Chapter 2.
Principles of Photography and Imaging

2-1. Introduction

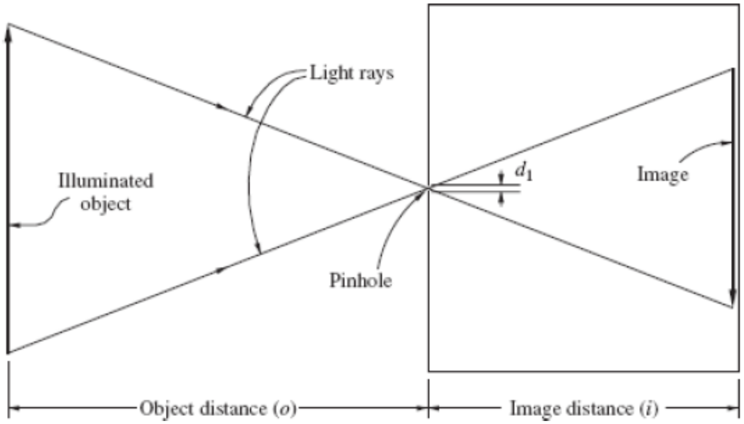

Figure 2-1. Principle of the pinhole camera

- ❖ The images were formed by light rays which passed through tiny holes in the tent
- ❖ The principle involved was actually that of the pinhole camera of the type shown in Fig. 2-1

- ❖ In the 1700s French artists used **the pinhole principle as an aid in drawing perspective views of illuminated objects** ⇨ While inside a dark box, they traced the outlines of objects projected onto the wall opposite a pinhole
- ❖ In 1839 Louis Daguerre of France developed **a photographic film which could capture a permanent record of images** that illuminated it ⇨ By placing this film inside a dark "pinhole box," a picture or photograph could be obtained without the help of an artist ⇨ This box used in conjunction with photographic film became known as a camera
- ❖ A more recent innovation in imaging technology is **the digital camera** which relies on electronic sensing devices rather than conventional film
  ⇨ The resulting image, called a *digital image*, is stored in computer memory

2-2. Fundamental Optics

❖ Understanding of some of the fundamental principles of optics is essential to the study of photography and imaging

The science of optics consists of two principal branches :

(1) physical optics

(2) geometric optics

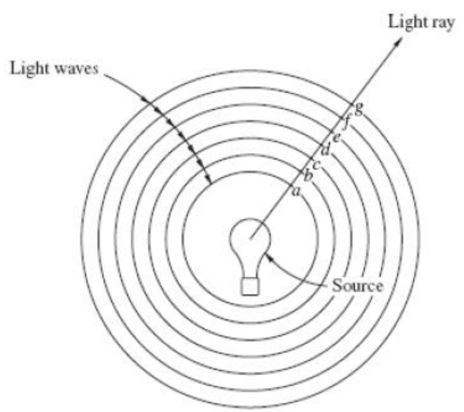

Figure 2-2. Light waves emanating from a point source in accordance with the concept of physical optics

1) physical optics

- Light is considered to travel through a transmitting medium such as air in a series of electromagnetic waves emanating from a point source
- Conceptually this can be visualized as a group of concentric circles expanding or *radiating* away from a light source, as illustrated in Fig. 2-2
- Each light wave has its own *frequency*, *amplitude*, and *wavelength*

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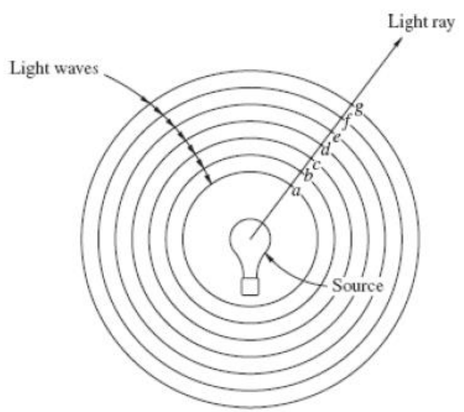

Figure 2-2. Light waves emanating from a point source in accordance with the concept of physical optics

1) physical optics

- Frequency is the number of waves that pass a given point in a unit of time
- Amplitude is the measure of the height of the crest or depth of the trough
- Wavelength is the distance between any wave and the next succeeding one

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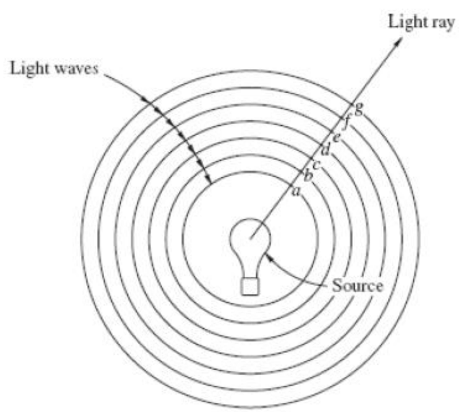

Figure 2-2. Light waves emanating from a point source in accordance with the concept of physical optics

1) physical optics

- The speed with which a wave moves from a light source is called its ***velocity***

$$V = f\lambda \qquad (2\text{-}1)$$

V is velocity, usually expressed in units of meters per second;
f is frequency, generally given in cycles per second, or *hertz*;
λ is wavelength, usually expressed in meters

- Light has an extremely high velocity, moving at the rate of 2.99792458 × 10 meters per second (m/s) in a vacuum

2-2. Fundamental Optics

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The science of optics consists of two principal branches :

(1) physical optics

(2) geometric optics

1) geometric optics

- Light is considered to travel from a point source through a transmitting medium in straight lines called *light rays*
- In Fig. 2-3, an infinite number of light rays radiate in all directions from any point source
- The entire group of radiating lines is called a *bundle of rays*

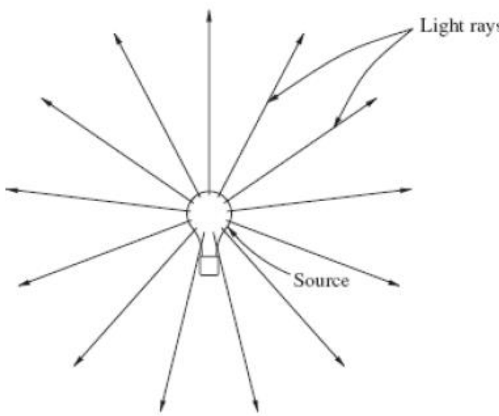

Figure 2-3. Bundle of rays emanating from a point source in accordance with the concept of geometric optics

2-2. Fundamental Optics

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(1) physical optics

(2) geometric optics

1) geometric optics

- This concept of radiating light rays develops logically from physical optics if one considers the travel path of any specific point on a light wave as it radiates away from the source
- In Fig. 2-2, for example, point a radiates to $b, c, d, e, f,$ etc. as it travels from the source, thus creating a light ray

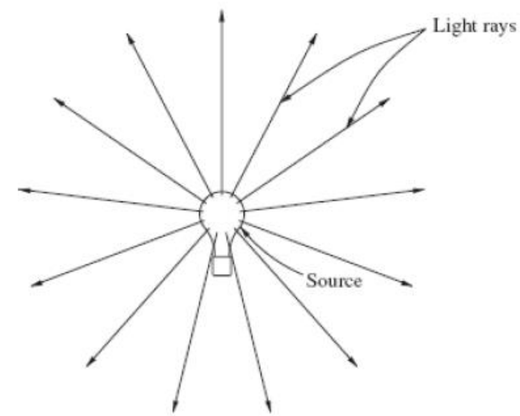

Figure 2-3. Bundle of rays emanating from a point source in accordance with the concept of geometric optics

- Light is considered to travel from a point source through a transmitting medium in straight lines called light rays

2-2. Fundamental Optics

- In analyzing and solving photogrammetric problems, rudimentary line diagrams are often necessary
  - basic knowledge of the behavior of light, and especially of geometric optics, is prerequisite to a thorough understanding of the science of photogrammetry

- When light passes from one transmitting material to another, it undergoes a change in velocity in accordance with the composition of the substances through which it travels

- Light achieves its maximum velocity traveling through a vacuum, it moves more slowly through air, and travels still more slowly through water and glass

- The rate at which light travels through any substance is represented by the refractive index of the material
  - The ratio of the speed of light in a vacuum to its speed through a substance

$$n = \frac{c}{V} \qquad (2\text{–}2)$$

2-2. Fundamental Optics

$$n = \frac{c}{V} \qquad (2-2)$$

- In Eq. (2-2), n is the **refractive index** of a material, c is the **velocity of light in a vacuum**, and V is its **velocity in the substance**
- The *refractive index* for any material, which depends upon the wavelength of the light, is <u>determined through experimental measurement</u>
- Typical values for indexes of refraction of common media

Media	Typical values for indexes of refraction
vacuum	1.0000
air	1.0003
water	1.33
glass	1.5 to 2.0

2-2. Fundamental Optics

❖ When light rays pass from one homogeneous, transparent medium to a second such medium having a different refractive index, the path of the light ray is bent or refracted, unless it intersects the second medium normal to the interface

❖ If the intersection occurs obliquely, as shown in Fig. 2-4, then the *angle of incidence*, ϕ, is related to the *angle of refraction*, ϕ', by the law of refraction, frequently called ***Snell's law***

$$n \sin\phi = n' \sin\phi' \qquad (2\text{−}3)$$

- n : the refractive index of the first medium
- n′: the refractive index of the second medium
- ϕ : measured from the normal to the incident
- ϕ' : measured from refracted rays

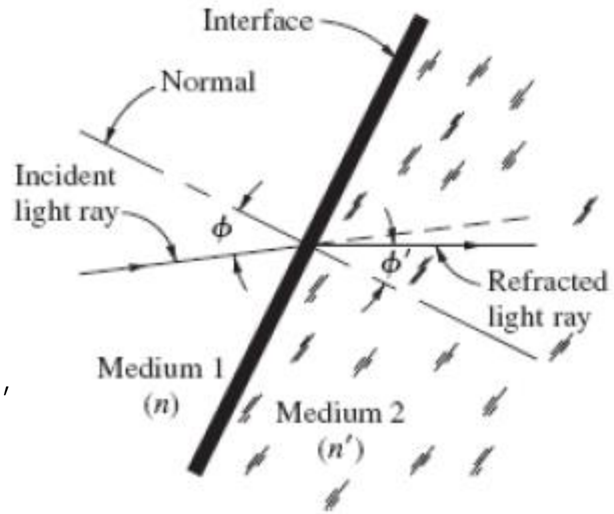

Figure 2−4. Refraction of light rays

2-2. Fundamental Optics

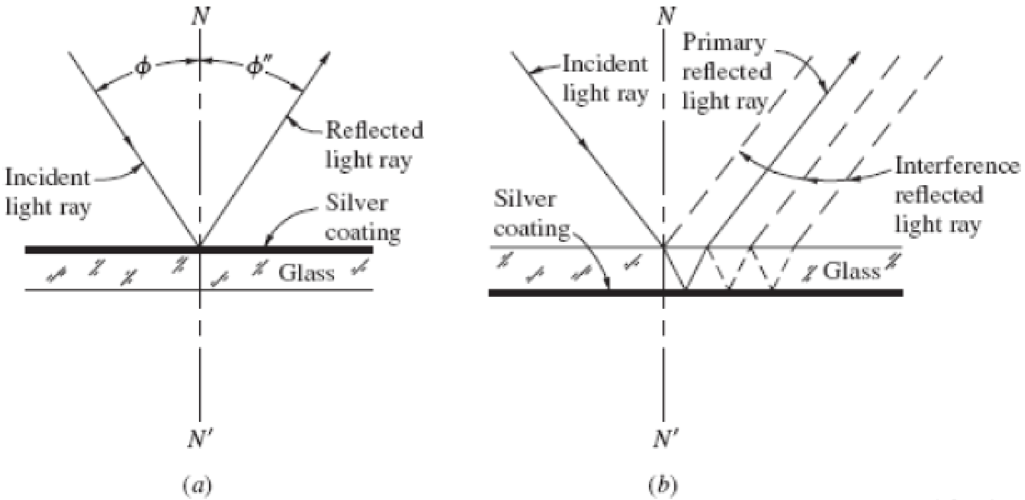

Figure 2–5. (a) First-surface mirror demonstrating the angle of incidence ϕ
and angle of reflection ϕ''; (b) back-surfaced mirror

❖ Light rays can also be made to change directions by reflection

❖ When a light ray strikes a smooth surface such as a highly polished metal mirror, it is reflected so that the *angle of reflection* ϕ'' is equal to the incidence angle ϕ, as shown in Fig 2-5a

❖ Both angles lie in a common plane and are measured from NN', the normal to the reflecting surface

❖ Plane mirrors used for nonscientific purposes generally consist of a plane sheet of glass with a thin reflective coating of silver on the back ⇨ This type of **"backsurfaced" mirror** is optically undesirable, however, because <u>it creates multiple reflections that interfere with the primary reflected light ray</u>, as shown in Fig. 2-5b

❖ These undesirable reflections may be avoided by using *first-surface* mirrors, which have their silver coating on the front of the glass, as shown in Fig. 2-5a

2-3. Lenses

Principles of refraction

- A simple lens consists of a piece of optical glass that has been ground so that it has either two spherical surfaces or one spherical surface and one flat surface ⇨ to gather light rays from object points and bring them to focus at some distance on the opposite side of the lens

❖ Tiny pinhole : most primitive device with function of lens

⇨ Theoretically allows a single light ray from each object point to pass

❖ The tiny hole of diameter d of the pinhole camera illustrated in Fig. 2-1 produces an inverted image of the object

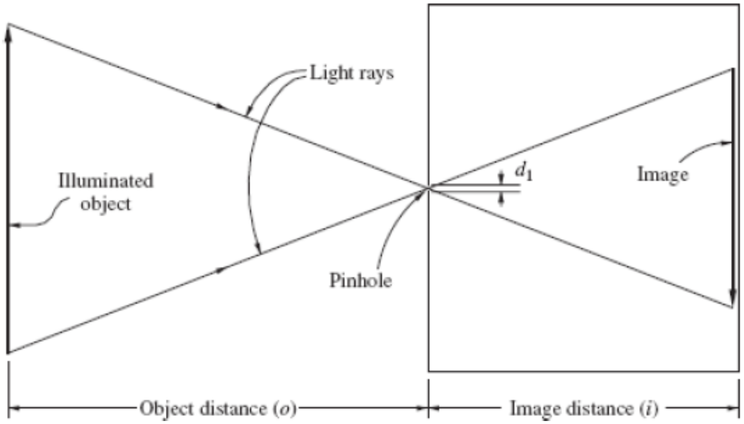

Figure 2-1. Principle of the pinhole camera

❖ Pinholes allow so little light to pass, however, that they are unsuitable for photogrammetric work

❖ For practical purposes they are replaced with larger openings occupied by glass lenses

2-3. Lenses

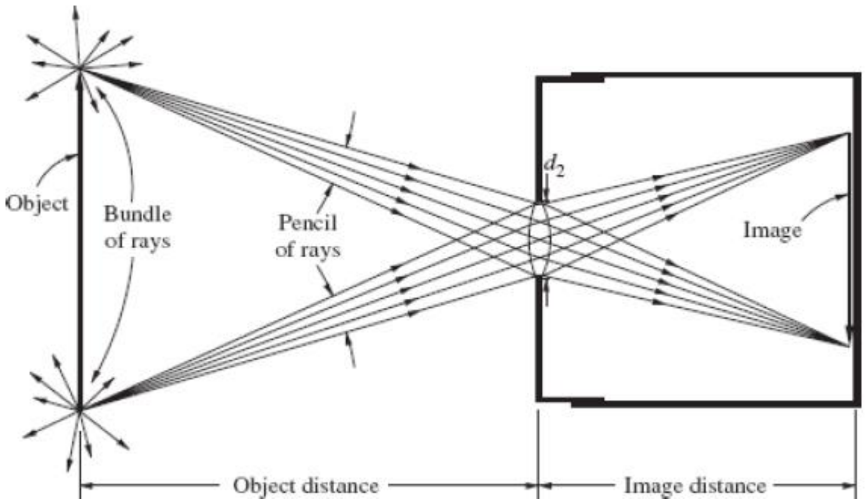

Figure 2–6. Pencils of light and image formation in
a single–lens camera

- The advantage of a lens over a pinhole is <u>the increased amount of light that is allowed to pass</u>
- A lens gathers an entire *pencil* of rays from each object point instead of only a single ray
- As shown in Fig.2-6., when an object is illuminated, each point in the object reflects a bundle of light rays
- A lens placed in front of the object gathers a pencil of light rays from each point's bundle of rays and brings these rays to focus at a point in a plane on the other side of the lens, called the image plane
- An infinite number of image points, focused in the image plane, form the image of the entire object.
- The image is inverted by the lens in Fig. 2-6.

2-3. Lenses

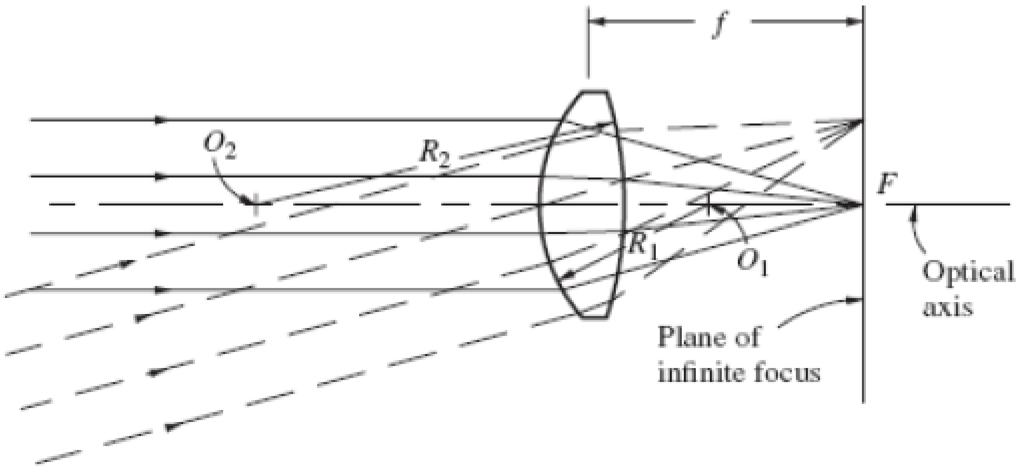

Figure 2-7. Optical axis, focal length, and plane of infinite focus of a lens

- The optical axis of a lens is defined as <u>the line joining the centers of curvature of the spherical surfaces of the lens</u> (points O_1 and O_2 of Fig. 2-7)
- R1 and R2 are the radii of the lens surfaces, and the optical axis is the line O_1O_2.
- Light rays that are parallel to the optical axis as they enter a lens come to focus at F, the focal point of the lens
- The distance from the focal point to the center of a lens is f, the focal length of the lens
- <u>A plane perpendicular to the optical axis passing through the focal point</u> is called the plane of infinite focus, or simply the *focal plane*
- Parallel rays entering a *converging lens* (one with two convex exterior surfaces, as shown in Fig. 2-7), regardless of the angle they make with the optical axis, are ideally brought to focus in the plane of infinite focus (see the dashed rays of the figure)

2-3. Lenses

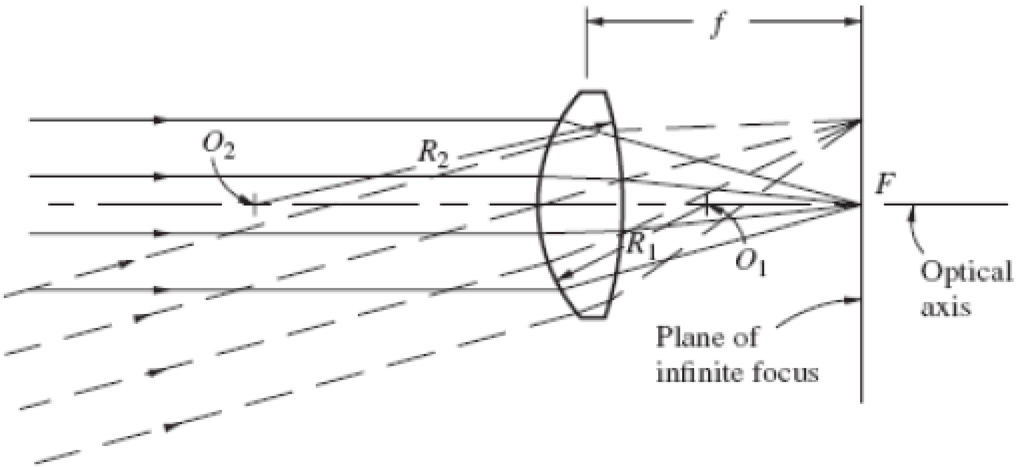

Figure 2-7. Optical axis, focal length, and plane of infinite focus of a lens

- A pencil of incident light rays coming from an object located an infinite distance away from the lens will be parallel, as illustrated in Fig. 2-7, and the image will come to focus in the plane of infinite focus

- For objects located some finite distance from the lens, the *image distance* (distance from lens center to image plane) is greater than the focal length

- *Lens formula*, expresses the relationship of object distance o and image distance i to the focal length f of a converging lens:

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f} \qquad (2\text{-}4)$$

- If the focal length of a lens and the distance to an object are known, the resulting distance to the image plane can be calculated by using the lens formula

2-3. Lenses

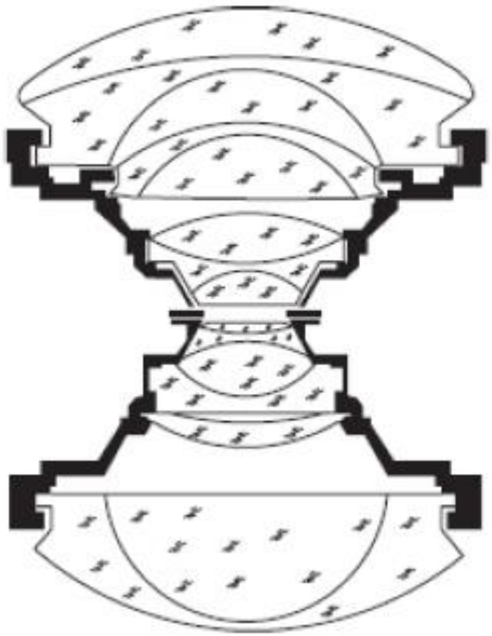

Figure 2-9. Cross section of SAGA-F lens. (Drawing from brochure courtesy of LH Systems, LLC.)

- The preceding analysis of lenses was simplified by assuming that their thicknesses were negligible
  - ⇨ With *thick lenses*, this assumption is no longer valid
- Thick lenses may consist of a single thick element or a combination of two or more elements which are either cemented together in contact or otherwise rigidly held in place with airspaces between the elements
- A thick "combination" lens used in an aerial camera is illustrated in Fig. 2-9
- *Nodal points*, termed the *incident* nodal point and the *emergent* nodal point, lie on the optical axis
- Any light ray directed toward the incident nodal point passes through the lens and emerges on the other side in a direction parallel to the original incident ray and directly away from the emergent nodal point

2-3. Lenses

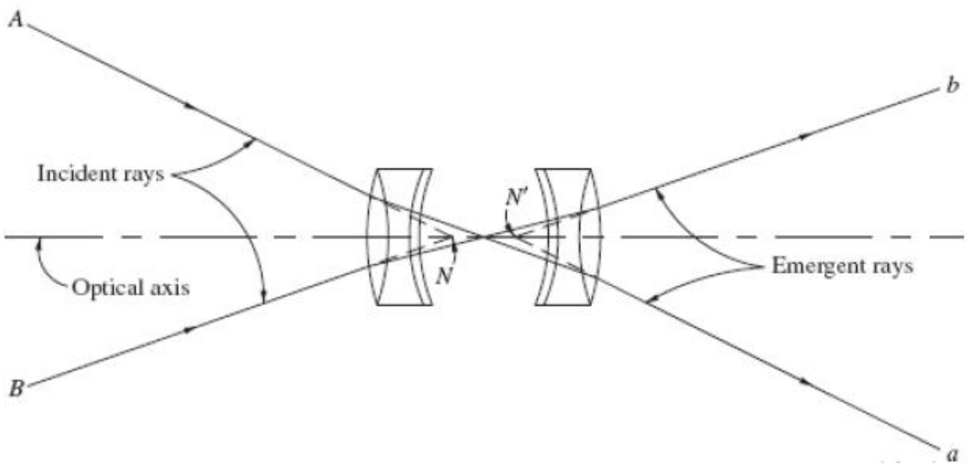

Figure 2-10. Nodal points of a thick lens

- ❖ In Fig. 2-10. rays AN and $N'a$ are parallel, as are rays BN and $N'b$. Points N and N' are the incident and emergent nodal points, respectively, of the thick lens
- ❖ Such light rays do not necessarily pass through the nodal points, as illustrated by the figure

- ❖ If parallel incident light rays (rays from an object at an infinite distance) pass through a thick lens, they will come to focus at the plane of infinite focus
- ❖ The focal length of a thick lens is the distance from the emergent nodal point N' to this plane of infinite focus
- ❖ It is impossible for a single lens to produce a perfect image; it will, instead, always be somewhat blurred and geometrically distorted
- ❖ The imperfections that cause blurring, or degrade the sharpness of the image, are termed *aberrations*

2-3. Lenses

- *Lens distortions*, on the other hand, do not degrade image quality but deteriorate the geometric quality (or positional accuracy) of the image
- Lens distortions are classified as either *symmetric radial* or *decentering*
  - Both occur if light rays are bent, or change directions, so that after they pass through the lens, they do not emerge parallel to their incoming directions
  - Symmetric radial distortion, as its name implies, causes imaged points to be distorted along radial lines from the optical axis
- Outward radial distortion is considered positive, and inward radial distortion is considered negative
  - Decentering distortion, which has both tangential and asymmetric radial components, causes an off-center distortion pattern
- *Resolution* or *resolving power* of a lens is the ability of the lens to show detail
- One common method of measuring lens resolution is to count the number of *line pairs* (black lines separated by white spaces of equal thickness) that can be clearly distinguished within a width of 1 millimeter (mm) in an image produced by the lens
- The *modulation transfer function* (MTF) is another way of specifying the resolution characteristics of a lens

2-3. Lenses

- Good resolution is important in photogrammetry because photo images must be sharp and clearly defined for precise measurements and accurate interpretative work
- The *depth of field* of a lens is <u>the range in object distance that can be accommodated by a lens without introducing significant image deterioration</u>
- For a given lens, depth of field can be increased by reducing the size of the lens opening (*aperture*)
- For aerial photography, depth of field is seldom of consequence, because variations in the object distance are generally a very small percentage of the total object distance
- For close-range photography, depth of field is often extremely critical
- The shorter the focal length of a lens, the greater its depth of field, and vice versa
  - If depth of field is critical, it can be somewhat accommodated either through the selection of an appropriate lens or by reducing aperture size
- *Vignetting* and *falloff* are lens characteristics which <u>cause resultant images to appear brighter in the center than around the edges</u>
- Compensation can be provided for these effects in the lens design itself, by use of an antivignetting filter in the camera, or through lighting adjustments in the printing process

2-4. Single-Lens Camera

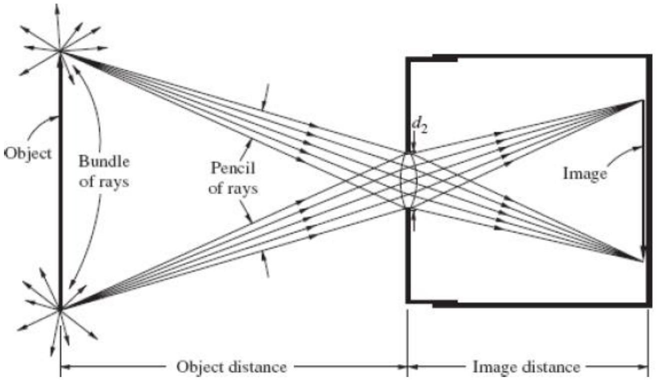

Figure 2-6. Pencils of light and image formation in a single-lens camera

- The geometry of the single-lens camera, depicted in Fig. 2-6, is similar to that of the pinhole camera
- In the single-lens camera, the size of the aperture (d_2 in Fig. 2-6) is much larger than a pinhole, requiring a lens in order to maintain focus

$$\frac{1}{o}+\frac{1}{i}=\frac{1}{f} \qquad (2\text{-}4)$$

- Instead of object distances and image distances being unrestricted as with the pinhole camera, with the lens camera these distances are governed by the lens formula, Eq. (2-4)
- To satisfy this equation, the lens camera must be focused for each different object distance by adjusting the image distance
- When object distances approach infinity, such as for photographing objects at great distances, the term $1/o$ in Eq. (2-4) approaches $zero$ and image distance i is then equal to f, the lens focal length
- With aerial photography, object distances are very great with respect to image distances; therefore aerial cameras are manufactured with their focus fixed for infinity
  - ⇨ It is accomplished by fixing image distance equal to the focal length of the camera lens

2-5. Illuminance

- **Illuminance** of any photographic exposure is the brightness or amount of light received per unit area on the image plane surface during exposure

- A common unit of illuminance is the *meter-candle*

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

- Illuminance is proportional to the amount of light passing through the lens opening during exposure, and this is proportional to the area of the opening

- Since the area of the lens opening is $\pi d^2/4$, illuminance is proportional to the variable d^2, the square of the diameter of the lens opening

2-5. Illuminance

- Image distance i is another factor which affects illuminance
- Illuminance is an effect that adheres to the ***inverse square law***, which means that <u>the amount of illuminance is inversely proportional to the square of distance from the aperture</u>
- According to this law, at the center of the photograph, illuminance is proportional to $1/i$
- As distances increase away from the center of the photograph, distances from the aperture likewise increase
  - ⇨ This causes decreased illuminance, an effect which can be quite severe for wide-angle lenses
  - ⇨ This is one aspect of the physical basis for lens falloff

$$\frac{1}{o}+\frac{1}{i}=\frac{1}{f} \qquad (2-4)$$

- Normally in photography, object distances are sufficiently long that the term $1/o$ in Eq. (2-4) is nearly zero, in which case i is equal to f

$$\sqrt{\frac{d^2}{f^2}}=\frac{d}{f}=\text{brightness factor} \qquad (2-5)$$

- At the center of a photograph, illuminance is proportional to the quantity $1/f^2$, and the two quantities may be combined so that illuminance is proportional to d^2/f^2
- The square root of this term is called the *brightness factor*

2-5. Illuminance

$$\sqrt{\frac{d^2}{f^2}} = \frac{d}{f} = \text{brightness factor} \quad (2\text{–}5)$$

- The inverse of Eq. (2-5) is also an inverse expression of illuminance and is the very common term *f-stop*, also called *f-number*

$$\text{f} - \text{stop} = \frac{f}{d} \quad (2\text{–}6)$$

- According to Eq. (2-6), *f*-stop is the ratio of focal length to the diameter of the lens opening, or *aperture*

- As the aperture increases, *f*-stop numbers decrease and illuminance increases, thus requiring less exposure time, i.e., faster shutter speeds
- Because of this correlation between *f*-stop and shutter speed, *f*-stop is the term used for expressing *lens speed* or the "light-gathering" power of a lens
- Illuminance produced by a particular lens is correctly expressed by Eq. (2-6), whether the lens has a very small diameter with short focal length or a very large diameter with a long focal length
- *f*-stop is the same for two different lenses, the illuminance at the center of each of their images will be the same

2-6. Relationship of Aperture and Shutter Speed

- *Total exposure* of photographic film is likewise the product of illuminance and time of exposure

- Its unit is *meter-candle-seconds*, although in certain applications a different unit, the *microlux-second* is used

- In making photographic exposures, the correct amounts of illuminance and time may be correlated using a *light meter*

- Illuminance is regulated by varying *f*-stop settings on the camera, while time of exposure is set by varying the shutter speed

- Variations in *f*-stop settings are actually variations in the diameter of the aperture, which can be controlled with a ***diaphragm***—*a* circular shield that enlarges or contracts, changing the diameter of the opening of the lens and thus regulating the amount of light that is allowed to pass through the lens

2-6. Relationship of Aperture and Shutter Speed

- With a lens camera, **as the diameter of the aperture increases**, enabling faster exposures, the depth of field becomes less and lens distortions become more severe

- At times a small diaphragm opening is desirable, and there are times when the reverse is true

- To photograph a scene with great variations in object distances and yet retain sharp focus of all images, a large depth of field is required

- In this case, to maximize depth of field, the picture would be taken at a slow shutter speed and large *f*-stop setting, corresponding to a small-diameter lens opening

- On the other hand, in photographing rapidly moving objects or in making exposures from a moving vehicle such as an airplane, a fast shutter speed is essential, to reduce image motion

- In this situation a small *f*-stop setting corresponding to a large-diameter lens opening would be necessary for sufficient exposure

2-6. Relationship of Aperture and Shutter Speed

Figure 2-11. Digital single-lens reflex camera having a minimum f-stop setting of f-2.8 and variable shutter speeds ranging down to 1/4000 S.
(Courtesy University of Florida)

Example

- minimum *f*-stop setting of f-2.8
- Varying shutter speeds down to 1/4000 second(s)
- An *f*-stop number 1, or *f*-1, occurs, according to Eq.(2-6), when the aperture diameter equals the lens focal length
- Let $d_1 = f$, where d_1 is the aperture diameter

  ⇨ $\frac{f}{d_1} = 1 = f - \text{stop}$

- At *f*-stop = 1, $\text{Aperture area} = A_1 = \frac{\pi(d_1)^2}{4}$
- If the aperture diameter is reduced to d_2 , giving a lens opening area of one-half of A_1

  ⇨ $A_2 = \frac{A_1}{2} = \frac{\pi(d_2)^2}{4} = \frac{\pi(d_1)^2}{2(4)}$

- From the above, $d_2 = d_1/\sqrt{2}$, and the corresponding *f*-stop number is

  ⇨ $f - \text{stop} = \frac{f\sqrt{2}}{d_1} = 1\sqrt{2} = 1.4$

2-6. Relationship of Aperture and Shutter Speed

- Many digital cameras have automatic controls that will set the *f*-stop and shutter speed for proper exposure
- In addition to **a manual mode**, they typically provide:

1) A fully automatic mode, where both *f*-stop and shutter speed are appropriately selected
2) An aperture priority mode, where the user inputs a fixed *f*-stop and the camera selects the appropriate shutter speed
3) A shutter priority mode, where the user inputs
4) A fixed shutter speed and the camera selects the appropriate *f*-stop

2-7. Characteristics of Photographic Emulsions

- Photographic films consist of two parts ⇨ *emulsion* and *backing* or *support*
- The **emulsion** contains light-sensitive silver halide crystals
- These are placed on the backing or support in a thin coat, as shown in Fig.2-12

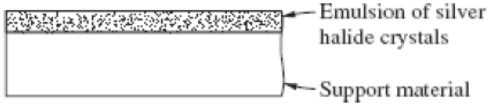

Figure 2–12. Cross section of a photographic film.

- The support material is usually paper, plastic film, or glass
- An emulsion that has been exposed to light contains an invisible image of the object, called the latent image
- When the latent image is developed, areas of the emulsion that were exposed to intense light turn to free silver and become black
- The degree of darkness of developed images is a function of the total exposure (product of illuminance and time) that originally sensitized the emulsion to form the latent image

2-7. Characteristics of Photographic Emulsions

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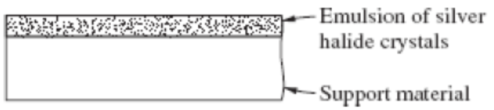

Figure 2-12. Cross section of a photographic film.

- The support material is usually paper, plastic film, or glass

- In any photographic exposure, there will be variations in illuminance received from different objects in the photographed scene, and therefore between black and white there will exist various tones of gray which result from these variations in illuminance
- The crystals turn black, not gray, when exposed to sufficient light
- The greater the exposure, the greater the percentage of black in the mixture and hence the darker the shade of gray

2-7. Characteristics of Photographic Emulsions

- The degree of darkness of a developed emulsion is called its *density*
- The **greater** the **density**, the **darker** the **emulsion**
- Density of a developed emulsion on a transparent film can be determined by subjecting the film to a light source, and then comparing the intensity of incident light upon the film to that which passes through (transmitted light)
- The density $D = \log\left(\frac{\text{incident intensity}}{\text{transmitted intensity}}\right)$
- Since the intensity response of a human eye is nonlinear, the baseten logarithm (log) is used so that density will be nearly proportional to perceived brightness
- A density value of zero corresponds to a completely transparent film, whereas a film that allows 1 percent of the incident light to pass through has a density of 2
- A density value of zero corresponds to a completely transparent film, whereas a film that allows 1 percent of the incident light to pass through has a density of 2
- The amount of light incident to an emulsion and the amount transmitted can be measured with an instrument called a *densitometer*

2-7. Characteristics of Photographic Emulsions

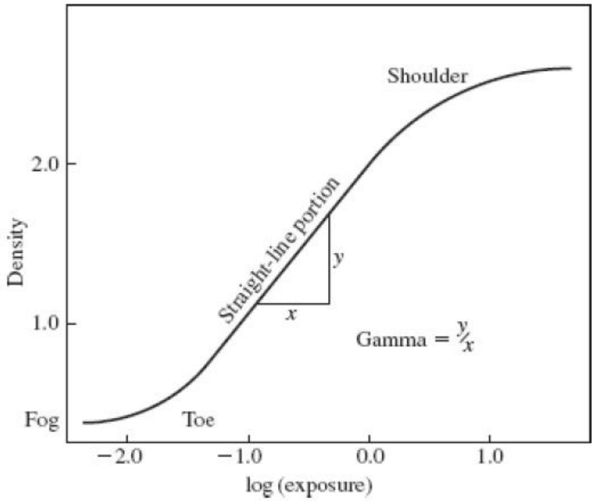

Figure 2−13. Typical "characteristic curve" of a photographic emulsion.

- A plot of density on the ordinate versus logarithm of exposure on the abscissa for a given emulsion produces a curve called the *characteristic curve*
  - ⇨ known as the *D-log E curve*, or the *H-and-D curve*
- A typical characteristic curve is shown in Fig. 2-13
- The lower part of the curve, which is concave upward, is known as the *toe* region
- The upper portion, which is concave downward, is the *shoulder* region
- A *straight-line* portion occurs between the toe and shoulder regions
- The slope of the straight-line portion of the curve is a measure of the contrast of the film
- The steeper the slope, the greater the *contrast* (change in density for a given range of exposure)
- Contrast of a given film is expressed as *gamma*, the slope of the straight-line portion of the curve, as shown on Fig. 2-13
- From the figure it is evident that for an exposure of zero the film has some density

2-7. Characteristics of Photographic Emulsions

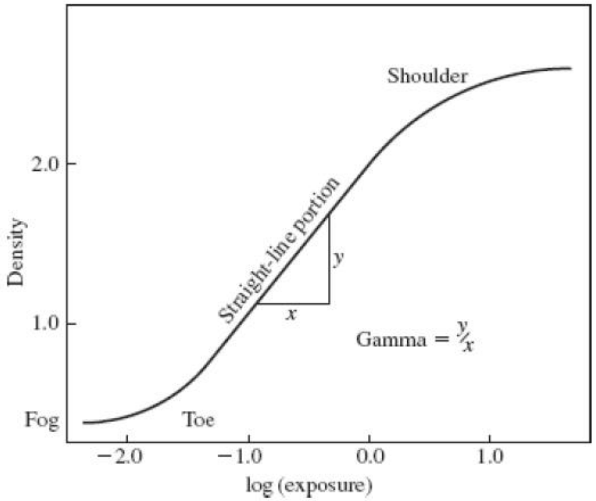

Figure 2–13. Typical "characteristic curve" of a photographic emulsion.

- A plot of density on the ordinate versus logarithm of exposure on the abscissa for a given emulsion produces a curve called the *characteristic curve*
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- The lower part of the curve, which is concave upward, is known as the *toe* region
- The upper portion, which is concave downward, is the *shoulder* region

- The density of an unexposed emulsion is called *fog*, and on the curve it is the density corresponding to the low portion of the toe region
- Exposures within the shoulder region affect the density very little
  ⇨ a properly exposed photograph is one in which the entire range of exposure occurs within the straight-line portion of the curve

2-7. Characteristics of Photographic Emulsions

- Light sensitivity of photographic emulsions is a function of the size and number of silver halide crystals or *grains* in the emulsion
- When the required amount of light exposes a grain in the emulsion, the entire grain becomes exposed regardless of its size
- If a certain emulsion is composed of grains smaller than those in another emulsion, such that approximately twice as many grains are required to cover the film, then this emulsion will also require about twice as much light to properly expose the *emulsion*
- Conversly, as grain size increases, the total number of grains in the emulsion decreases and the amount of light required to properly expose the emulsion decreases
- Film is said to be more sensitive and faster when it requires less light for proper exposure
- As sensitivity and grain size increase, the resulting image becomes coarse and *resolution* (sharpness or crispness of the picture) is reduced
- Film resolution can be tested by photographing a standard test pattern

2-7. Characteristics of Photographic Emulsions

- For films not used in aerial photography, the *International Standards Organization(ISO)* number is used to indicate film sensitivity or speed

- The ISO number assigned to a film is roughly equal to the inverse of shutter speed (in seconds) required for proper exposure in pure sunlight for a lens opening of *f*-16
  - ⇨ This rule of thumb, if a film is properly exposed in pure sunlight at *f*-16 and $\frac{1}{200}S$, it is classified ISO 200

- The sensitivity of films used in aerial photography is expressed as *aerial film speed* (AFS), which is different from, and should not be confused with, the ISO number

- Aerial film speed is determined by the point on the characteristic curve where density is 0.3 unit above the fog density

2-8. Processing and Printing Black-and-White Photographs

The five-step darkroom procedure for processing an exposed black-and-white emulsion

(1)Developing | (2)Stop bath | (3)Fixing | (4)Washing | (5)Drying

- The exposed emulsion is placed in a developer(chemical solution)
- It causes grains of silver halide that were exposed to light to be reduced to free black silver
- The free silver produces the blacks and shades of gray of which the image is composed
- Developers vary in strength and other characteristics and must therefore be carefully chosen to produce the desired results

2-8. Processing and Printing Black-and-White Photographs

The five-step darkroom procedure for processing an exposed black-and-white emulsion

(1)Developing | (2)Stop bath | (3)Fixing | (4)Washing | (5)Drying

- When proper darkness and contrast of the image have been attained in the developing stage, it is necessary to stop the developing action
- This is done with a stop bath—an acidic solution which neutralizes the basic developer solution

2-8. Processing and Printing Black-and-White Photographs

The five-step darkroom procedure for processing an exposed black-and-white emulsion

(1)Developing | (2)Stop bath | (3)Fixing | (4)Washing | (5)Drying

- Not all the silver halide grains are turned to free black silver as a result of developing
- Instead, there remain many undeveloped grains which would also turn black upon exposure to light if they were not removed
- To prevent further developing which would ruin the image, the undeveloped silver halide grains are dissolved out in the fixing solution

2-8. Processing and Printing Black-and-White Photographs

The five–step darkroom procedure for processing an exposed black–and–white emulsion

(1)Developing | (2)Stop bath | (3)Fixing | (4)Washing | (5)Drying

- The emulsion is washed in clean running water to remove any remaining chemicals
- If not removed, these chemicals could cause spotting or haziness of the image

2-8. Processing and Printing Black-and-White Photographs

The five-step darkroom procedure for processing an exposed black-and-white emulsion

(1)Developing | (2)Stop bath | (3)Fixing | (4)Washing | (5)Drying

- The emulsion is dried to remove the water from the emulsion and backing material

2-8. Processing and Printing Black-and-White Photographs

The five-step darkroom procedure for processing an exposed black-and-white emulsion

(1)Developing | (2)Stop bath | (3)Fixing | (4)Washing | (5)Drying

- The result obtained from developing black-and white film is a *negative*
  ⇨ it is reversed in tone and geometry from the original scene that was photographed
- A *positive* print is obtained by passing light through the negative onto another emulsion
- The configuration involved in this process may be either *contact* or *projection printing*
- In contact printing the emulsion side of a negative is placed in direct contact with the unexposed emulsion contained on printing material
- Together these are placed in a contact printer and exposed with the emulsion of the positive facing the light source

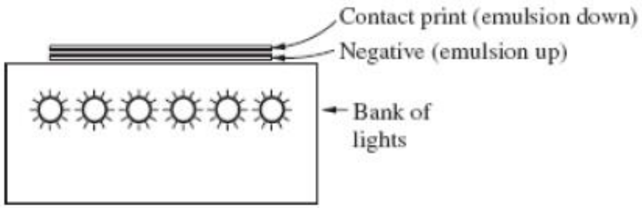

Figure 2-14. A contact printer.

- Figure 2-14 is a schematic of a single-frame contact printer
- In contact printing, the positive that is obtained is the same size as the negative from which it was made

2-8. Processing and Printing Black-and-White Photographs

- Uniform lighting across the negative during exposure of a positive print will underexpose the emulsion in darker areas of the negative and overexpose it in lighter areas
- Compensation for this can be made in a process called dodging
- If positives are desired at a scale either enlarged or reduced from the original negative size, a *projection printing process* can be used
- The geometry of projection printing is illustrated in Fig. 2-15

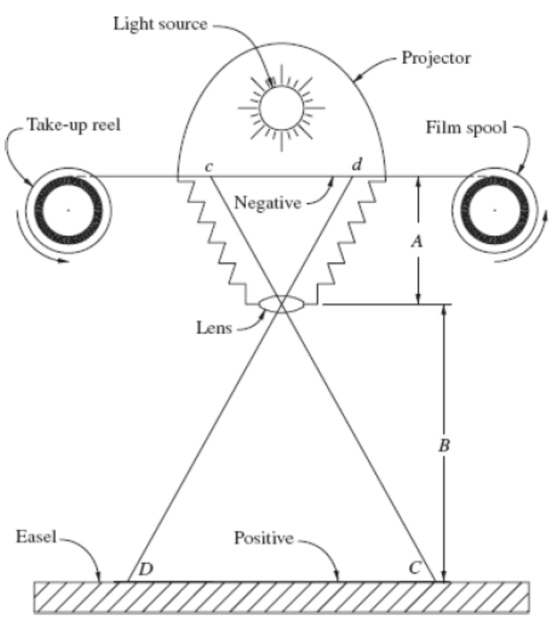

Figure 2-15. Geometry of enlargement with a projection printer.

- In this process, the negative is placed in the projector of the printer and illuminated from above
- Light rays carry images c and d, for example, from the negative, through the projector lens, and finally to their locations C and D on the positive, which is situated on the easel plane beneath the projector
  - The enlargement or reduction ratio from negative to positive size is equal to the ratio B/A

2-9. Spectral Sensitivity of Emulsions

- The sun and various artificial sources such as lightbulbs emit a wide range of *electromagnetic energy*
- The entire range of this electromagnetic energy is called the *electromagnetic spectrum*
- X-rays, visible light rays, and radio waves are some familiar examples of energy variations within the electromagnetic spectrum
- Electromagnetic energy travels in sinusoidal oscillations called *waves*

$$\boxed{c = f\lambda \quad (2\text{–}8)}$$

- The velocity of electromagnetic energy in a vacuum is constant and is related to frequency and wavelength through the Eq.2-8
- In Eq. (2-8), c is the velocity of electromagnetic energy in a vacuum, f is frequency, and λ is wavelength

2-9. Spectral Sensitivity of Emulsions

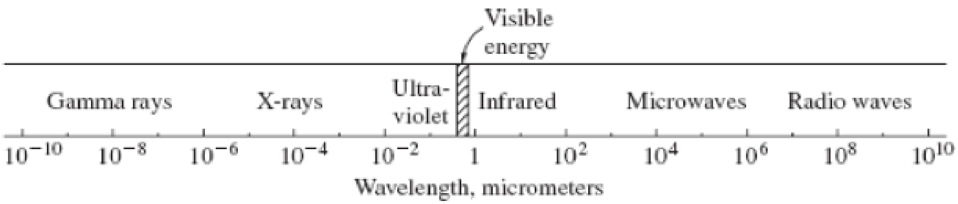

Figure 2–16. Classification of the electromagnetic spectrum by wavelength.

- Figure 2-16 illustrates the wavelength classification of the electromagnetic spectrum

- Visible light (that electromagnetic energy to which our eyes are sensitive) is composed of only a very small portion of the spectrum (see the figure)

- Energy having wavelengths slightly shorter than 0.4 μm is called ***ultraviolet***, and energy with wavelengths slightly longer than 0.7 μm is called ***near-infrared***
  - ➪ Ultraviolet and near-infrared cannot be detected by the human eye

- The primary colors—blue, green, and red—are composed of slightly different wavelengths
  - ➪ Blue is composed of energy having wavelengths of about 0.4 to 0.5 μm, green from 0.5 to 0.6 μm, and red from 0.6 to 0.7 μm

- To the human eye, other hues can be represented by combinations of the primary colors; e.g., yellow is perceived when red and green light are combined

- White light is the combination of all the visible colors

2-9. Spectral Sensitivity of Emulsions

- White light can be broken down into its component colors by passing it through a prism, as shown in Fig. 2-17
- Color separation occurs because of different refractions that occur with energy of different wavelengths
- To the human eye, an object appears a certain color because the object reflects energy of the wavelengths producing that color
- Just as the retina of the human eye is sensitive to variations in wavelength, photographic emulsions can also be manufactured with variations in wavelength sensitivity

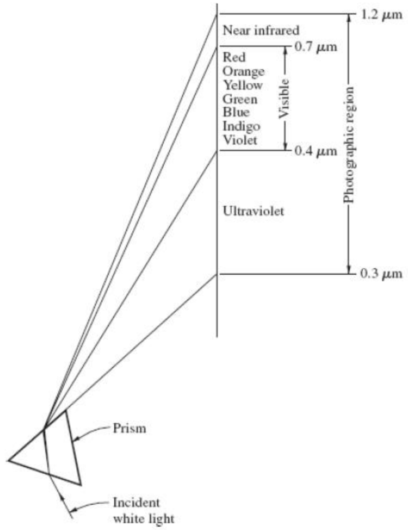

Figure 2-17. White light broken into the individual colors of the visible and near-visible spectrum by means of a prism. (Note that the range of wavelengths of transmitted light is non-linear.)

- Black-and-white emulsions composed of untreated silver halides are sensitive only to blue and ultraviolet energy
- The untreated emulsions are usually used on printing papers for making positives from negatives
- Red or yellow lights called safe lights can conveniently be used to illuminate the darkroom because these colors cannot expose a paper that is sensitive only to blue light

2-9. Spectral Sensitivity of Emulsions

- Emulsions sensitive to blue, green, and red are called *panchromatic*
- Emulsions can also be made to respond to energy in the near-infrared range
  ⇨ These emulsions are called *infrared*, or IR
- Infrared films make it possible to obtain photographs of energy that is invisible to the human eye - used for a variety of applications such as detection of crop stress, tree species mapping, etc.
- An early application of this type of emulsion was in camouflage detection, where it was found that dead foliage or green netting, which had the same green color as live foliage to the human eye, reflected infrared energy differently
- This difference could be detected through infrared photography

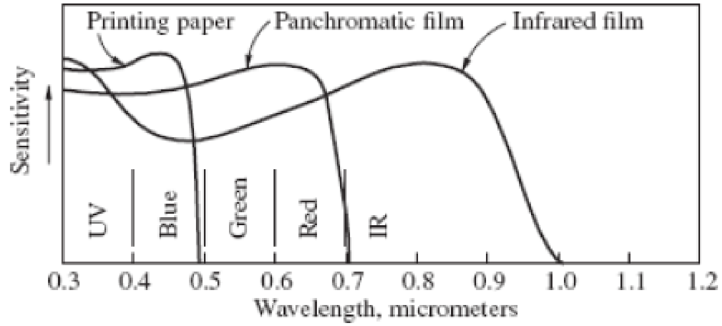

Figure 2-18. Typical sensitivities of various black-and-white emulsions.

- Figure 2-18 illustrates sensitivity differences of various emulsions

2-10. Filters

- Filters placed in front of camera lenses also allow only certain wavelengths of energy to pass through the lens and expose the film
- Atmospheric haze is largely caused by the scattering of ultraviolet and short blue wavelengths
- Pictures which are clear in spite of atmospheric haze can be taken through haze filters
- These filters block passage of objectionable scattered short wavelengths (which produce haze) and prevent them from entering the camera and exposing the film
  ⇨ Haze filters are almost always used on aerial cameras
- Filters for aerial mapping cameras are manufactured from high-quality optical glass
- In passing through the filter, light rays are subjected to distortions caused by the filter
  ⇨ The camera should therefore be calibrated, with the filter locked firmly in place
- After calibration, the filter should not be removed, for this would upset the calibration.

2-11. Color Film

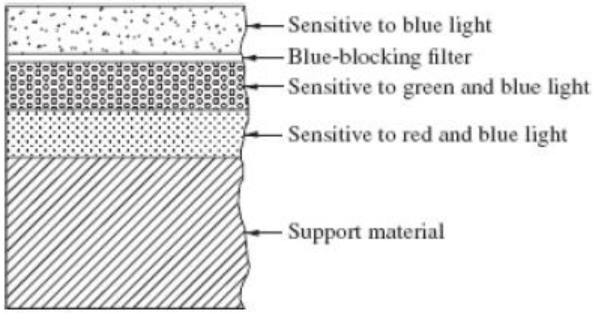

Figure 2–19. Cross section of normal color film.

- *Normal color* and *color infrared* emulsions are used for certain applications in photogrammetry
- Color emulsions consist of three layers of silver halides, as shown in Fig. 2-19
- The top layer is sensitive to blue light, the second layer is sensitive to green and blue light, and the bottom layer is sensitive to red and blue light
- A blue-blocking filter is built into the emulsion between the top two layers, thus preventing blue light from exposing the bottom two layers
- The result is three layers sensitive to blue, green, and red light, from top to bottom
- The sensitivity of each layer is indicated in Fig. 2-20
- In making a color exposure, light entering the camera sensitizes the layer(s) of the emulsion that correspond(s) to the color or combination of colors of the original scene

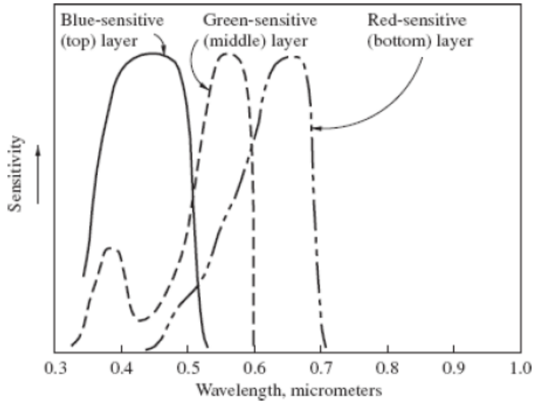

Figure 2-20. Typical color sensitivity of three layers of normal color film.

2-11. Color Film

- There are a variety of color films available, each requiring a slightly different developing process
- The remainder of the process depends on whether the film is *color negative* or *color reversal film*
- With **color negative film**, a negative is produced and color prints are made from the negative
- **Color reversal film** produces a true color transparency directly on the film
- During World War II there was great <u>interest in increasing the effectiveness of films in the infrared region of the spectrum</u>
  - ⇨ This interest led to the development of *color infrared* or *false-color film*

2-11. Color Film

Figure 2-21. (a) Normal color image and (b) color infrared image. Note that healthy vegetation, which appears green in the normal color image, appears red in the color infrared image. Circles tennis courts are painted green but appear gray in the color infrared image.

- The military called it *camouflage detection* film because it allowed photo interpreters to easily differentiate between camouflage and natural foliage
  - ⇨ Color Fig. 2-21a and b illustrate this effect

- Green tennis courts with brown backgrounds can be seen within the circles of Fig. 2-21a, a normal color image
- The color-infrared image of Fig. 2-21b depicts the same area, but uses various shades of red to represent reflected infrared energy
- The tennis courts in Fig. 2-21b now appear with a grayish color, not red like that of the surrounding vegetation

2-11. Color Film

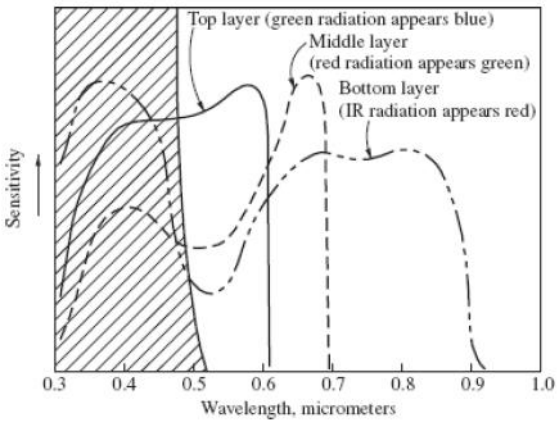

Figure 2-22. Typical sensitivity of color infrared (false-color) film.

- Figure 2-22 illustrates the sensitivity curves for each layer of color IR film
- The top layer is sensitive to ultraviolet, blue, and green energy
- The middle layer has its sensitivity peak in the red portion of the spectrum, but it, too, is sensitive to ultraviolet and blue light
- The bottom layer is sensitive to ultraviolet, blue, and infrared
- The shaded area of Fig. 2-22 illustrates the blocking effect of a yellow filter
- To view the exposure resulting from invisible IR energy, the IR sensitive layer must be represented by one of the three primary (visible) colors
- Objects that reflect red energy appear green, objects reflecting green energy appear blue
- It is this misrepresentation of color which accounts for the name *false color*

2-12. Digital Images

- A digital image is a computer-compatible pictorial rendition in which the image is divided into a fine grid of "picture elements," or *pixels*
- The image in fact consists of an array of integers, often referred to as digital numbers, each quantifying the *gray level*, or degree of darkness, at a particular element
- The image of the famous Statue of Liberty shown in Fig. 2-23a illustrates the principle
- This image has been divided into a pixel grid of 72 rows and 72 columns, with each pixel being represented by a value from 0 (dark black) to 255 (bright white)

(a)

(b)

190	237	234	223	227	220	219	231	115	2
237	227	223	228	229	237	229	219	190	1
231	227	223	227	229	219	196	216	217	96
229	218	220	219	160	120	164	183	127	136
219	218	219	213	214	210	113	2	54	127
217	213	223	227	223	222	199	54	70	128
219	217	207	196	183	187	207	149	74	126
217	216	210	218	217	203	145	70	73	127
207	223	227	203	145	127	200	136	75	80
227	219	218	223	219	190	115	70	71	74

(c)

Figure 2-23. Digital image of Statue of Liberty.

- A portion of the image near the mouth of the statue is shown enlarged in Figure 2-23b, and the digital numbers associated with this portion are listed in Fig. 2-23c
- Note the correspondence of low numbers to dark areas and high numbers to light areas
- Numbers in the range 0 to 255 can be accommodated by 1 byte, which consists of 8 binary digits, or bits.
- The entire image of Fig. 2-23a would require a total of 72×72=5184 bytes of computer storage

2-12. Digital Images

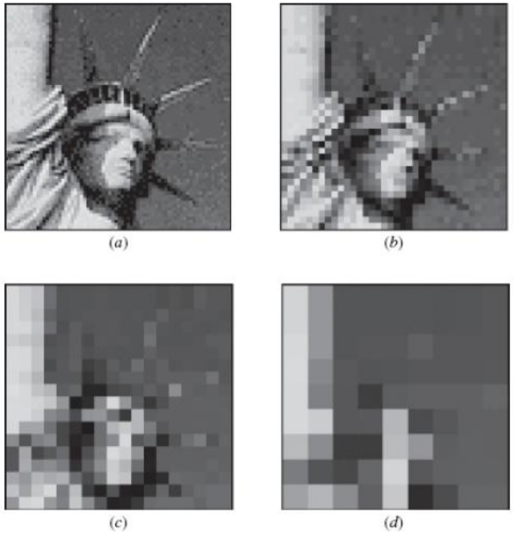

Figure 2-24. Digital image of Statue of Liberty at various spatial resolutions.

- Digital images are produced through a process referred to as *discrete sampling*
- In this process, a small image area (a pixel) is "sensed" to determine the amount of electromagnetic energy given off by the corresponding patch of surface on the object

- Discrete sampling of an image has two fundamental characteristics, *geometric resolution* and *radiometric resolution*
- Geometric (or spatial) resolution refers to the physical size of an individual pixel, with smaller pixel sizes corresponding to higher geometric resolution

2-12. Digital Images

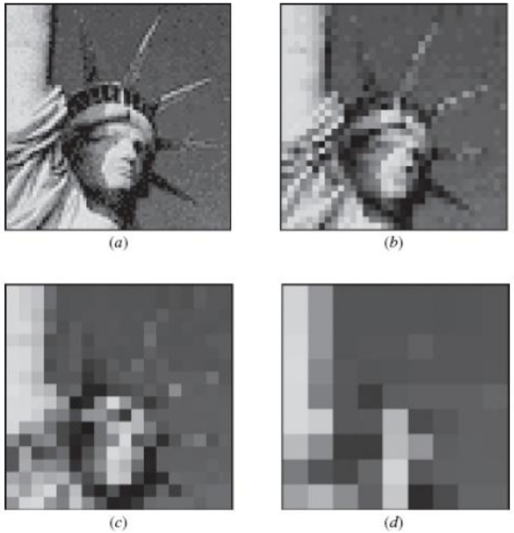

Figure 2-24. Digital image of Statue of Liberty at various spatial resolutions.

- Fig. 2-24 show the entire image of the Statue of Liberty and demonstrate the effect of different geometric resolutions on image clarity
- The original 72 × 72 pixel image of Fig. 2-24a and the half-resolution 36 × 36 image of Fig. 2-24b are readily discernible
- The 18 × 18 image of Fig. 2-24c is barely recognizable, and then only when the identity of the actual feature is known
- At the resolution of the 9 × 9 image of Fig. 2-24d, one sees a semiorganized collection of blocks bearing little resemblance to the original image, although the rough position of the face and the arm can be detected
- Obviously, geometric resolution is important for feature recognition in digital photographs

2-12. Digital Images

- Another fundamental characteristic of digital imagery is **radiometric resolution**, which can be further broken down into level of *quantization* and *spectral resolution*
- **Quantization** refers to the conversion of the amplitude of the original electromagnetic energy (analog signal) into a number of discrete levels (digital signal)
- Greater levels of quantization result in more accurate digital representations of the analog signal

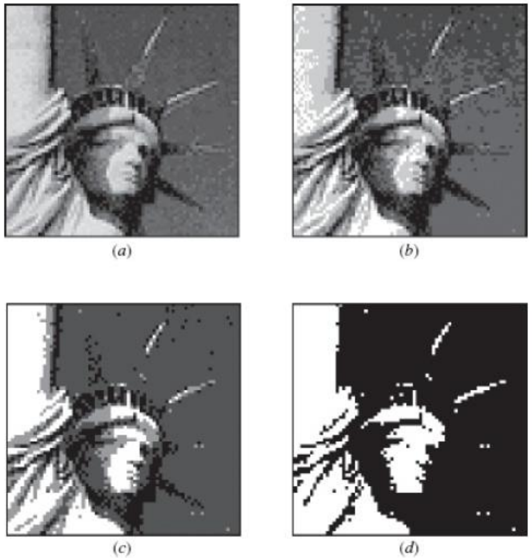

Figure 2-25. Digital image of Statue of Liberty at various quantization level.

- Figure 2-25 illustrates the effect of various levels of quantization for the statue image
- In this figure, part (a) shows the original image with 256 discrete quantization levels, while parts (b), (c), and (d) show 8, 4, and 2 levels, respectively
- Notice that in lower-level quantizations, large areas appear homogeneous and subtle tonal variations can no longer be detected

2-12. Digital Images

- Another fundamental characteristic of digital imagery is radiometric resolution, which can be further broken down into level of quantization and spectral resolution
- Quantization refers to the conversion of the amplitude of the original electromagnetic energy (analog signal) into a number of discrete levels (digital signal)
- Greater levels of quantization result in more accurate digital representations of the analog signal

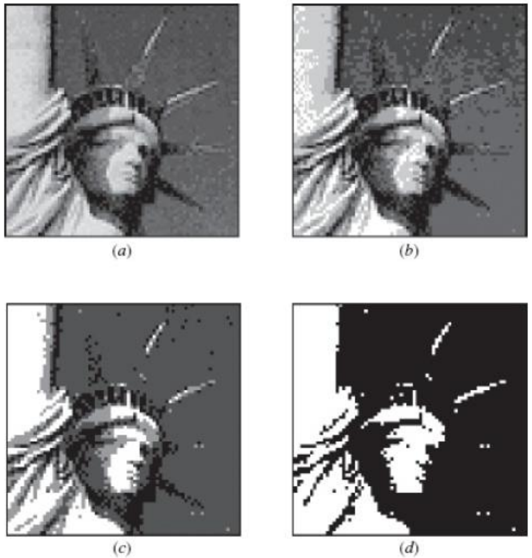

Figure 2-25. Digital image of Statue of Liberty at various quantization level.

- At the extreme is the 2-level quantization, which is also referred to as a binary image
- Quantization level has a direct impact on the amount of computer memory required to store the image
- The binary image requires only 1 bit of computer memory for each pixel ($2^1 = 2$), the 4-level image requires 2 bits ($2^2 = 4$), and the 8-level image requires 3 bits ($2^3 = 8$)

2-12. Digital Images

- Spectral resolution is another aspect of radiometric resolution
- The electromagnetic spectrum covers a continuous range of wavelengths
- In imaging, samples of electromagnetic energy are normally sensed only within narrow bands in the spectrum
- The spectral resolution of color film corresponds to three spectral bands or channels
- With a higher level of spectral resolution, a more accurate representation of an object's *spectral response pattern* can be made

2-13. Color Image Representation

- Highly accurate and precise portrayal of the analog signal in the digital realm is prohibitively expensive in terms of memory storage

- Color digital images generally utilize a simplification

- Digital images represent shades of color by varying the levels of brightness of the three primary colors or channels, individually

- The samples from these three channels form the digital representation of the original analog signal
  - This scheme is appropriately based on the theory that three types of cones (color-sensing components of the retina) in the human eye are likewise most sensitive to blue, green, and red energy

2-13. Color Image Representation

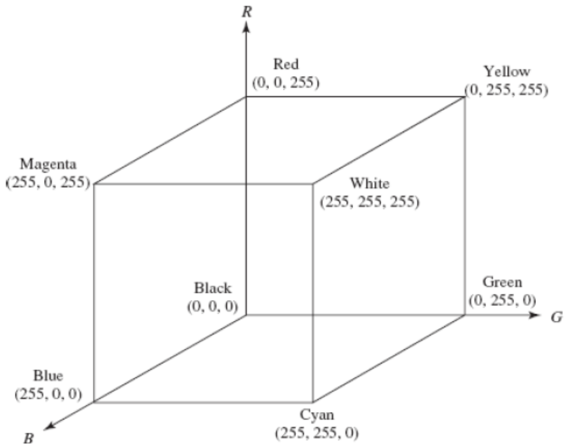

Figure 2–26. Blue–gren–red color cube.

- The color of any pixel can be represented by three-dimensional coordinates in what is known as BGR (or RGB) color space
- Assume for example that the digital number in each channel is quantified as an 8-bit value, which can range from 0 to 255

- The color of a pixel is thus represented by an ordered triplet consisting of a blue value, a green value, and a red value, each of which can range from 0 to 255
- This can be represented by the three-dimensional axis system shown in Fig. 2-26
- This figure shows the color cube, where a particular color has a unique set of B, G, R coordinates

2-13. Color Image Representation

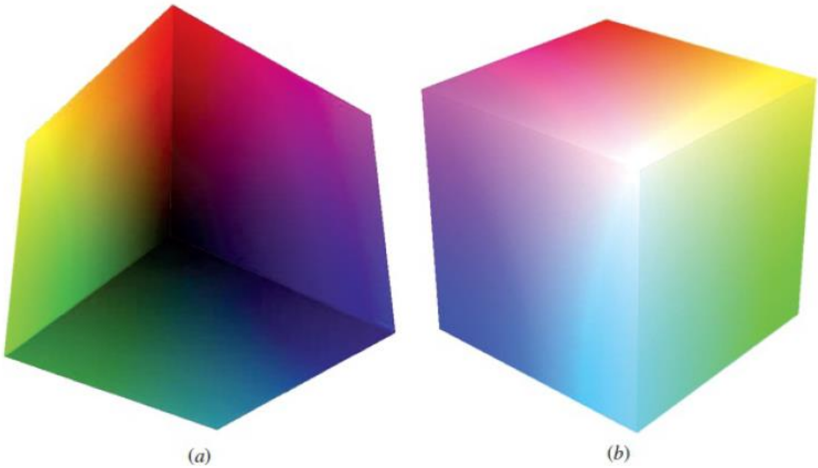

Figure 2-27. (a) A view of the color cube from behind the origin and (b) a view of the color cube from the opposite corner.

- Figure 2-27 is a color illustration of the color cube from (a) behind the origin and (b) from the opposite corner
- Note how the colors change from one region of the cube to another

- Even though a B,G,R position within the color cube is adequate to specify any given color, this scheme does not lend itself to convenient human interpretation
- The *intensity-hue-saturation (IHS)* system, on the other hand, is more readily understood by humans
  - ⇨ This system can be defined as a set of cylindrical coordinates in which the height, angle, and radius represent intensity, hue, and saturation, respectively

2-13. Color Image Representation

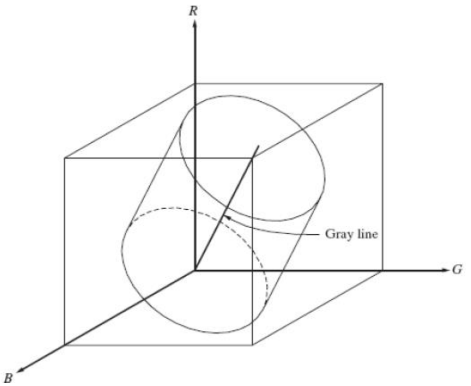

Figure 2–28. Position of gray line as axis of cylindrical intensity–hue–saturation system.

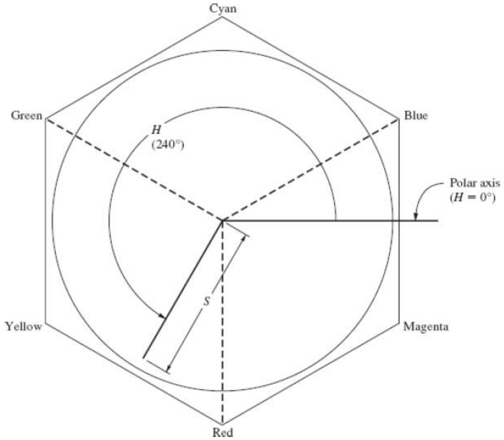

Figure 2–29. Representation of hue and saturation with respect to color values.

- The axis of the cylinder is the *gray line* which extends from the origin of the color cube to the opposite corner where the levels of blue, green, and red are maximum, as shown in Fig. 2-28
- For any particular color, intensity represents overall brightness irrespective of color, hue represents the specific mixture of wavelengths that define the color, and saturation represents the boldness of the color
- The representations of hue and saturation are illustrated in Fig. 2-29, which is a two-dimensional view showing the projection of the color cube and base of the cylinder as viewed along the gray line toward the origin
- Hue and saturation appear as a set of polar coordinates with the direction of the 0° hue axis being arbitrarily chosen as halfway between blue and magenta

2-13. Color Image Representation

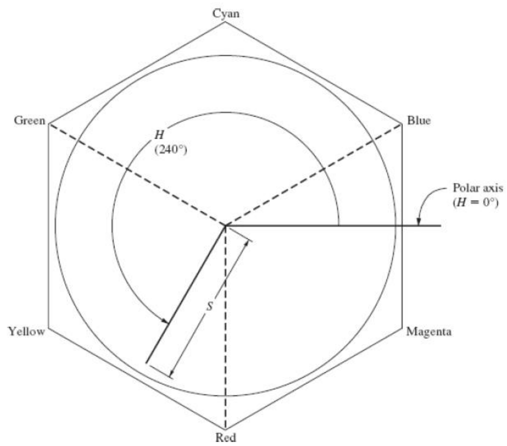

Figure 2-29. Representation of hue and saturation with respect to color values.

Figure 2-30. Representation of hue and saturation corresponding to Fig. 2-29.

- Figure 2-30 is a color image that shows the color cube in a position corresponding to Fig. 2-29. This figure allows a visual interpretation of the effects of hue and saturation

- Conversion from the system of *B, G, R* coordinates to *I, H, S* is accomplished by starting with the intensity (cylinder) axis lined up with the red axis and then rotating so the intensity axis lines up with the gray line

- Then the standard cartesian-to-cylindrical coordinate conversion is applied

2-13. Color Image Representation

$$X = \frac{B - G}{\sqrt{2}} \quad \text{(2-8)}$$

$$Y = \frac{B + G - 2R}{\sqrt{6}} \quad \text{(2-9)}$$

$$I = \frac{B + G + R}{\sqrt{3}} \quad \text{(2-10)}$$

$$H = \tan^{-1}\left(\frac{Y}{X}\right) \quad \text{(2-11)}$$

$$S = \sqrt{X^2 + Y^2} \quad \text{(2-12)}$$

$$X = S \cos H \quad \text{(2-13)}$$

$$Y = S \sin H \quad \text{(2-14)}$$

$$B = \frac{X}{\sqrt{2}} + \frac{Y}{\sqrt{6}} + \frac{I}{\sqrt{3}} \quad \text{(2-15)}$$

$$G = -\frac{X}{\sqrt{2}} + \frac{Y}{\sqrt{6}} + \frac{I}{\sqrt{3}} \quad \text{(2-16)}$$

$$R = -\frac{2Y}{\sqrt{6}} + \frac{I}{\sqrt{3}} \quad \text{(2-17)}$$

- To convert from *B, G, R* to *I, H, S*, first compute two intermediate variables X and Y by Eqs. (2-8) and (2-9)
- Then intensity, hue, and saturation can be computed by Eqs. (2-10), (2-11), and (2-12)
- In order for the full range of hues to be accommodated, the full-circle inverse tangent function (e.g., ATAN2 in many programming languages or spreadsheets) must be used in Eq. (2-11)
- To convert back from *I, H, S* to *B, G, R* intermediate values of *X* and *Y* are computed by Eqs. (2-13) and (2-14)
- Then **blue, green, and red** can be computed by Eqs. (2-15), (2-16), and (2-17)

2-13. Color Image Representation

$$X = \frac{B - G}{\sqrt{2}} \quad \text{(2-8)}$$

$$Y = \frac{B + G - 2R}{\sqrt{6}} \quad \text{(2-9)}$$

$$I = \frac{B + G + R}{\sqrt{3}} \quad \text{(2-10)}$$

$$H = \tan^{-1}\left(\frac{Y}{X}\right) \quad \text{(2-11)}$$

$$S = \sqrt{X^2 + Y^2} \quad \text{(2-12)}$$

$$X = S \cos H \quad \text{(2-13)}$$

$$Y = S \sin H \quad \text{(2-14)}$$

$$B = \frac{X}{\sqrt{2}} + \frac{Y}{\sqrt{6}} + \frac{I}{\sqrt{3}} \quad \text{(2-15)}$$

$$G = -\frac{X}{\sqrt{2}} + \frac{Y}{\sqrt{6}} + \frac{I}{\sqrt{3}} \quad \text{(2-16)}$$

$$R = -\frac{2Y}{\sqrt{6}} + \frac{I}{\sqrt{3}} \quad \text{(2-17)}$$

- When conversion is done from *B, G, R* to *I, H, S* the resulting value of intensity can range from 0 to $255\sqrt{3}$, hue can range from $-\pi$ to $+\pi$, and saturation can range from 0 to $255\sqrt{\frac{2}{3}}$ (assuming the ranges for the *B, G, R* coordinates were each 0 to 255)
- Since it is often desirable to store the *I, H, S* values as 1-byte integers, they may have to be rescaled to the 0-to-255 range
- When these values are rescaled, the conversion process may no longer be perfectly reversible due to loss of precision

2-14. Digital Image Display

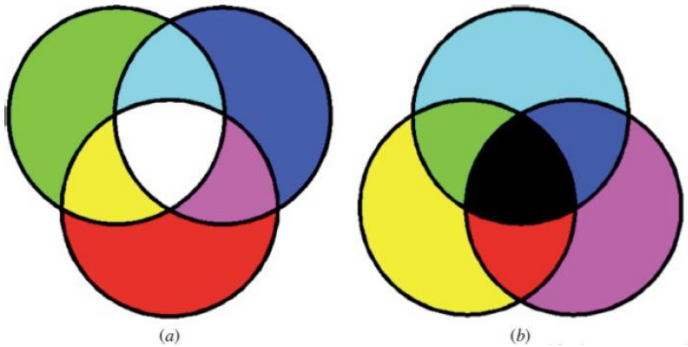

Figure 2–31. Illustration of the (a) color additive process and (b) color subtractive process.

- The *B, G, R* system discussed in the preceding section is an example of a ***color-additive*** process
- The **color-additive process** is used to produce images on typical TV or computer displays
- Digital printing is a color-subtractive process because certain colors are absorbed (subtracted) from the ambient white light

- Figure 2-31a illustrates the mixing of colors in a color additive process
  - The three circles represent active light sources of red, green, and blue light
  - The regions of intersection show the resulting colors that occur when the light sources are combined

- Figure 2-31b illustrates the mixing of colors in a *color subtractive* process
  - The three circles represent pigments or inks having the colors of cyan, magenta, and yellow

- The regions of intersection show the resulting colors that occur when the pigments or inks are combined

2-14. Digital Image Display

- For the display of a digital color image on TV or computer monitor, the area within each pixel emits light of various intensities for each of the primary colors (red, green, and blue), which mix to produce the appropriate color.

- Printing of color images uses the process of color subtraction, but it is more complicated because the intensity of pigment or ink cannot be easily controlled

- The *complementary* colors of yellow, magenta, and cyan are used instead of the primary colors of blue, green, and red.

- By varying the spatial density of the ink dots, the amounts of blue, green, and red energy being absorbed will likewise vary, allowing the full range of colors to be produced

- Generally, black ink is incorporated into the scheme, which allows darker grays and black to be produced.