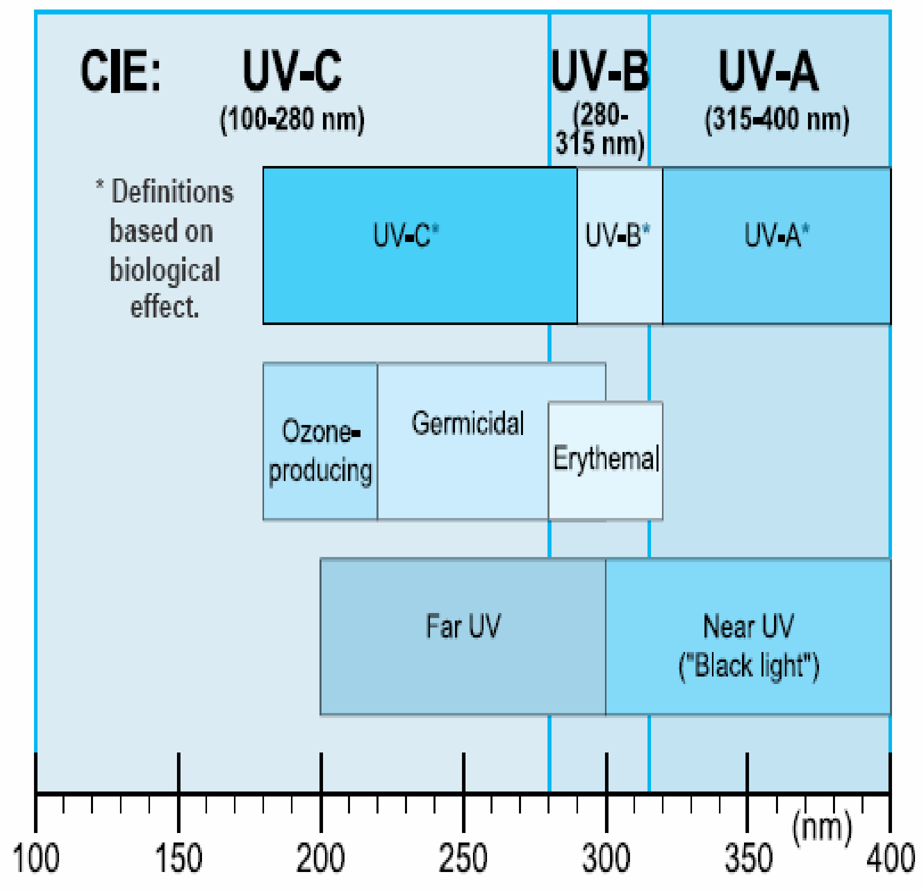
Ultraviolet Light (자외선)



Short wavelength UV light exhibits more quantum properties than its visible and infrared counterparts. Ultraviolet light is arbitrarily broken down into three bands, according to its anecdotal effects.

UV-A is the least harmful and most commonly found type of UV light, because it has the least energy. UV-A light is often called black light, and is used for its relative harmlessness and its ability to cause fluorescent materials to emit visible light - thus appearing to glow in the dark. Most phototherapy and tanning booths use UV-A lamps.

UV-B is typically the most destructive form of UV light, because it has enough energy to damage biological tissues, yet not quite enough to be completely absorbed by the atmosphere. UV-B is known to cause skin cancer. Since most of the extraterrestrial UV-B light is blocked by the atmosphere, a small change in the ozone layer could dramatically increase the danger of skin cancer.

Short wavelength UV-C is almost completely absorbed in air within a few hundred meters. When UV-C photons collide with oxygen atoms, the energy exchange causes the formation of ozone. UV-C is almost never observed in nature, since it is absorbed so quickly. Germicidal UV-C lamps are often used to purify air and water, because of their ability to kill bacteria.

Visible Light (가시광선)

Photometry is concerned with the measurement of optical radiation as it is perceived by the human eye. The CIE 1931 Standard Observer established a standard based on the average human eye response under normal illumination with a 2° field of view. The tristimulus values graphed below represent an attempt to describe human color recognition using three sensitivity curves. The y(λ) curve is identical to the CIE V(λ) photopic vision function. Using three tristimulus measurements, any color can be fully described.

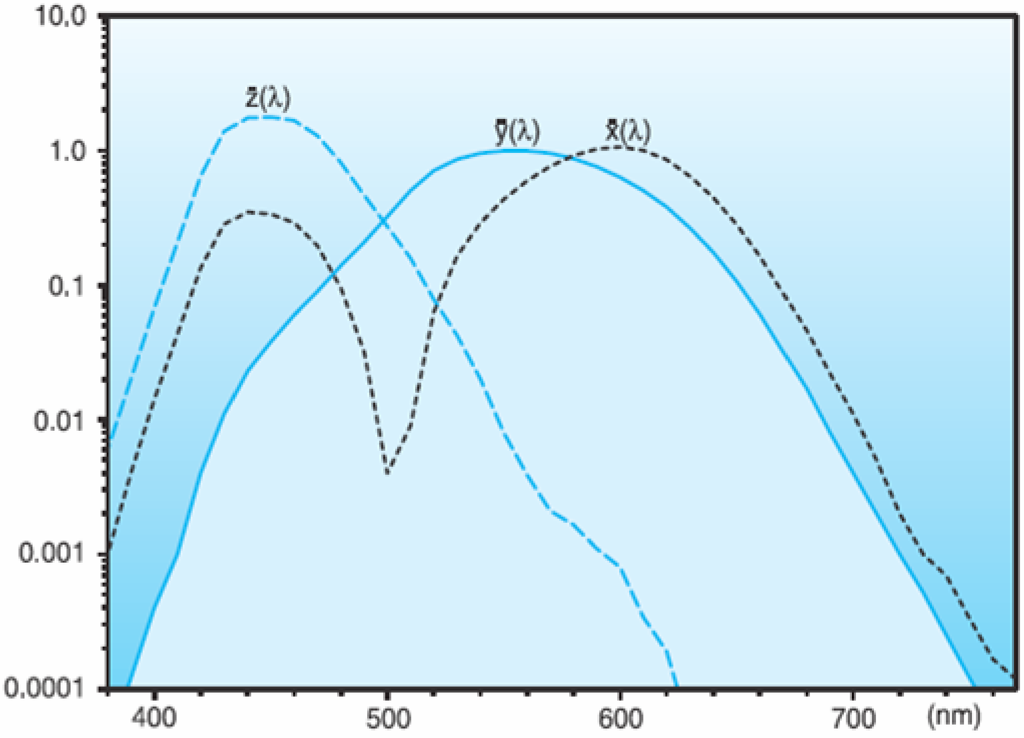
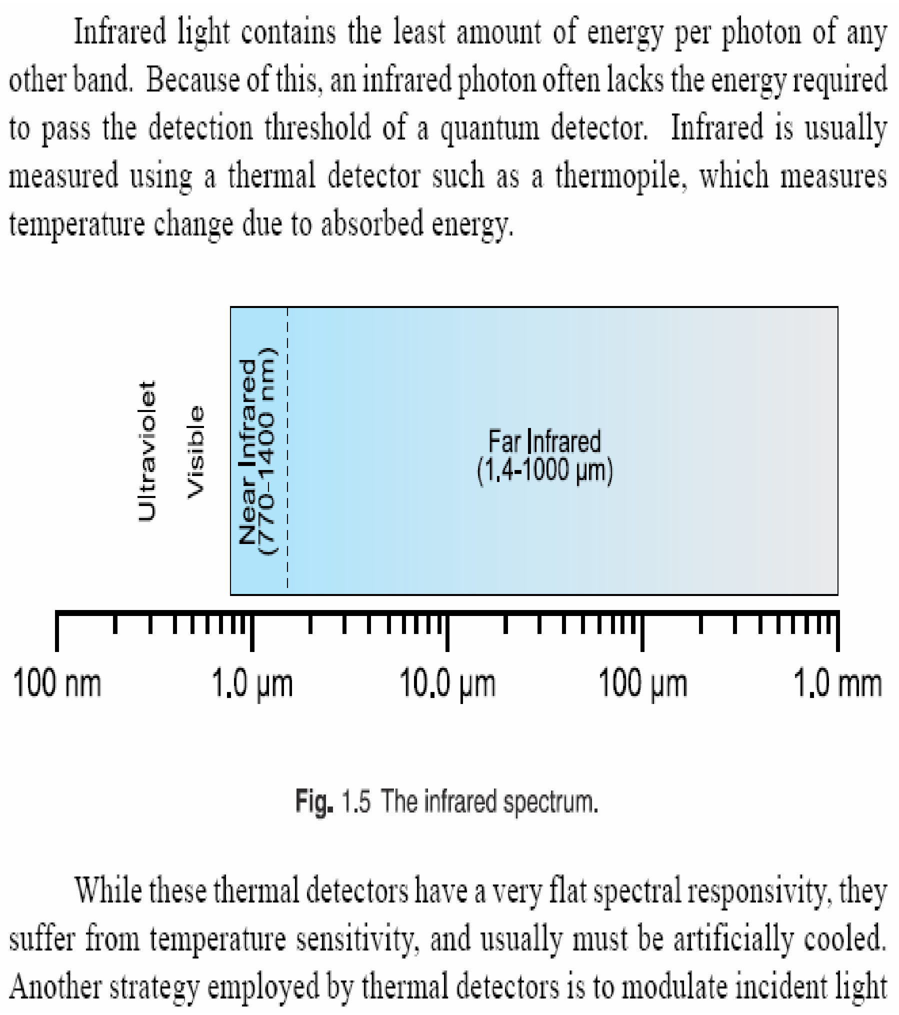
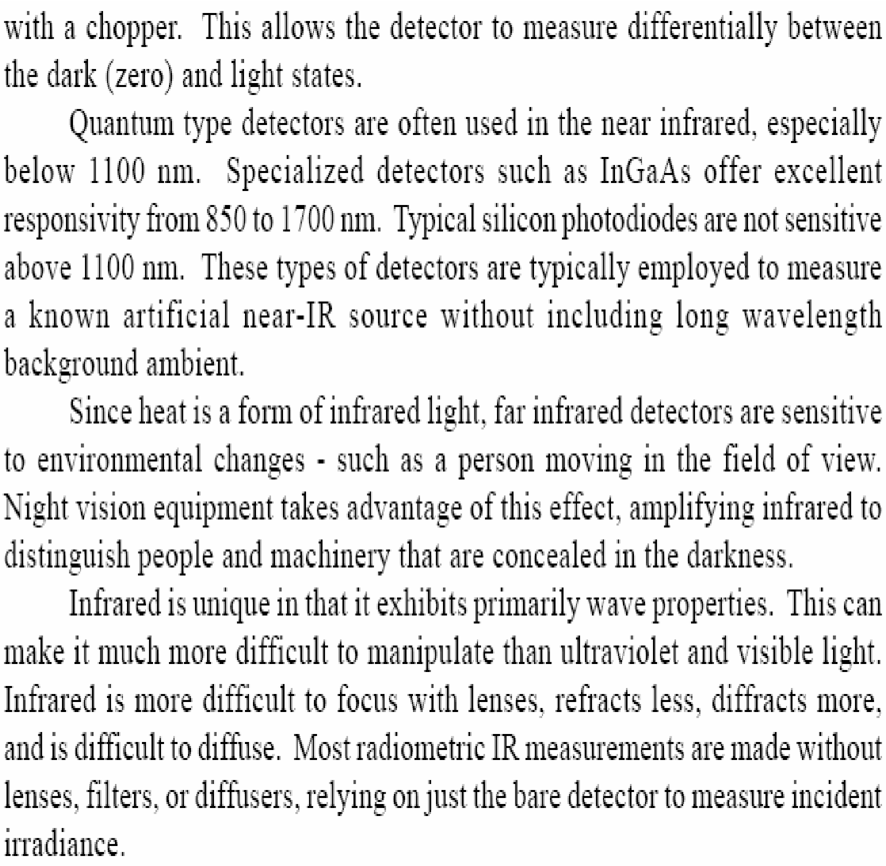


Fig. 1.3 CIE spectral tristimulus values

Infrared Light (적외선)

Infrared light contains the least amount of energy per photon of any other band. Because of this, an infrared photon often lacks the energy required to pass the detection threshold of a quantum detector. Infrared is usually measured using a thermal detector such as a thermopile, which measures temperature change due to absorbed energy.

Fig. 1.5 The infrared spectrum.

While these thermal detectors have a very flat spectral responsivity, they suffer from temperature sensitivity, and usually must be artificially cooled. Another strategy employed by thermal detectors is to modulate incident light with a chopper. This allows the detector to measure differentially between the dark (zero) and light states.

Quantum type detectors are often used in the near infrared, especially below 1100 nm. Specialized detectors such as InGaAs offer excellent responsivity from 850 to 1700 nm. Typical silicon photodiodes are not sensitive above 1100 nm. These types of detectors are typically employed to measure a known artificial near-IR source without including long wavelength background ambient.

Since heat is a form of infrared light, far infrared detectors are sensitive to environmental changes - such as a person moving in the field of view. Night vision equipment takes advantage of this effect, amplifying infrared to distinguish people and machinery that are concealed in the darkness.

Infrared is unique in that it exhibits primarily wave properties. This can make it much more difficult to manipulate than ultraviolet and visible light. Infrared is more difficult to focus with lenses, refracts less, diffracts more, and is difficult to diffuse. Most radiometric IR measurements are made without lenses, filters, or diffusers, relying on just the bare detector to measure incident irradiance.

How Light Behaves – Reflection (반사)

Light reflecting off of a polished or mirrored surface obeys the law of reflection: the angle between the incident ray and the normal to the surface is equal to the angle between the reflected ray and the normal.

Precision optical systems use first surface mirrors that are aluminized on the outer surface to avoid refraction, absorption, and scatter from light passing through the transparent substrate found in second surface mirrors.

When light obeys the law of reflection, it is termed a specular reflection. Most hard polished (shiny) surfaces are primarily specular in nature. Even transparent glass specularly reflects a portion of incoming light.

Diffuse reflection is typical of particulate substances like powders. If you shine a light on baking flour, for example, you will not see a directionally shiny component. The powder will appear uniformly bright from every direction.

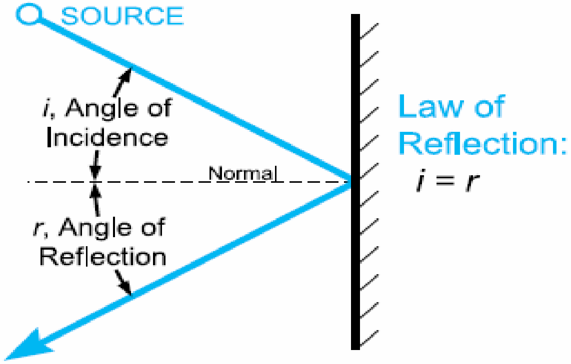
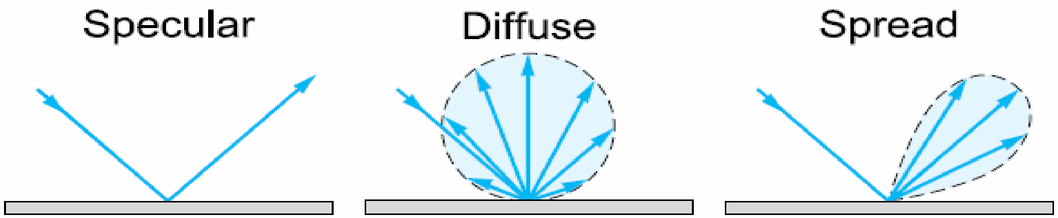


Fig. 3.1 Law of reflection.

Many reflections are a combination of both diffuse and specular components. One manifestation of this is a spread reflection, which has a dominant directional component that is partially diffused by surface irregularities.



How Light Behaves – Transmission (투과)

Transmission: Beer-Lambert or Bouger's Law

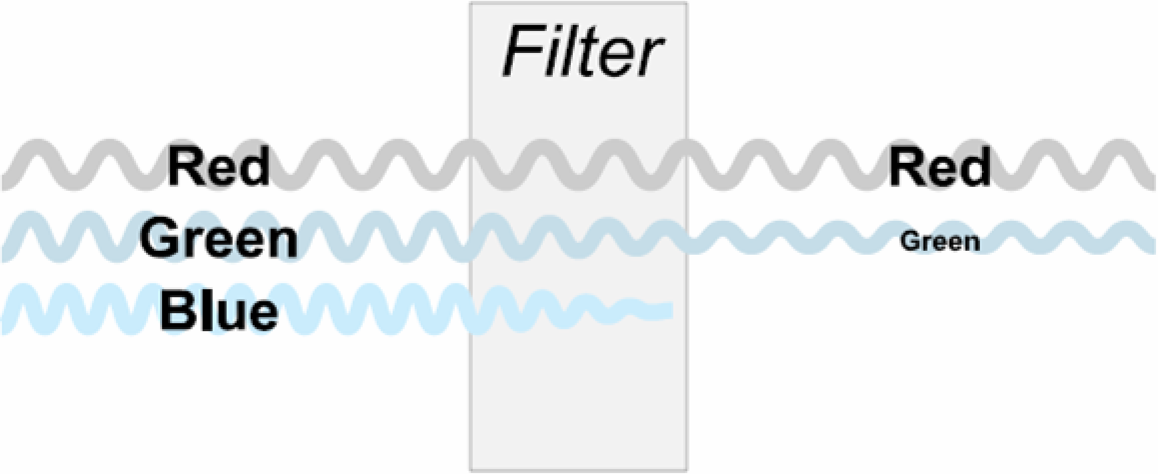


Fig. 3.3 Transmission through an optical filter.

Absorption by a filter glass varies with wavelength and filter thickness. Bouger's law states the logarithmic relationship between internal transmission at a given wavelength and thickness.

$$\log_{10}(\tau_1) / d_1 = \log_{10}(\tau_2) / d_2$$

Internal transmittance, τ_i, is defined as the transmission through a filter glass after the initial reflection losses are accounted for by dividing external transmission, T, by the reflection factor P_d.

$$\tau_i = T / P_d$$

Example: The external transmittance for a nominal 1.0 mm thick filter glass is given as $T_{1.0}$ = 59.8 % at 330 nm. The reflection factor is given as P_d = 0.911. Find the external transmittance $T_{2.2}$ for a filter that is 2.2 mm thick.

Solution:

$\tau_{1.0} = T_{1.0} / P_d = 0.598 / 0.911 = 0.656$

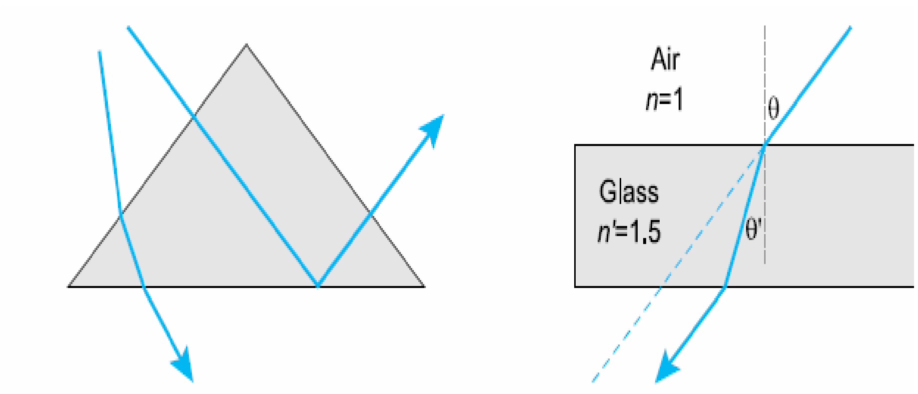
$\tau_{2.2} = [\tau_{1.0}]^{2.2}/1.0 = [0.656]^{2.2} = 0.396$

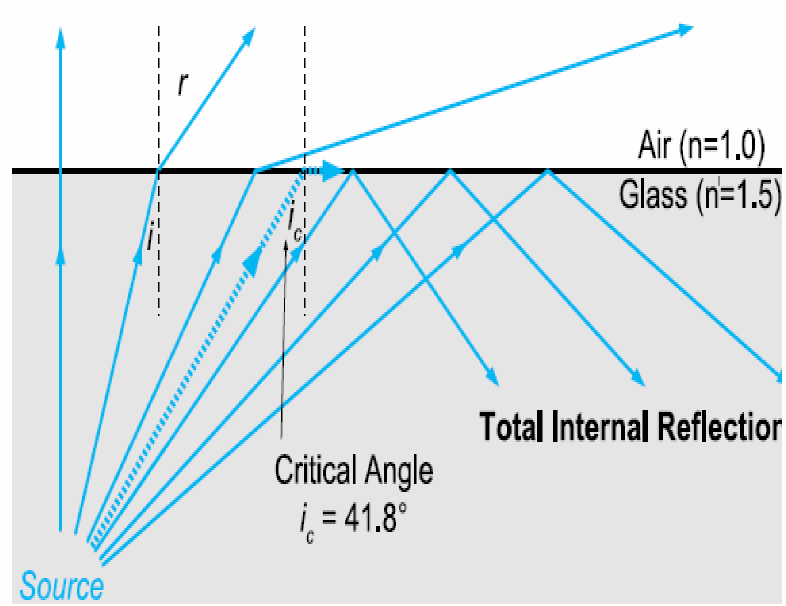
$T_{2.2} = \tau_{2.2} * P_d = (0.396)(0.911) = 0.361$

So, for a 2.2 mm thick filter, the external transmittance at 330 nm would be 36.1%

How Light Behaves – Refraction (굴절)

Refraction: Snell's Law





Refraction and total internal reflection.

When light passes between dissimilar materials, the rays bend and change velocity slightly, an effect called refraction. Refraction is dependent on two factors: the incident angle, θ, and the refractive index, n of the material, as given by Snell's law of refraction:

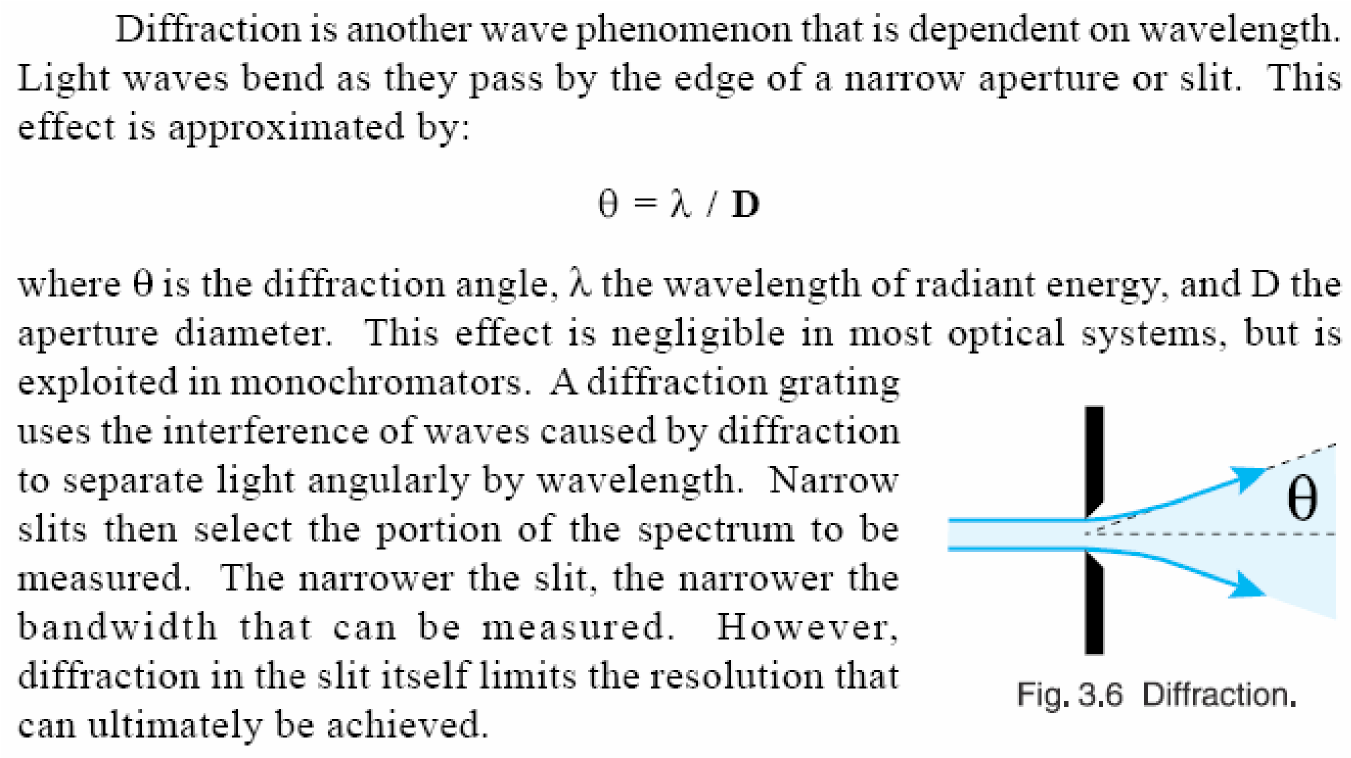
$$n \sin(\theta) = n' \sin(\theta')$$

For a typical air-glass boundary, (air n = 1, glass n' = 1.5), a light ray entering the glass at 30° from normal travels though the glass at 19.5° and straightens out to 30° when it exits out the parallel side.

Note that since sin(0°) = 0, light entering or exiting normal to a boundary does not bend. Also, at the internal glass-air boundary, total internal reflection occurs when n'sin(θ') = 1 (at θ' = 41.8° for n' = 1.5 glass.

The index of refraction itself is also dependent on wavelength. This angular dispersion causes blue light to refract more than red, causing rainbows and allowing prisms to separate the spectrum.

How Light Behaves – Diffraction (회절)



Diffraction is another wave phenomenon that is dependent on wavelength. Light waves bend as they pass by the edge of a narrow aperture or slit. This effect is approximated by:

$$\theta = \lambda \,/\, \mathbf{D}$$

where θ is the diffraction angle, λ the wavelength of radiant energy, and D the aperture diameter. This effect is negligible in most optical systems, but is exploited in monochromators. A diffraction grating uses the interference of waves caused by diffraction to separate light angularly by wavelength. Narrow slits then select the portion of the spectrum to be measured. The narrower the slit, the narrower the bandwidth that can be measured. However, diffraction in the slit itself limits the resolution that can ultimately be achieved.

Fig. 3.6 Diffraction.

How Light Behaves – Interference (간섭)

When wave fronts overlap in phase with each other, the magnitude of the wave increases. When the wave fronts are out of phase, however, they cancel each other out. Interference filters use this effect to selectively filter light by wavelength. Thin metal or dielectric reflective layers separated by an optical distance of n'd = λ/2, or half the desired wavelength provide in phase transmission.

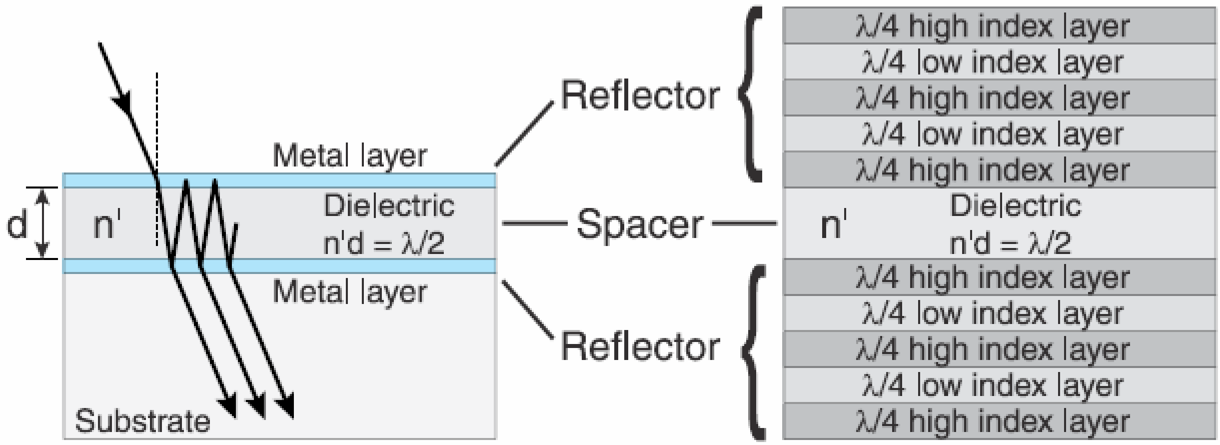


Fig. 3.7 A thin film metal interference filter and an all dielectric interference filter.

The center wavelength shifts with angle, since the optical path increases as the cosine of the angle. Special input optics are required to provide a cosine response while transmitting light through the filter at a near normal angle.

Manipulating Light – Diffusion (확산)

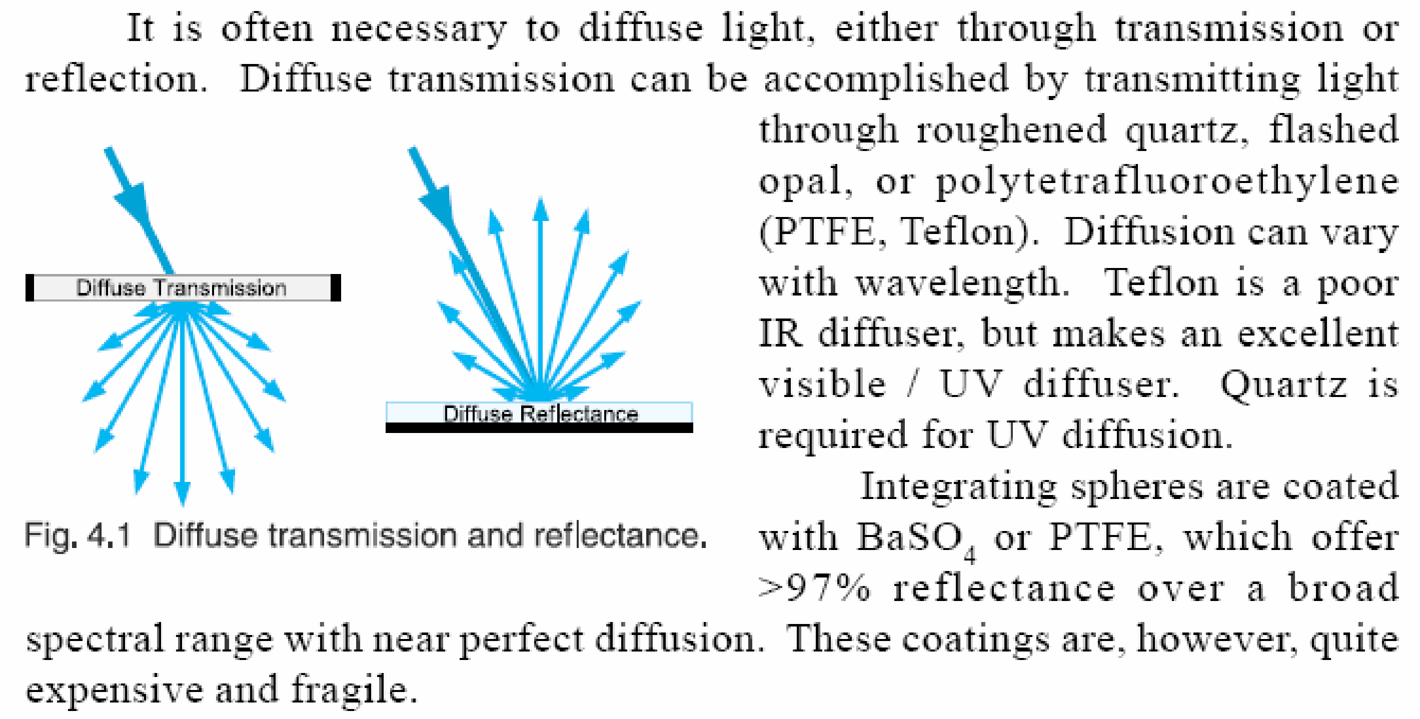
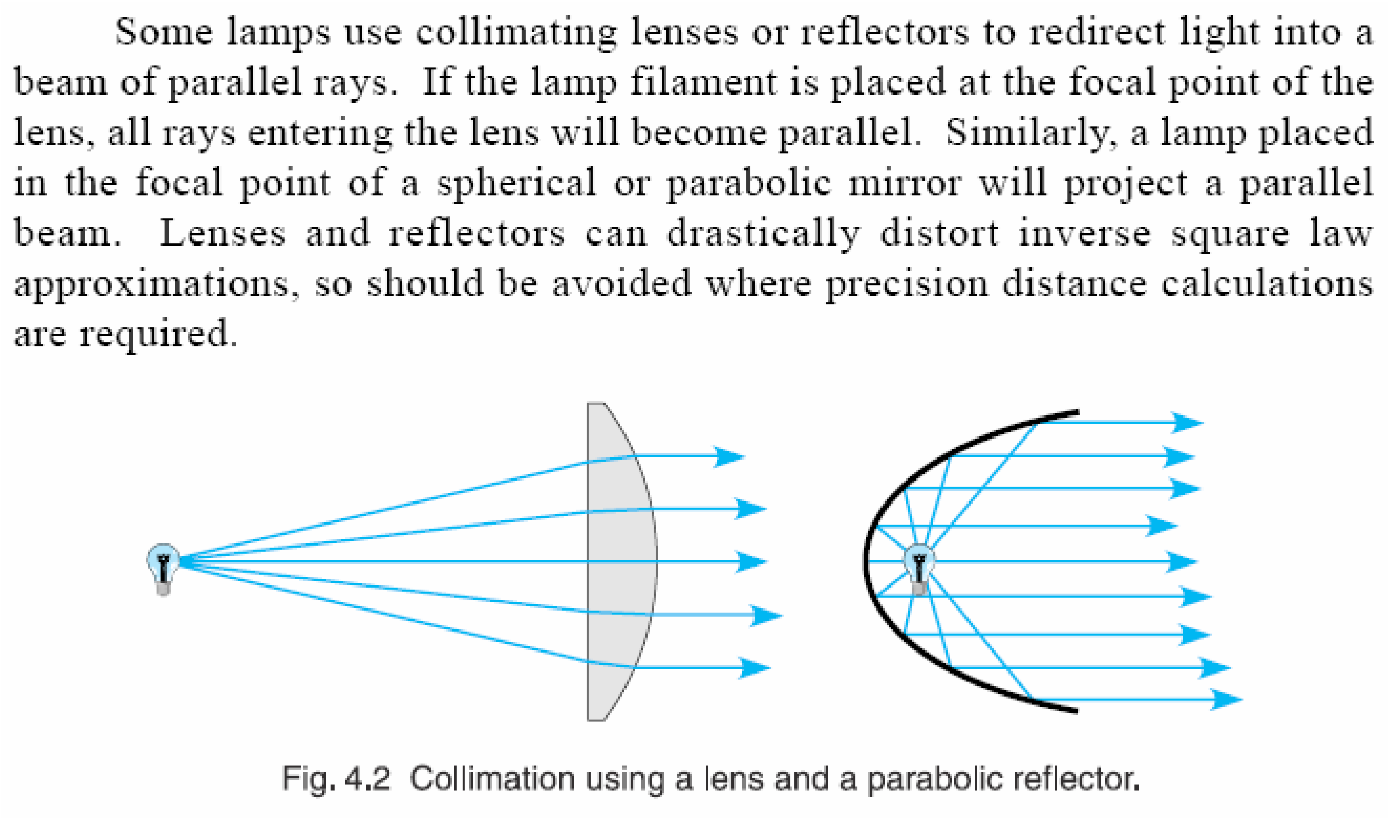


Fig. 4.1 Diffuse transmission and reflectance.

It is often necessary to diffuse light, either through transmission or reflection. Diffuse transmission can be accomplished by transmitting light through roughened quartz, flashed opal, or polytetrafluoroethylene (PTFE, Teflon). Diffusion can vary with wavelength. Teflon is a poor IR diffuser, but makes an excellent visible / UV diffuser. Quartz is required for UV diffusion.

Integrating spheres are coated with $BaSO_4$ or PTFE, which offer >97% reflectance over a broad spectral range with near perfect diffusion. These coatings are, however, quite expensive and fragile.

Manipulating Light – Collimation



Some lamps use collimating lenses or reflectors to redirect light into a beam of parallel rays. If the lamp filament is placed at the focal point of the lens, all rays entering the lens will become parallel. Similarly, a lamp placed in the focal point of a spherical or parabolic mirror will project a parallel beam. Lenses and reflectors can drastically distort inverse square law approximations, so should be avoided where precision distance calculations are required.

Fig. 4.2 Collimation using a lens and a parabolic reflector.

Basic Principles – Point Source Approximation

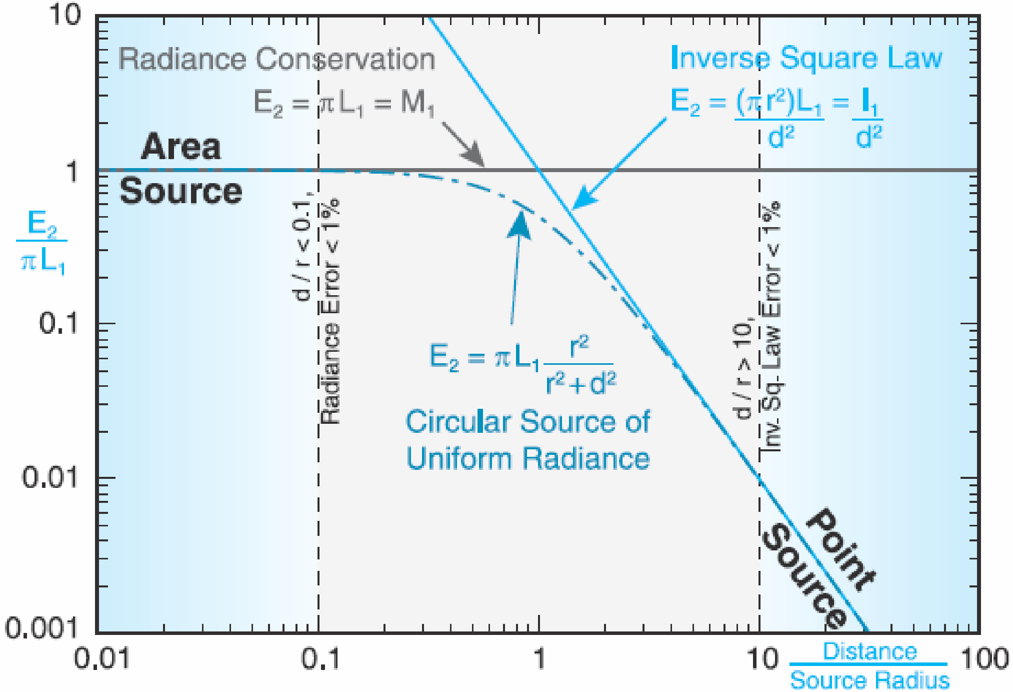


Fig. 6.2 Inverse square law approximation error.

The inverse square law can only be used in cases where the light source approximates a point source. A general rule of thumb to use for irradiance measurements is the "five times rule": the distance to a light source should be greater than five times the largest dimension of the source. For a clear enveloped lamp, this may be the length of the filament. For a frosted light bulb, the diameter is the largest dimension. Figure 6.2 below shows the relationship between irradiance and the ratio of distance to source radius. Note that for a distance 10 times the source radius (5 times the diameter), the error from using the inverse square is exactly 1 %, hence the "five times" approximation.

Note also, that when the ratio of distance to source radius decreases to below 0.1 (1/20 the diameter of the source), changes in distance hardly affect the irradiance (< 1 % error). This is due to the fact that as the distance from the source decreases, the detector sees less area, counteracting the inverse square law. The graph above assumes a cosine response. Radiance detectors restrict the field of view so that the d/r ratio is always low, providing measurements independent of distance.