Ex. 6.2

- Calculate the luminance of a light-emitting surface
  - (a) A-19 standard, 100W incandescent light bulb with a maintained output of 1700 lm.
    - Assume that the bulb is spherical.
    - Assume that the bulb is a Lambertian surface.
    - Luminance=intensity/projected area.

(b) an opal glass globe of 8-in diameter and a transmittance of 35% surrounds the above bulb.

Ex. 6.3

- Calculate the luminance of a 34W, T12, 4ft fluorescent lamp. Assume that the lamp is a diffuse (Lambertian) emitter.
  - Given: 2770 lm, diameter: (12/8)" = 1.5" =3.8cm

Ex. 6.4 (from 12^{th} Ed.)

- Assume a uniform illuminance of 500 lux, a diffuse reflectance of 0.77. Calculate the luminance of the surface.

Transmittance and reflectance

- (Luminous) Transmittance, transmission factor, coeff. of transmission = the ratio of the total transmitted light to the total incident light
  - Clear glass: τ = 0.8-0.9
  - Frosted glass: τ = 0.7-0.85
  - Solid opal glass: τ = 0.1-0.4
- (Luminous) reflectance, reflectance factor, reflectance coeff. = the ratio of the total reflected light to the total incident light
- Transmittance + reflectance + absorptance = 1.0
  - Perfect reflection: well-silvered mirror
  - Perfect absorption: an object covered with lamp black or matte-finish (무광택) black paint

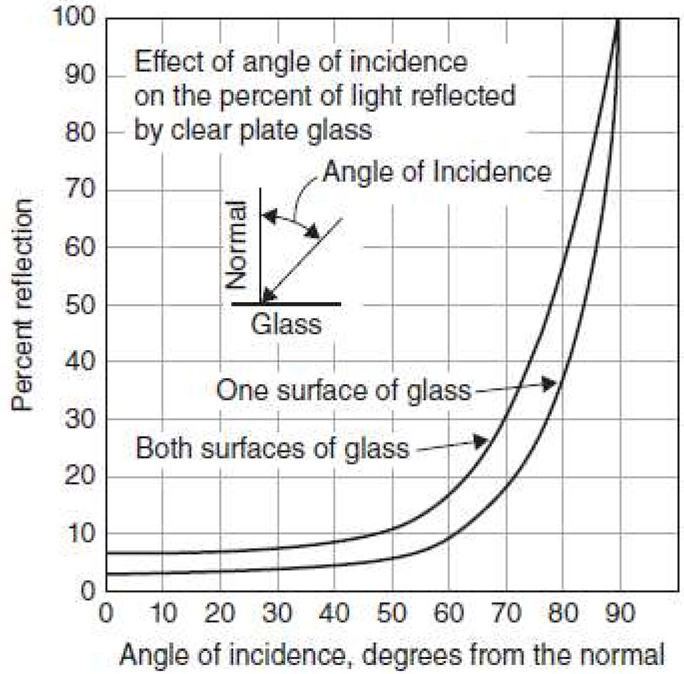


Fig. 6.5 Relation between angle of incidence and percentage of reflectance. This effect is important when considering the penetration of sunlight into interior spaces and, conversely, the exterior glare produced by reflection of the sun from building windows.

Frosted

Solid opal

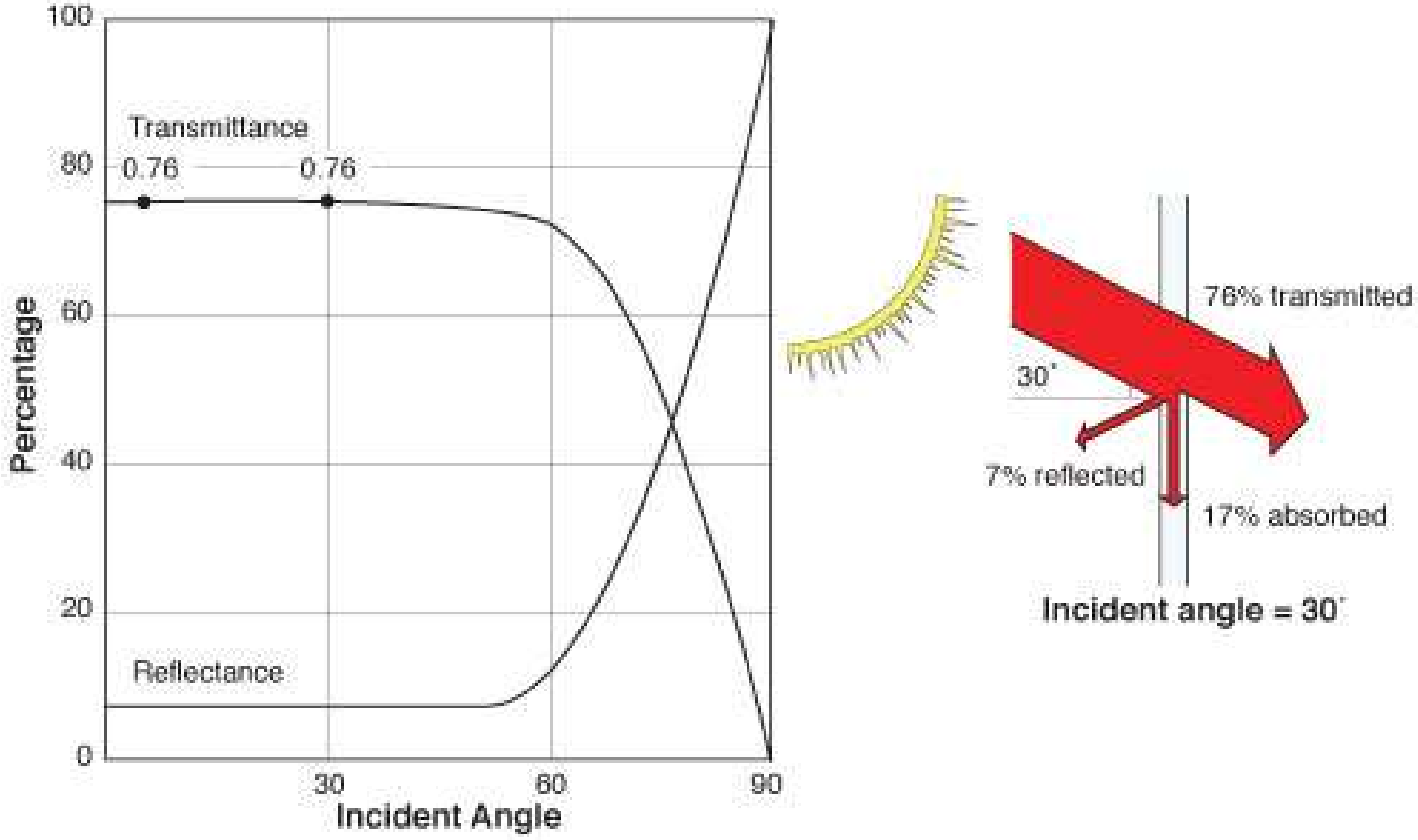
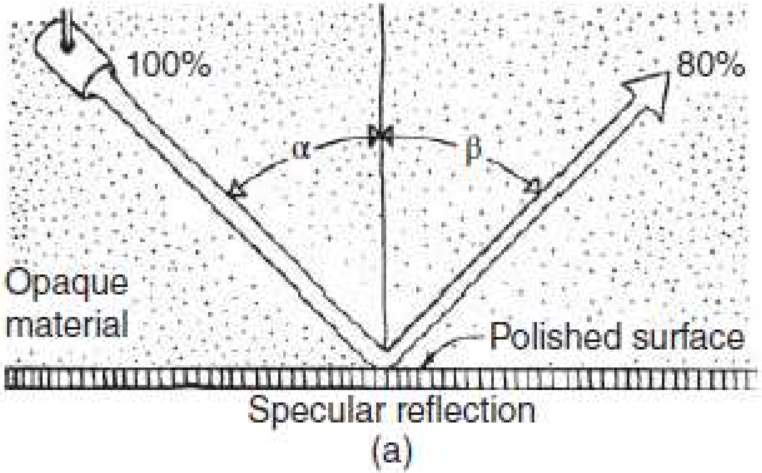
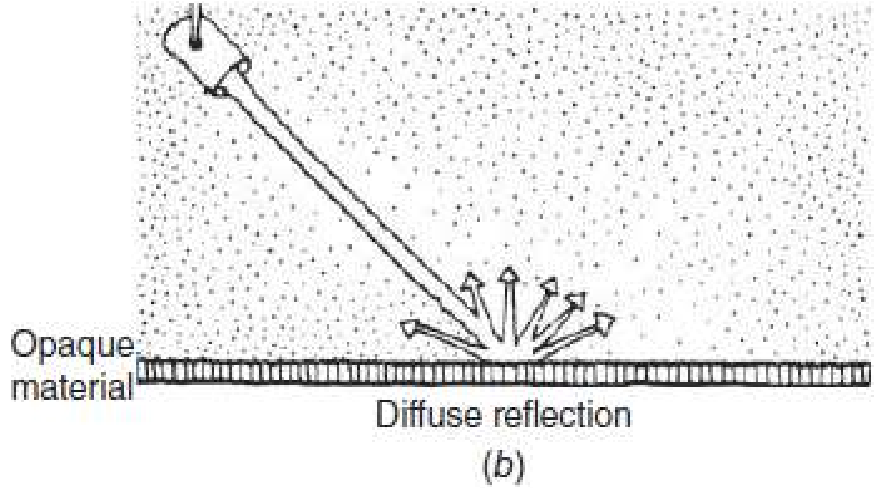


Image source: https://www.commercialwindows.org/transmittance.php

Specular vs. diffuse





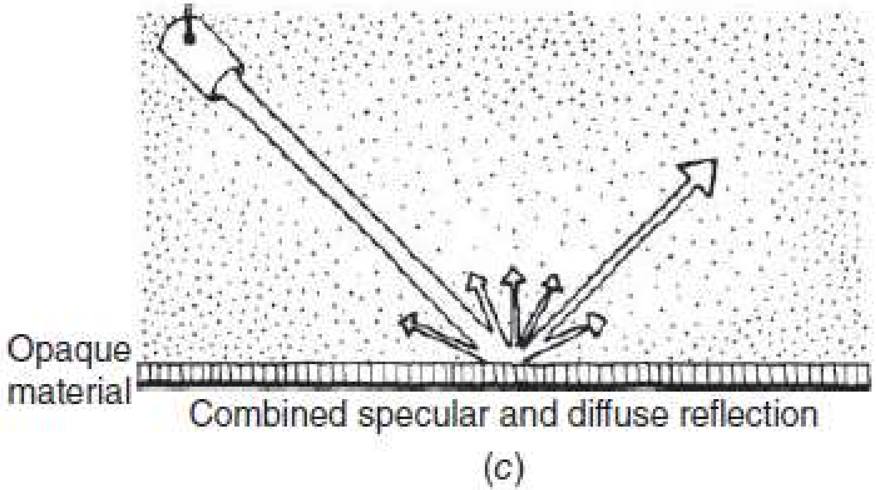
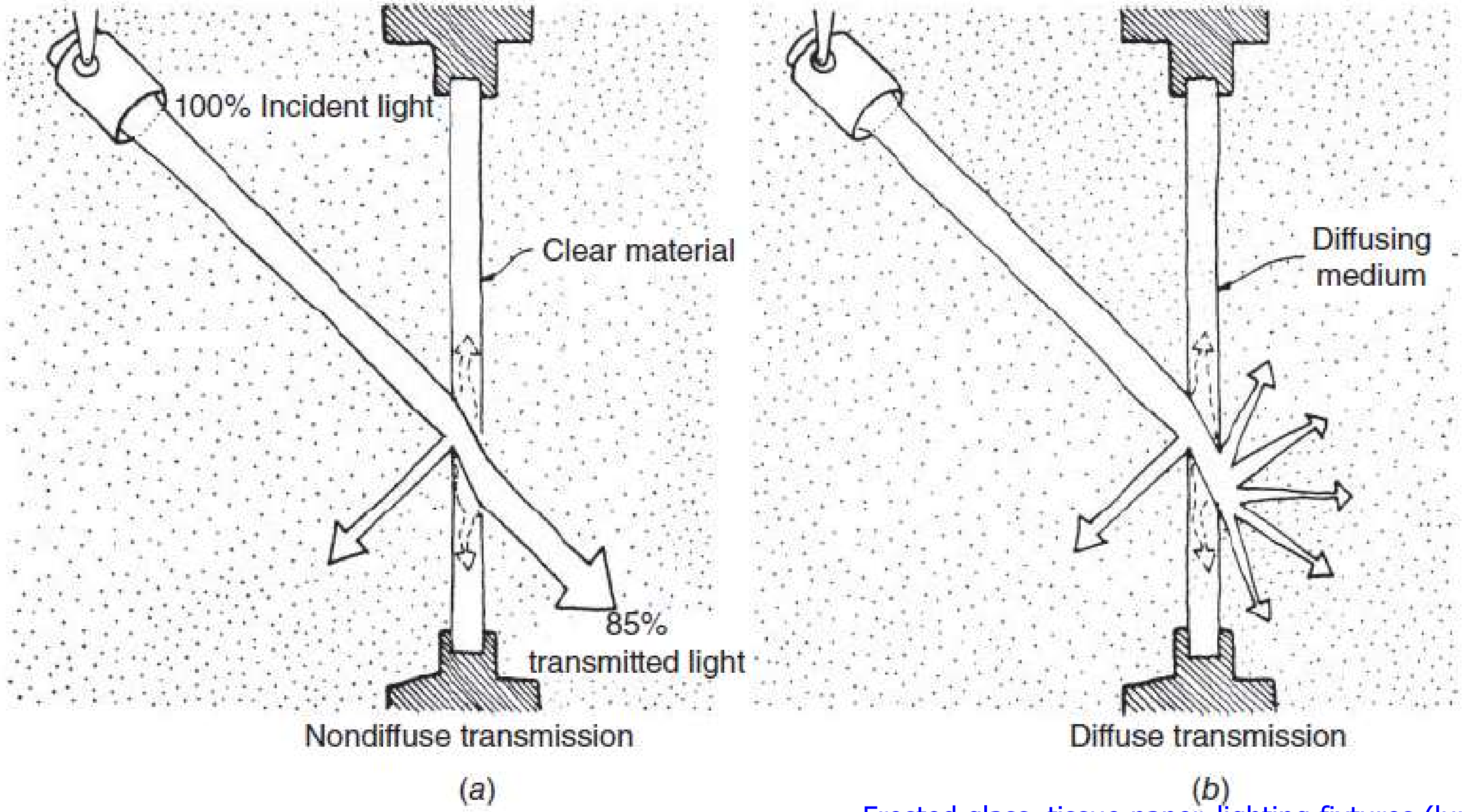


Fig. 6.6 *Reflection characteristics. (a) In specular reflection, angle of incidence equals angle of reflection ($\alpha = \beta$). Because 80% of light is reflected, reflectance is 80%; 20% of light is absorbed. (b) In diffuse reflection, incident light is spread in all directions by multiple reflections on the unpolished surface. Such surfaces appear equally bright from all viewing angles. (c) Most materials exhibit a combination of specular and diffuse reflection. Such a surface mirrors the source while producing a bright background.*



Frosted glass, tissue paper, lighting fixtures (luminaires)

Fig. 6.7 *Transmission characteristics. (a) In nondiffuse transmission, the light is refracted (bent) but emerges in the same beam as it enters. Clear materials such as glass, water, and certain plastics exhibit this type of transmission. In the instance illustrated, the transmittance is 85% (the remaining 15% is reflected and absorbed). The source of light is clearly visible through the transmitting medium. (b) With diffuse transmission, the source of light is not visible and, in the case of multiple sources, the diffusing surface exhibits generally uniform brightness if the spacing between the light sources does not exceed approximately 1½ times their distance from the material.*

Illuminance measurement

Fig. 6.8 Electronic, digital, color-corrected, and cosine-corrected illuminance meter from Konica-Minolta.

Fig. 6.9 Digital meter (from Li-Cor) has a variety of sensors that measure illuminance, solar irradiance, or photosynthetic radiation. Due to its small size, the illuminance sensor can be easily used for architectural model measurements.

Illuminance measurement

- Correction: color & cosine
  - Color correction: the human eye is not equally sensitive to the various wavelengths (colors) → max. sensitivity at high E levels (555nm, yellow green area), whereas sensitivity at the red and blue ends of the spectrum is quite low. (10 units of blue light has the same visual effect as 1 unit of yellow-green light)
  - Cosine correction: Correction for light incident at oblique angles that does not reach the cell due to reflection from the surface glass and shielding of the light-sensitive cell by the meter housing.
- Measuring point: 75 cm above the floor (height of normal working plane)
- Additive feature: daylight and electric light (서로 더하거나 뺄 수 있음)

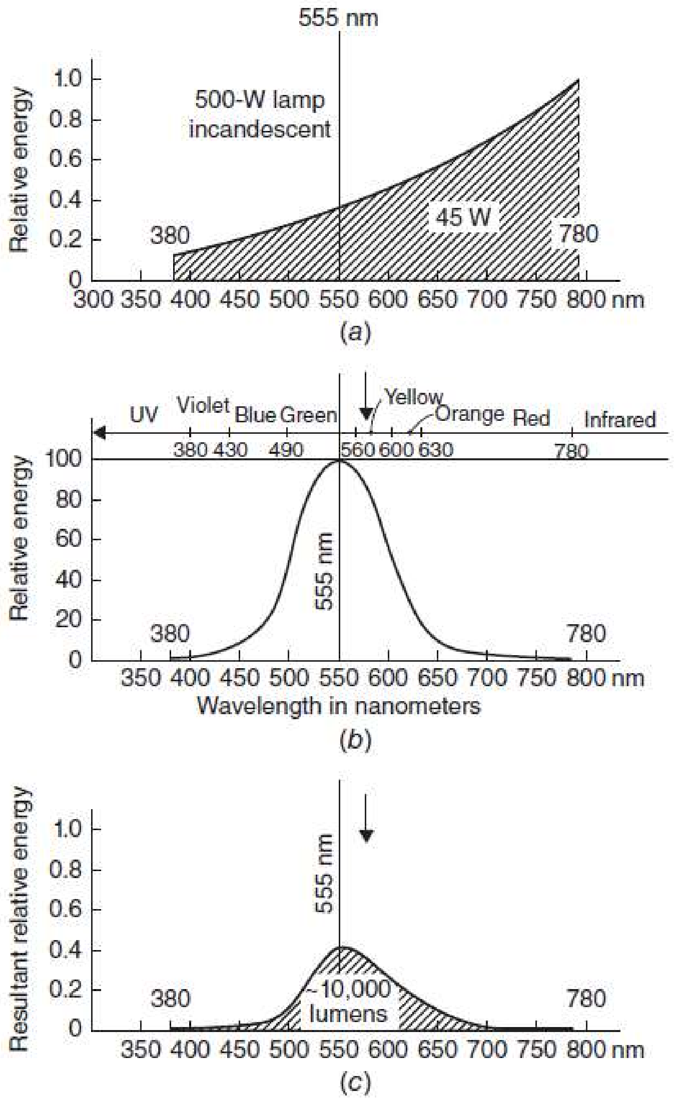


Fig. 6.3 *Graphical demonstration of the method by which the unit of light flux is defined. (a) The spectrum of the light produced by a 500-W incandescent lamp amounts to approximately 45 W measured radiometrically. When engaged by the human eye, whose spectral sensitivity curve is given in (b), this light power is perceived as shown in (c). The new light power curve is expressed in lumens and indicates the quantity of light as perceived by the eye.*

→ What the incandescent lamp produces

→ What happens when the light enters the eye

→ The resultant *"understood"* light power

Lighting survey

- Should establish
  - Type, rating, and age of sources
  - Type, design, and model of luminaires
  - Maintenance schedule
- Should measure
  - Mounting height of luminaires
  - Spacing and pattern of luminaires
  - Reflectances of walls, floor, ceiling, and major items of furniture and equipment
  - Illuminance levels of horizontal and vertical planes

Luminance measurement

- Luminance is more meaningful.
  - Illuminance is what is incident on the surface.
  - It is luminance that we see, not illuminance.
- Why illuminance measurements are widely taken as a measure of the adequacy of a lighting installation:
  - illuminance meters are cheaper and simpler than luminance meters
  - Design recommendations are given in terms of illuminance levels.

Fig. 6.10 *Direct-reading, narrow-angle, spot-type luminance meter has an acceptance angle of 1°, a range of 0.001 to 299,000 cd/m² (0.001 to 87,000 fL), a variable response speed to permit measurement of flickering sources, and a comparison mode that permits direct luminance comparison of two sources. Results are displayed digitally.*

Calculated luminance

- For a diffuse luminous source, the cell of an illuminance meter is placed directly against the surface (Fig. 6.11).
- The lux reading must be divided by π to obtain the diffuse source luminance in cd/m^2.

Fig. 6.11 When the cell of a direct-reading illuminance meter is held in contact with a luminous source, the surface luminance can be read directly or calculated.

Reflectance measurements

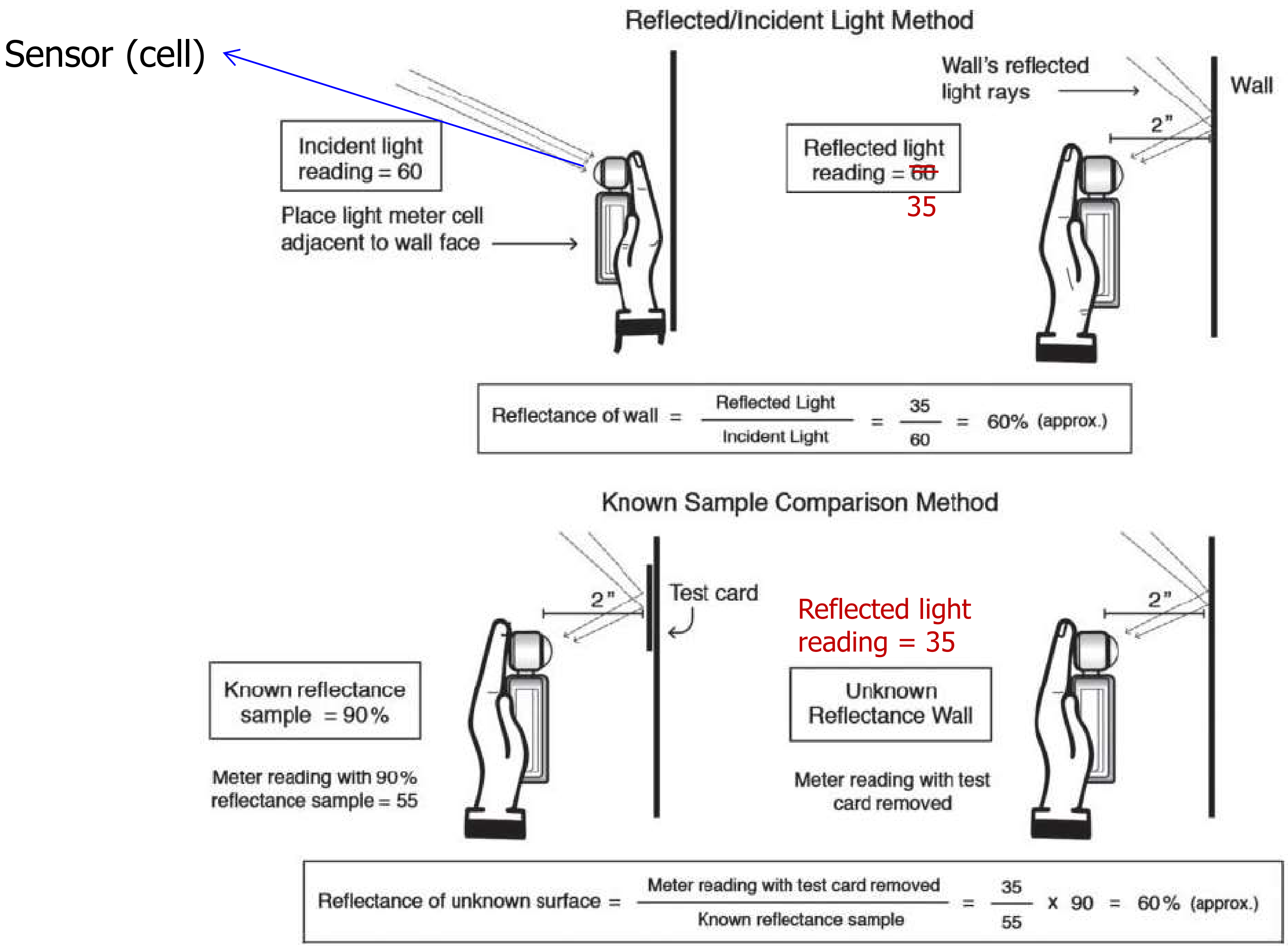


Fig. 6.12 *Two simple methods of measuring the diffuse reflectance of a surface. (Drawn by Martin Lee.)*

The luminance value can be obtained: $L = \rho E/\pi$

Inverse square law (ISL)

$$E \propto \frac{I}{r^2} \longrightarrow \text{operational definition}$$

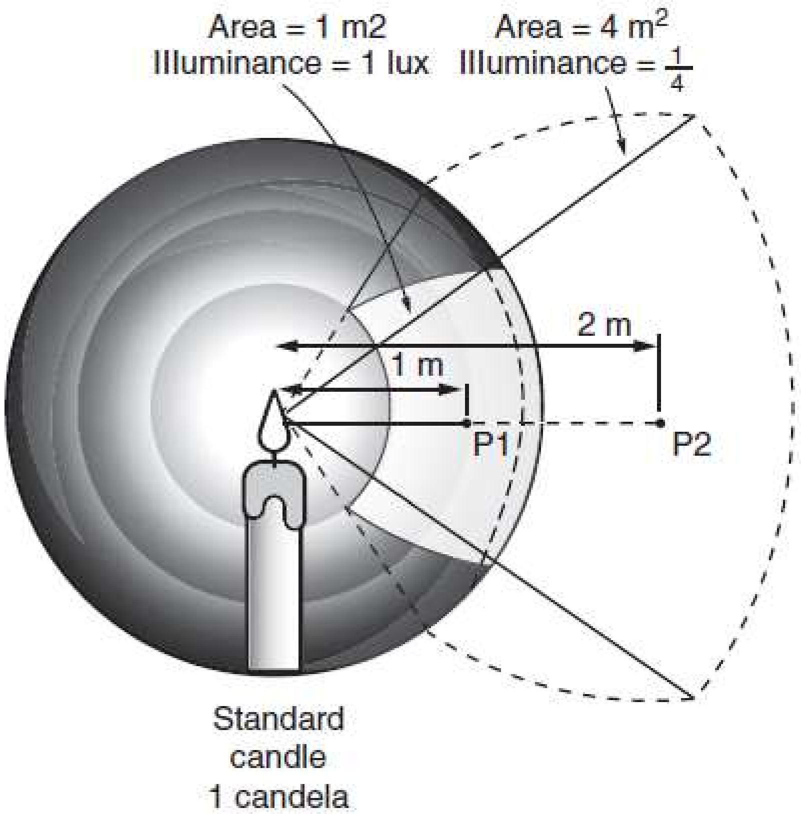


Fig. 6.13 Relationship among candelas, lumens, and lux defined with reference to a standard light source of 1 mean spherical cp (1 cd) located at the center of a sphere with a 1-m radius. (Drawn by Martin Lee.)

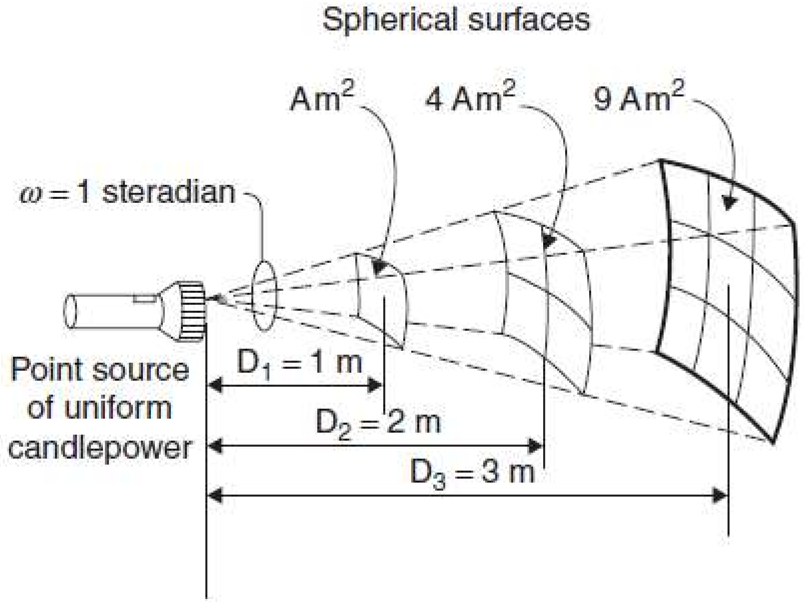


Fig. 6.14 Demonstration of inverse square law properties using a solid angle of unit size. Note that the surfaces are necessarily spherical because points on a planar surface are not equidistant from the source.

Intensity distribution curve

- CDC: candlepower distribution curve
- A photocell is rotated around the source in a single plane, illuminance is measured, and intensity (I, cd) is calculated. (Fig. 6.13, 6.14 → lux = cd intensity/distance²) ← the illumination is inversely proportional to the square of the distance from the source.
- 30° 방향으로 300cd. 이 램프에서 1m 떨어져 있으면 30° 에 위치한 점은 $300/(1)^2=300$ lux, 2m 떨어져 있으면 $300/(2)^2=75$ lux

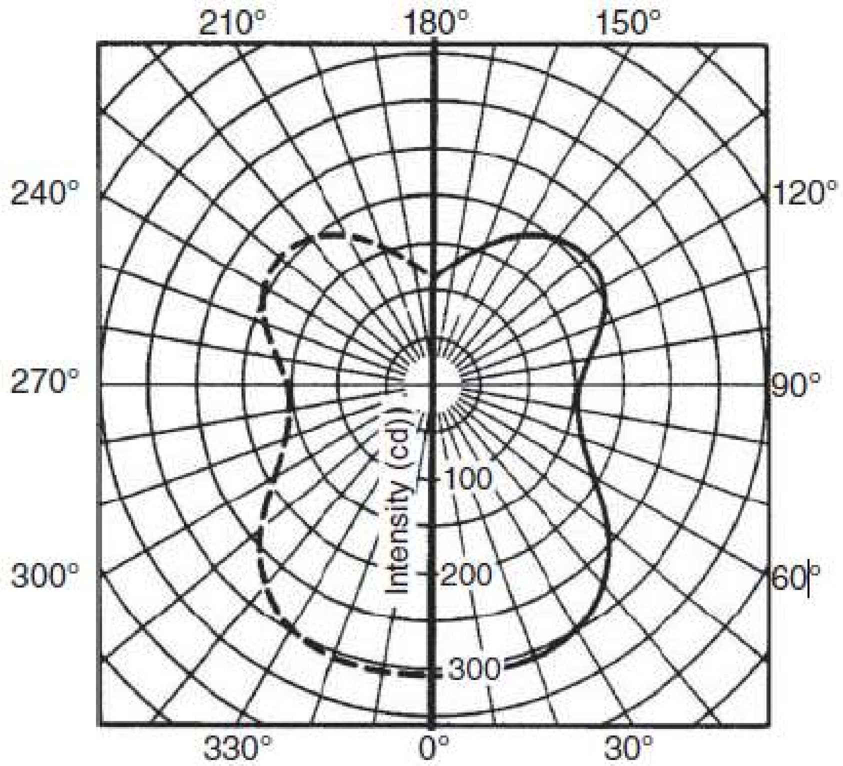


Fig. 6.15 Typical luminous intensity (cd) distribution curve for a general diffuse-type luminaire. Because the unit is symmetrical about its vertical axis, only one curve need be shown. Furthermore, only the right side of this curve need be shown, due to symmetry.

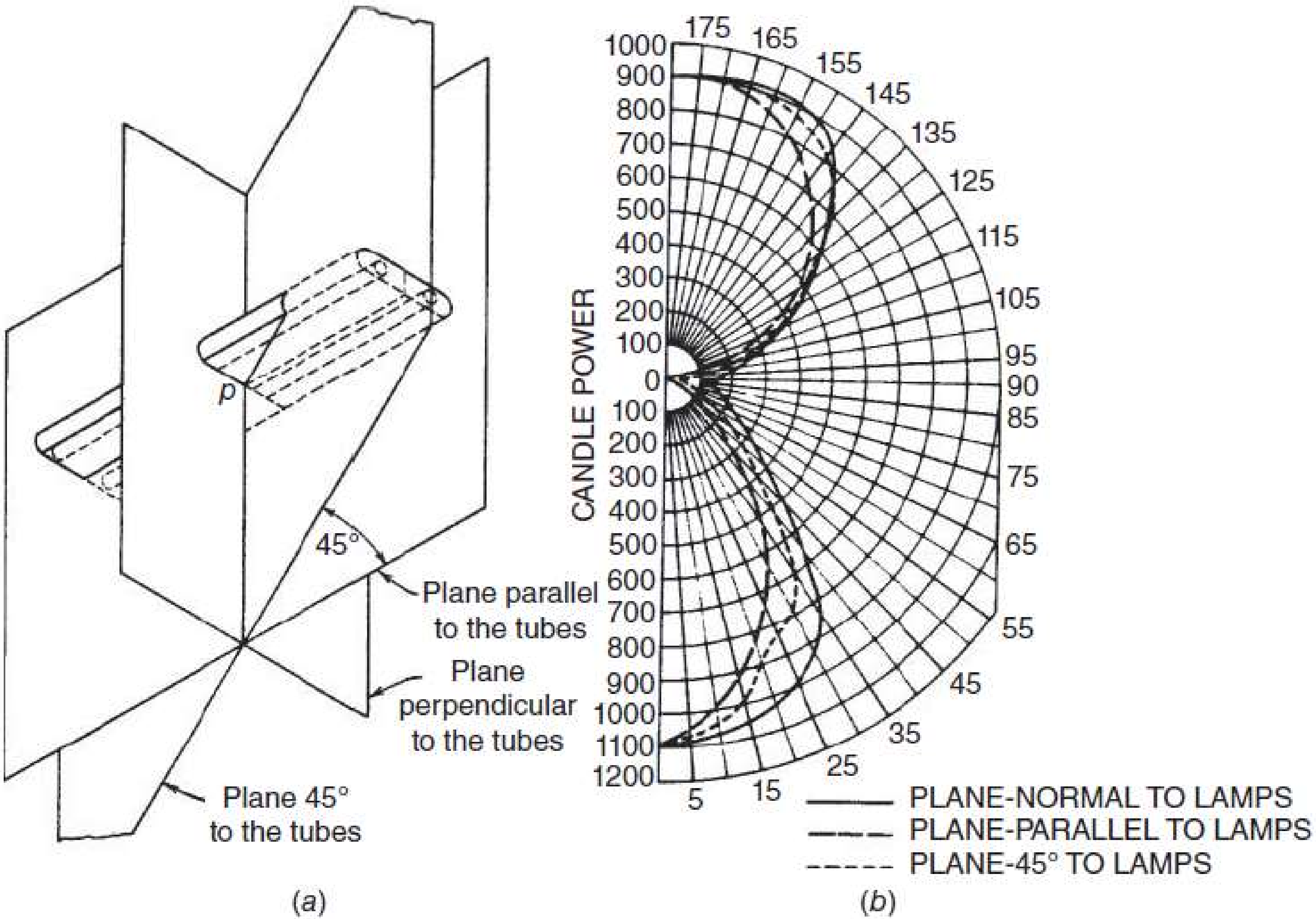


Fig. 6.16 *(a) Due to the asymmetry of a fluorescent luminaire, intensity distribution curves in (at least) three planes are required. (b) Photometric distribution for this luminaire is symmetrical in each individual plane; therefore, only one side of a curve is required. By convention, the right side is used.*

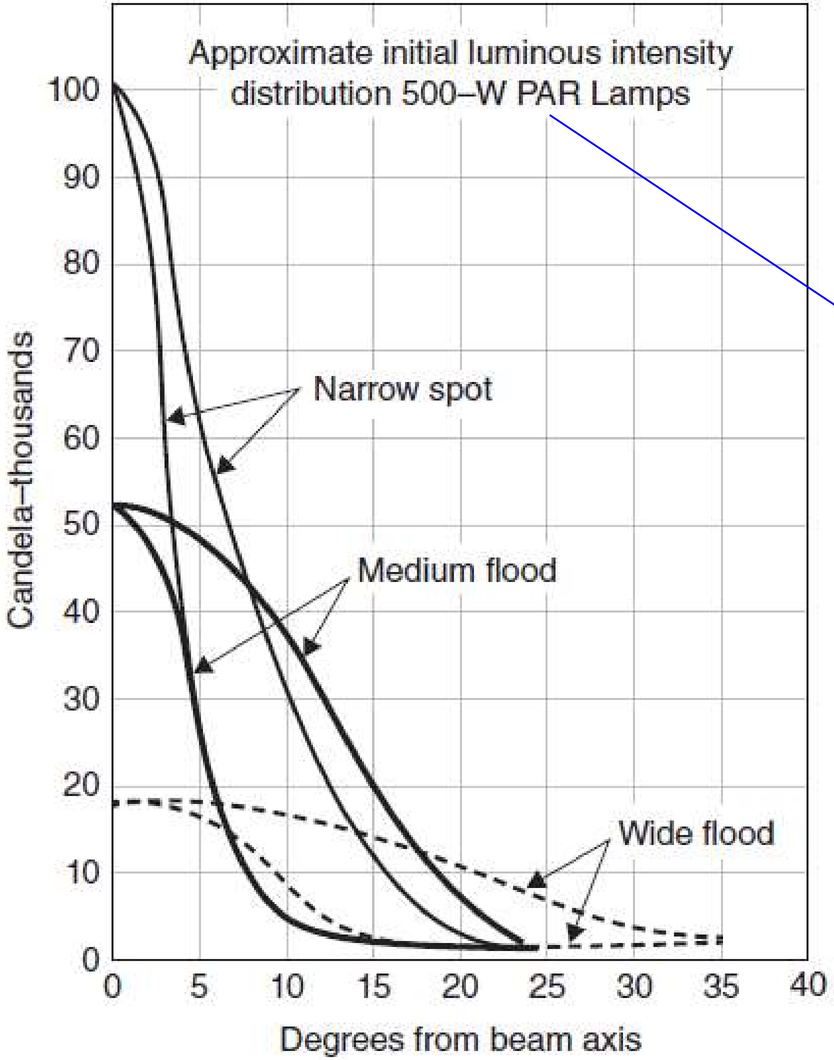
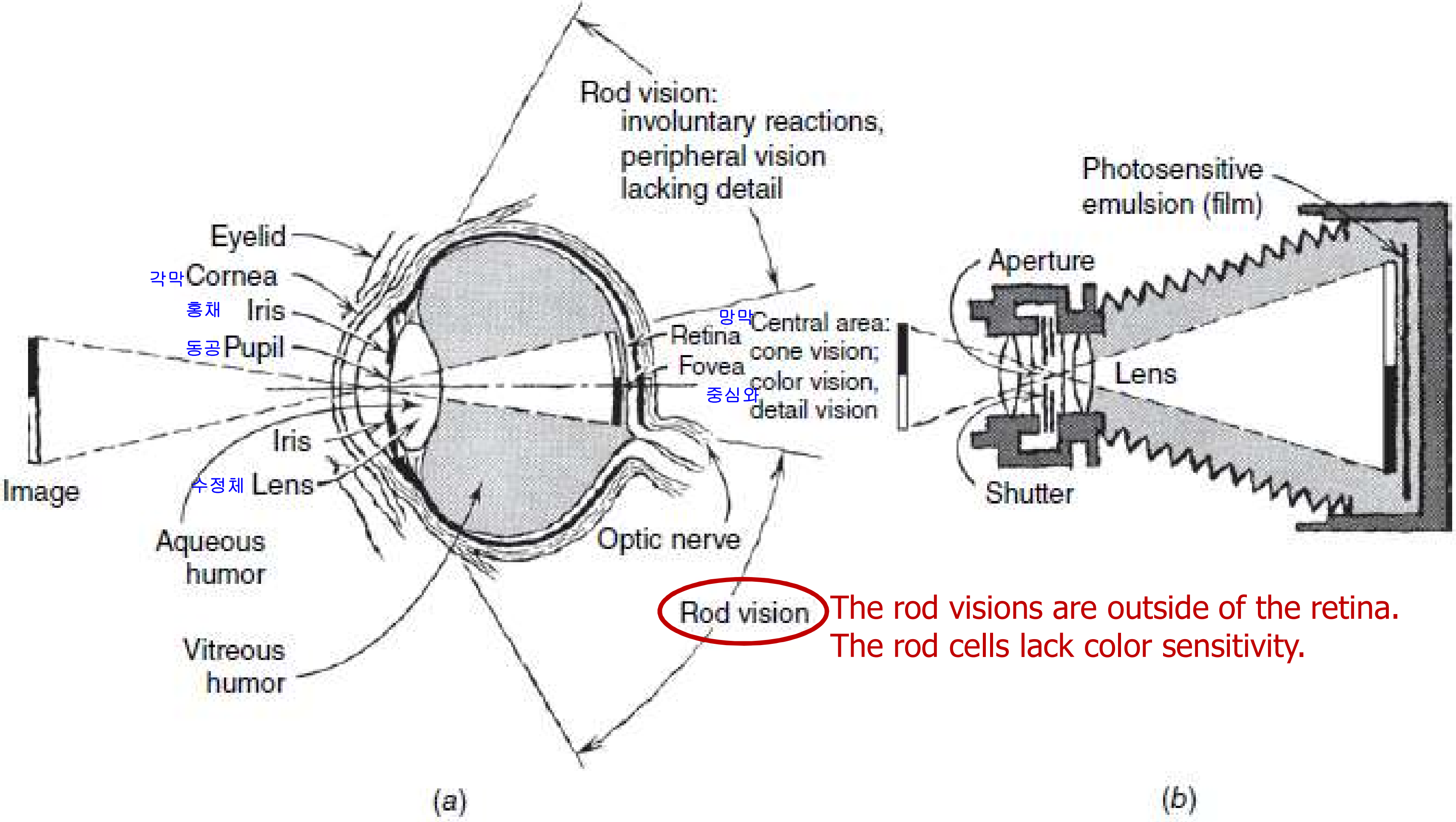


Fig. 6.17 Luminous intensity distribution curves plotted in rectangular coordinates. Note that candela values near the cutoff angles are easily read, which is not the case in polar plots.

PAR: Parabolic Aluminized Reflector lamp
(알루미늄 반사경 램프)

Light and sight

The cones are the central portion of the eye.
The cones give us the capacity to perceive color.
The cones are responsible for the ability to discriminate detail.



The rod visions are outside of the retina.
The rod cells lack color sensitivity.

Fig. 6.18 The human eye (a) and a camera (b) operate on similar optic principles. The cornea acts as an outer refracting lens that introduces light into the iris. The iris and pupil control the extent of opening of the eye, and correspond roughly to an f-stop range of f2.1 to f11. The lens, which acts as a perfectly smooth automatic zoom lens, can focus from about 2 in. (50 mm) to infinity.

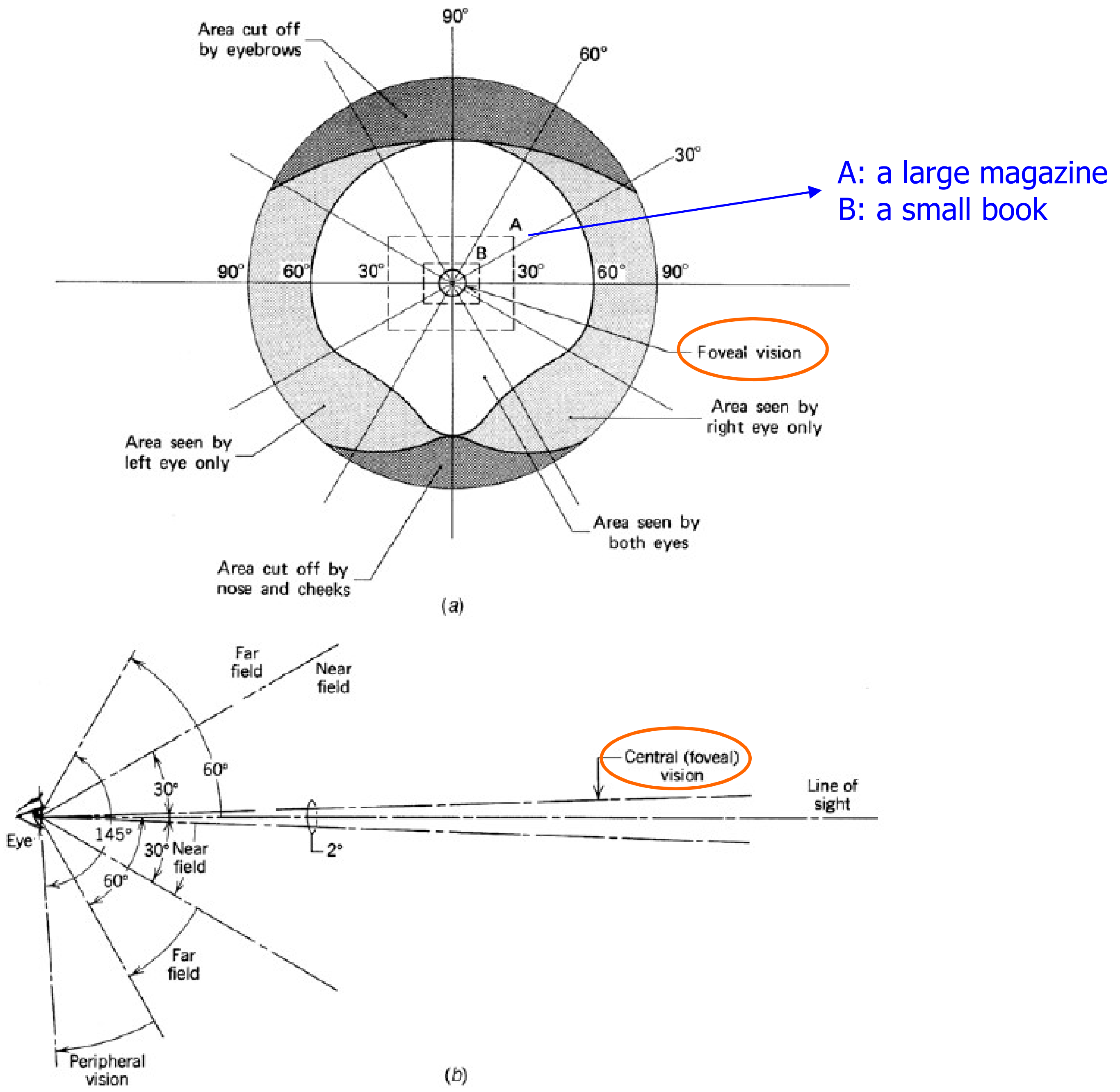


Fig. 6.19 The fields of vision of a normal pair of human eyes (a) and the subtended angles (b). Rectangles A and B superimposed on the field of vision in (a) represent a large magazine and a small book, respectively.

Factors in visual acuity

- (1) Task
  - Primary factors
    - Size
    - Luminance (brightness)
    - Contrast, including color contrast
    - Exposure time – needed or given
  - Secondary factors
    - Type of object
    - Degree of accuracy required
    - Task: moving or stationary
    - Peripheral patterns
- (2) Observer
  - Primary factors
    - Condition of eyes (both health and age)
    - Adaptation level
    - Fatigue level
  - Secondary factors
    - Subjective impression: psychological reactions
- (3) Lighting condition
  - Primary factors
    - Illumination level
    - Disability glare
    - Discomfort glare
  - Secondary factors
    - Luminance ratios
    - Brightness patterns
    - Chromaticity

Size of visual object

- Visual acuity is proportional to the physical size of the object being viewed.
- The actual parameter is not size but subtended visual angle.

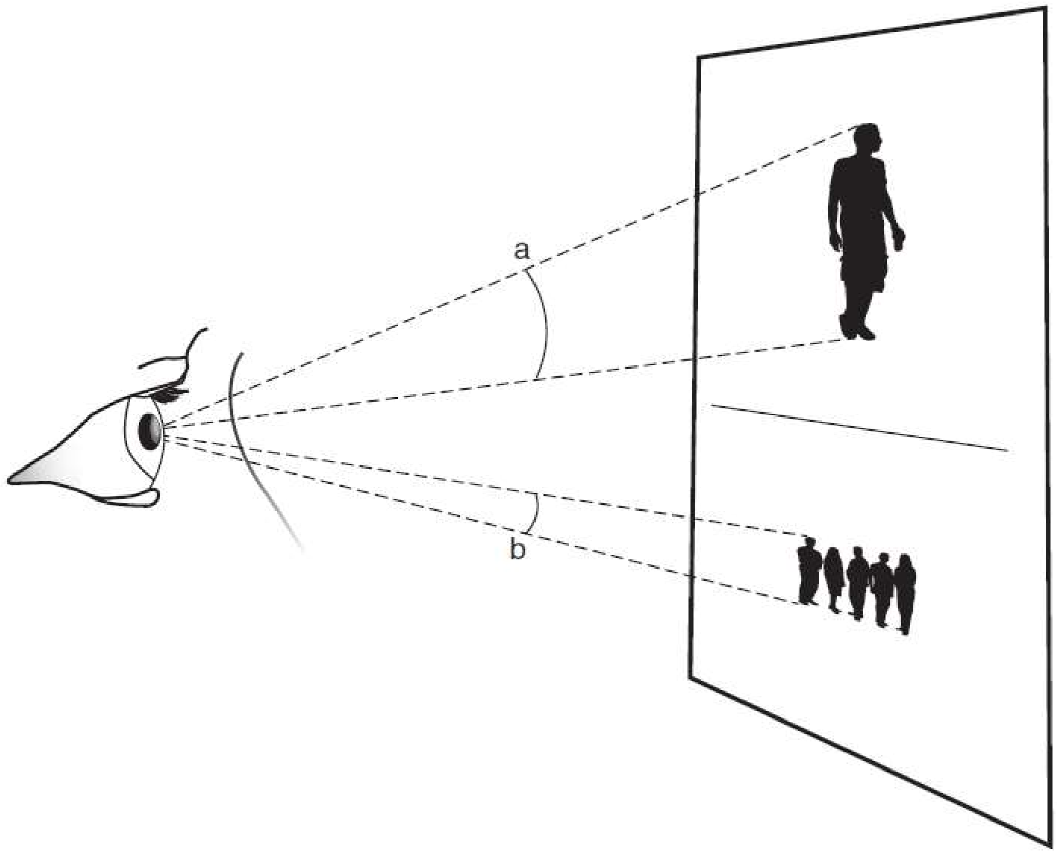


Fig. 6.20 Relationship between object size and visibility is demonstrated by comparison of subtended angles a and b. (Drawn by Martin Lee.)

Subjective brightness

- Adaptation
  - 암순응 (dark adaptation: going from light to dark): 2 minutes for cone vision (sensation of color) to 40 minutes for rod vision (lack of color sensitivity and lack of detail discrimination)
  - 명순응 (light adaptation: going from dark to light): much faster than dark adaptation
  - Department store (백화점), tunnel(터널) 등
- Purkinje effect (퍼킨지 효과)
  - Light adapted eye: maximum sensitivity occurs at 555 nm (yellow-green region)
  - dark adapted eye: maximum sensitivity occurs at 520 nm (blue green region) → blue green color stands out
  - Important in the lighting design of restaurants. As the light dims, the warm colors (yellow, orange, red) become grayed and blues and violets stand out.

Typical luminance values

TABLE 6.2 Typical Luminance Values[a]

Object	Luminance cd/m²	Luminance Footlamberts
Black glove on a cloudy night	0.0003	0.0001
Wall brightness in a well-lighted office	100	30
A sheet of white paper in an office	120	35
Green electroluminescent lamp	150	45
Asphalt paving—overcast day	1300	380
North sky	3500	1000
Moon, candle flame	4,000–5000	1200-1500
Fluorescent tube	6,000–8000	1800-2400
Kerosene flame	8500	2500
Hazy sky or fog	15,000	4400
Snow in sunlight	25,000	7300
100-W inside-frost incandescent lamp	50,000	14,600
Sun	2.3 E9	0.67 E9

[a]Values are rounded off.

Preferred and permissible luminances

TABLE 6.3 Example Luminances

Item	cd/m²	Footlamberts
Recommended road luminance, night	1–2	0.3-0.6
Minimum luminance for discernible chromatic distinctions	2–3	0.6-0.9
Clearly discernible human features	15–20	4.5-6.0
Preferred wall luminance	25–150	8-45
Preferred ceiling luminance	50–250	15-75
Preferred task luminance	100–500	30-150
Permissible luminaire luminance (depending upon position)	1000–7000	300-2100

Contrast and adaptation

- The contrast is the single most important factor in visual acuity because the eye sees only contrast.

Contrast is a dimensionless ratio, defined as:

$$C = \frac{L_T - L_B}{L_B} \text{ or } \frac{L_B - L_T}{L_B} \text{ or } \left|\frac{L_B - L_T}{L_B}\right| \qquad (6.7)$$

where L_T and L_B are the luminance of the task and background, respectively, in consistent units. Thus, C varies from 0 (no contrast) to 1.0 (maximum contrast). In most situations, the illuminance on the task and background is the same. Therefore, because luminance is the product of illuminance (lux) and reflectance, contrast can also be expressed as:

$$C = \left|\frac{R_B - R_T}{R_B}\right| \qquad (6.8)$$

for the black-on-white lettering that you are now reading,

$$C = \frac{0.77 - 0.045}{0.77} = 0.94$$

which accounts for the excellent legibility. (We are

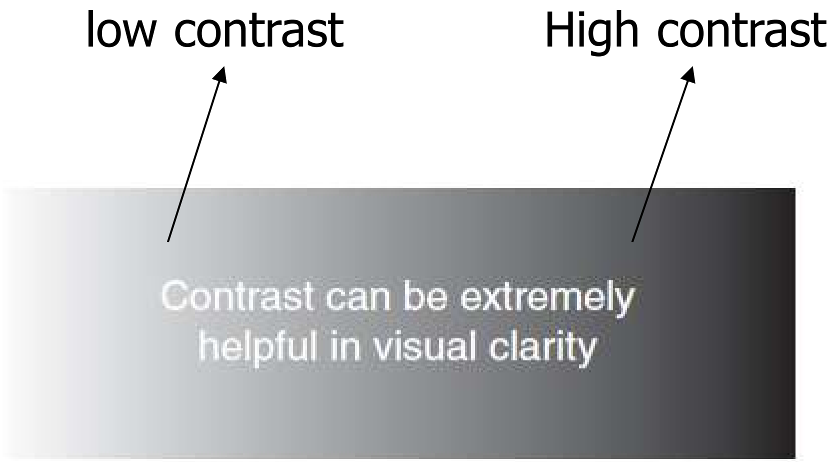


Fig. 6.21 *High contrast is helpful when the seeing task involves detection of silhouette detail. (Martin Lee.)*

Contrast and adaptation

3.4 cd/m²=minimum discernible
3,400cd/m²=north sky (daylight condition)

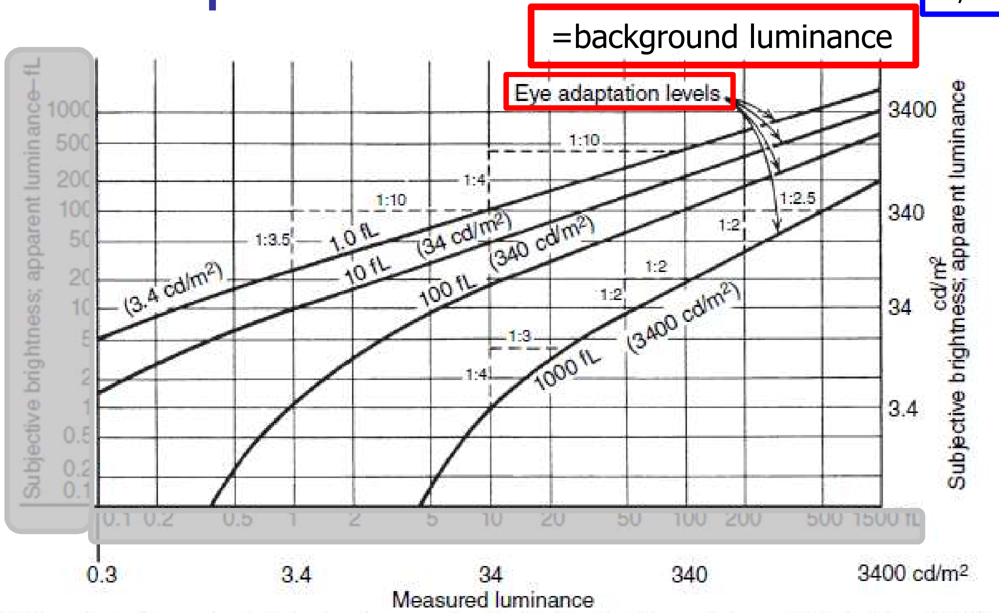


Fig. 6.22 The effect of an eye's adaptation level on perceived (subjective) brightness is shown. (Adapted from H. Cotton. 1960. Principles of Illumination. New York: John Wiley & Sons.)

- Key takeaway #1: Visual acuity increases with increased adaptation level.
  - Visual acuity is, by definition, the ability to distinguish between different levels of luminance.
  - 1:3.5 vs. 1:10 (adaptation level of 3.4cd/m²) vs. 1:2 vs. 1:2 (adaptation level of 3,400cd/m²)
  - At an adaptation level of 3.4cd/m², a measured luminance ratio of 1:10 (horizontal scale) appears to be only approximately 1: 4 (vertical scale) → The apparent ratio is smaller than the actual one.
  - The low adaptation level causes the eye to diminish the difference between brightnesses. This effect become smaller as the adaptation level rises, until at an adaptation level of 3,400cd/m² (daylight condition), the apparent and actual ratios correspond.
- Key takeaway #2: At high adaptation levels, apparent brightness is lower than actual brightness and vice versa.
  - At an adaptation level of 3.4cd/m²: actual luminance of 34cd/m² appears to be 340cd/m² (10배 차이)
  - At an adaptation level of 340cd/m²: apparent and actual luminance levels correspond (e.g. 340cd/m²)
  - At an adaptation level of 3,400cd/m² : actual luminance of 340cd/m² appears to be 68cd/m². Actual luminance of 170cd/m2 appears to be 34cd/m².
  - Sources of light that would be entirely acceptable at a higher adaptation level can easily become annoying glare at a low adaptation level.

Exposure time

- Registering a visual image is not an instantaneous process, but requires finite amounts of time.
- Longer exposure time is required for moving object (not static). Under dim light, more time is needed to distinguish fine detail (어두운 곳일수록, 정적인 대상보다 동적인 대상이 될수록, 시각적 이미지를 파악하는데 더 많은 시간 소요)
- Law of diminishing returns
  - Improved performance does not necessarily result from improved illumination.
  - Increasing the luminance by a factor 6, the seeing time is halved. A further sixfold increase in luminance reduced the time only 20%. (밝기를 6배 늘리면 seeing time을 50% 줄임. 다시 6배 늘이면 seeing time의 20% 줄임.)
  - The speed of reading and comprehension are substantially independent of illuminance levels above a minimum but are very dependent on the contrast quality of the material.

Secondary task-related factors

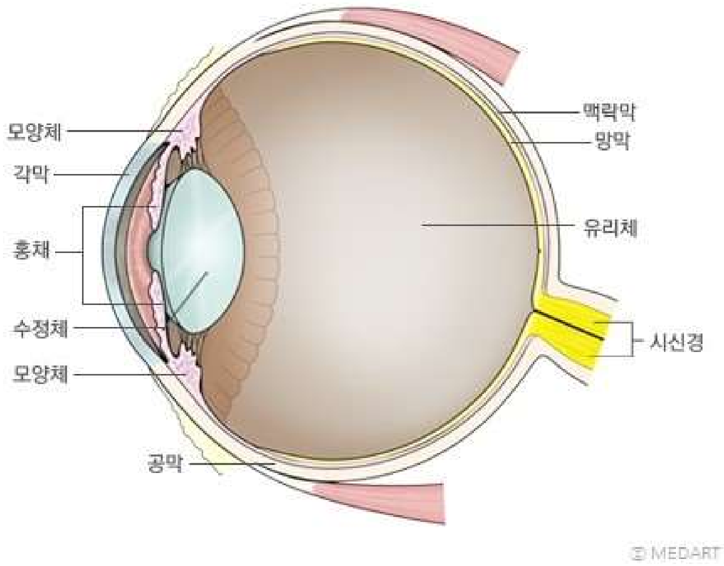
- Spray painting a large metal object or packing fruit (mechanical, repetitious) vs. inspecting the painted object for defects or the fruit of bruises (continuous judgment) → the lighting should be different
- Secondary factors:
  - Type of object
  - Degree of accuracy required
  - Task: moving or stationary
  - Peripheral patterns (visual surround, glare, …): movement of vehicles, machines, persons

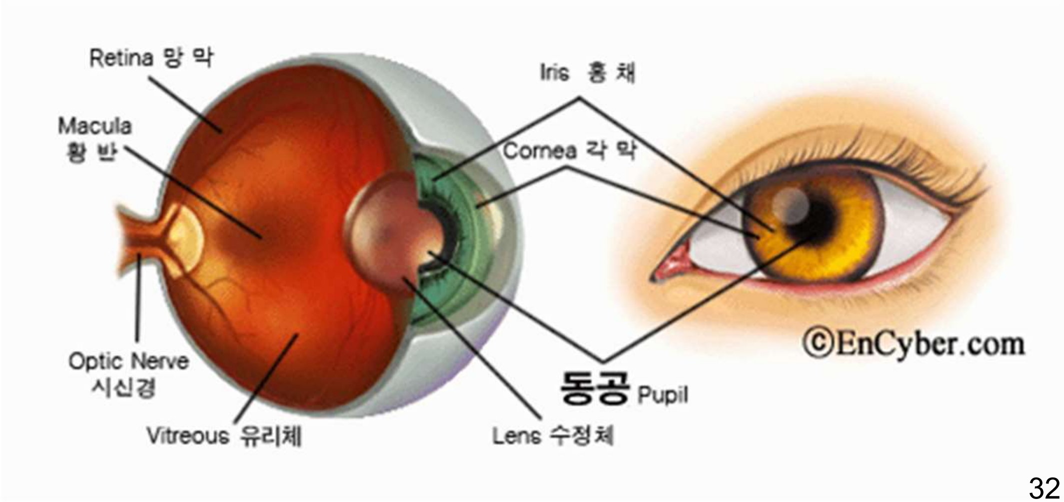
Observer-related visibility factors

- The visual performance of healthy eyes decreases with age: The age of the worker is an important parameter.
- Excellent visual performance under excellent lighting conditions may not be synonymous with maximum comfort or minimum fatigue. The reverse may sometimes be true.
  - ‘eyestrain’ results from extensive and intensive eye use. Excellent lighting conditions can still produce fatigue because of the demanding nature of the task.
- Interrelationships: lighting + task + observer

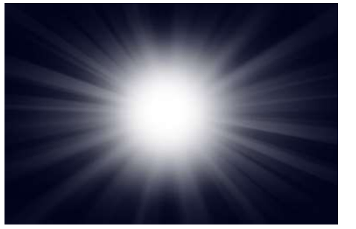
The aging eye

- Cornea (각막)
  - Cloudy → reduction of visual clarity and acuity → requiring more light
- Lens (수정체)
  - Thickening and yellowing → flexibility is reduced
  - Gradual clouding
- Pupil (동공): control of the amount of light. The pupil muscles react more slowly as they age. The slower pupil results in severe glare sensations with even small brightness changes.
  - 적은 휘도 변화에도 동공의 반응은 느려져서 현휘 유발





Quality of lighting



Example of luminous ceiling

- Two rooms with the same average illuminance
  - Room #1: a bare bulb
  - Room #2: luminous ceiling
- Luminance, diffusion, uniformity, chromaticity
- Glare: excessive luminance and/or excessive luminance ratios
  - Direct glare: caused by light sources in the field of vision
  - Reflected glare or veiling reflection caused by reflection of light source in a viewed surface

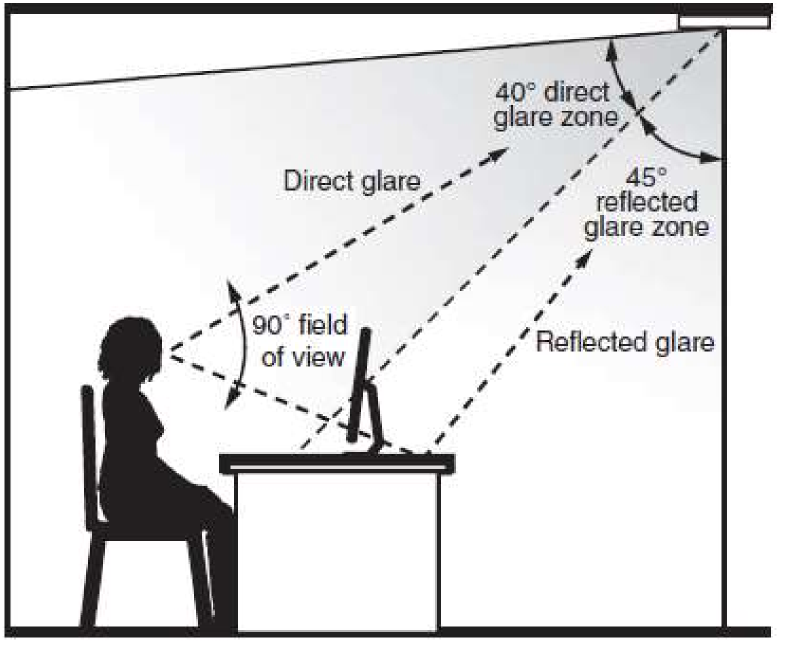


Fig. 6.23 *Glare zones. Direct glare assumes a head-up position, whereas reflected glare assumes eyes down at a reading angle. (Drawn by Martin Lee.)*