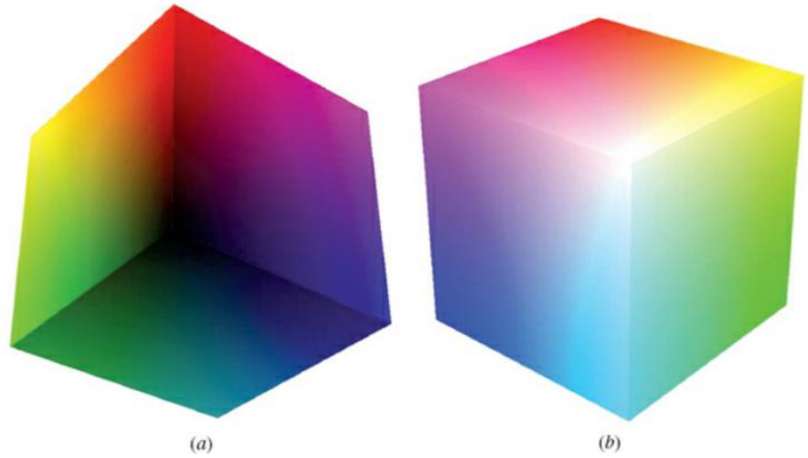


Figure 2-27 (*a*) A view of the color cube from behind the origin and (*b*) a view of the color cube from the opposite corner.

13. Color Image Representation

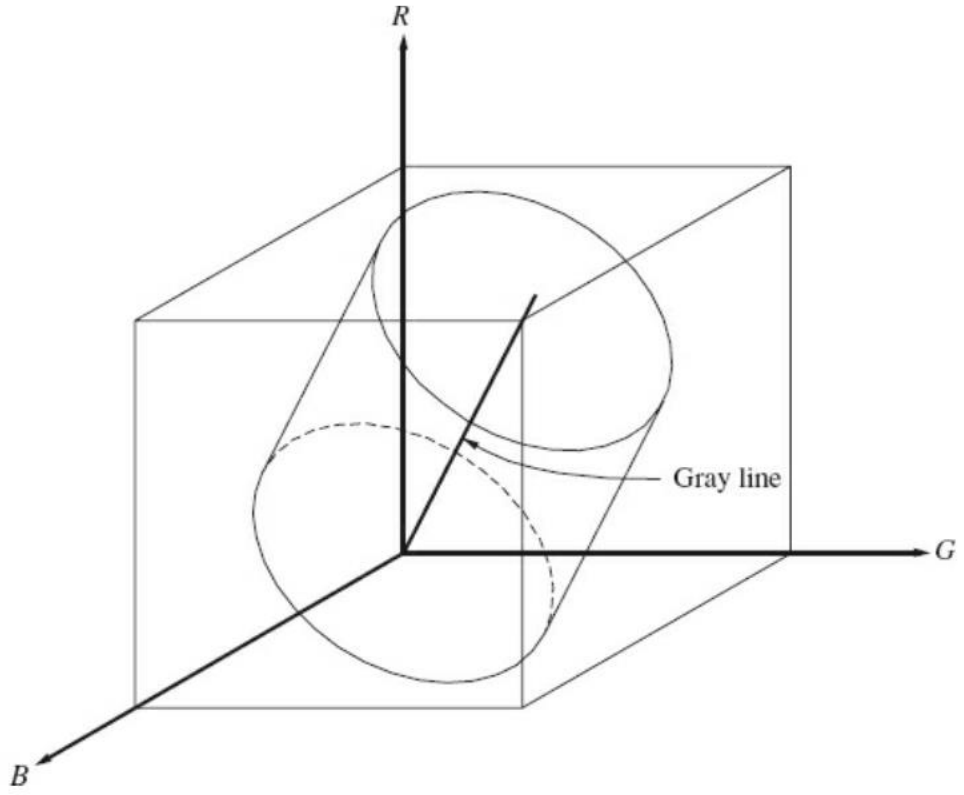


FIGURE 2-28 Position of gray line as axis of cylindrical intensity-hue-saturation system.

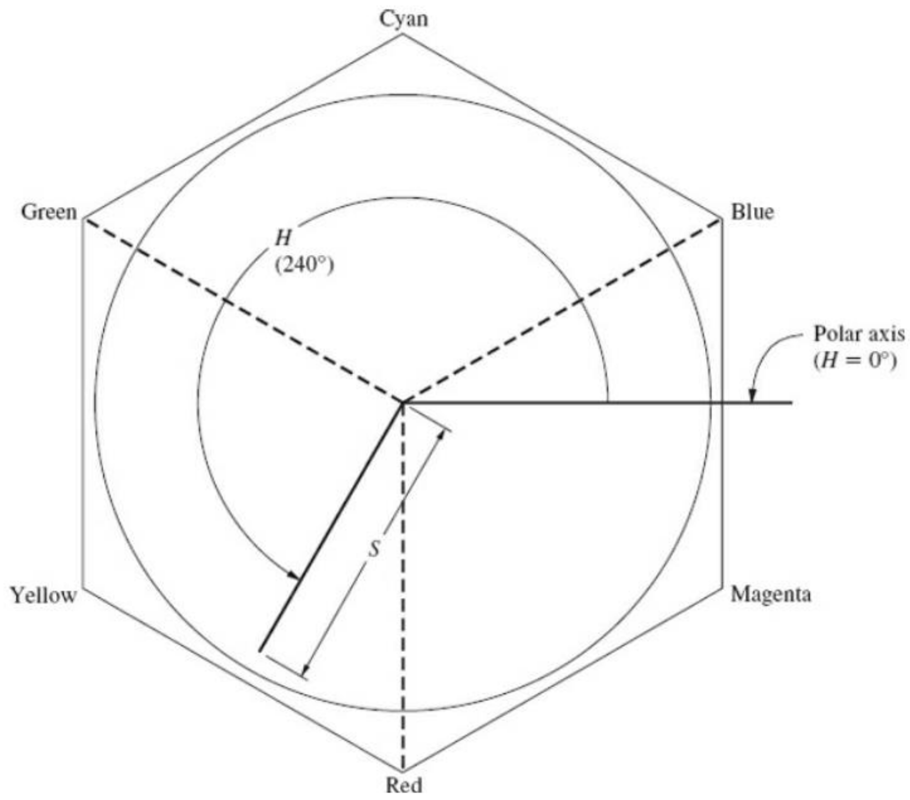


FIGURE 2-29 Representation of hue and saturation with respect to color values.

13. Color Images Representation

- RGB to HIS

$$X = \frac{B - G}{\sqrt{2}}, \qquad Y = \frac{B + G - 2R}{\sqrt{6}}$$

$$I = \frac{B+G+R}{\sqrt{3}} \ (0\sim255\sqrt{3}) \ , \quad H = \tan^{-1}\left(\frac{Y}{X}\right) \ (-\pi\sim\pi),$$

$$S = \sqrt{X^2 + Y^2} \ (0\sim255\sqrt{\frac{2}{3}})$$

- HIS to RGB

$$X = S\cos H, \qquad Y = S\sin H$$

$$B = \frac{X}{\sqrt{2}} + \frac{Y}{\sqrt{6}} + \frac{I}{\sqrt{3}}, \quad B = -\frac{X}{\sqrt{2}} + \frac{Y}{\sqrt{6}} + \frac{I}{\sqrt{3}}, \quad R = -\frac{2Y}{\sqrt{6}} + \frac{I}{\sqrt{3}}$$

14. Digital Image Display

- A computer display/TV produce colors by color-additive process while digital printing uses a color-subtractive process because certain colors are absorbed (subtracted).

- Intensity of a color can be expressed using patterning even though spatial resolution is somewhat lost.

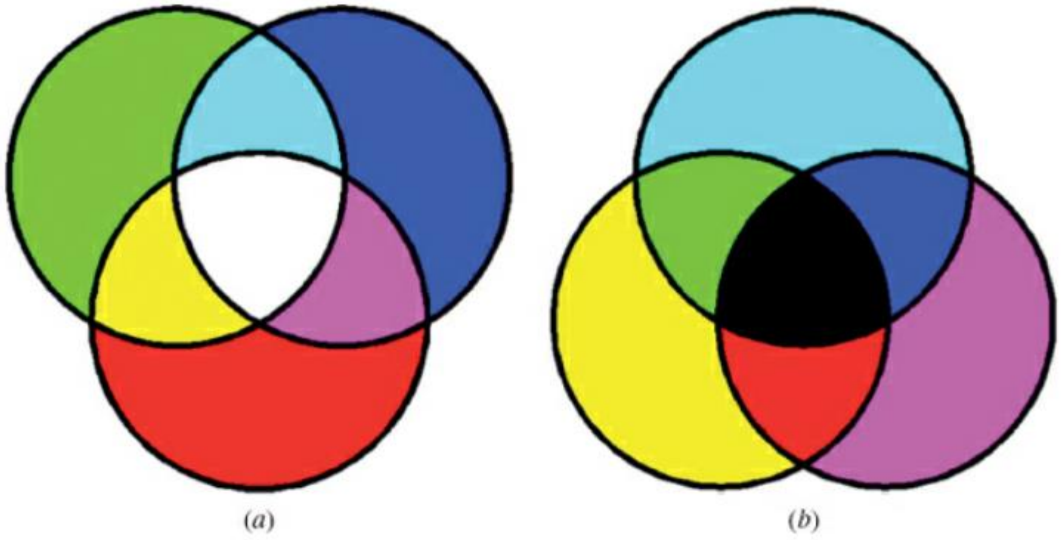


FIGURE 2-31 Illustration of the (*a*) color additive process and (*b*) color subtractive process.