

Frequently Asked Questions

Dichroic Filters

How do dichroic filters work?

Dichroic filters are used to separate heat from light in low voltage MR-type lamps and in PAR lamps for general lighting and photo-optic applications.

Considering light as wave motions, let us represent a ray of light of a single wavelength as in **Figure 1**. Light of longer wavelength would have a greater distance from crest to crest.

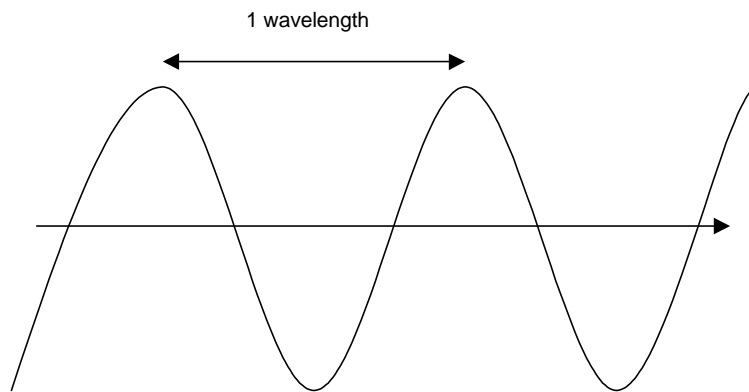


Fig. 1. Wave representation of a ray of light having a single wavelength.

Interference

When two rays of the same wavelength occupy the same path and are in phase, their effects add, as in **Figure 2**. In other words, the light will be brighter. On the other hand, if they are one-half wavelength out of phase and of the same magnitude, as in **Figure 3**, they cancel each other and we have the phenomenon of *interference*. Both of these effects occur in nature in the colors seen in soap bubbles and in other thin films, such as an oil slick on a highway.

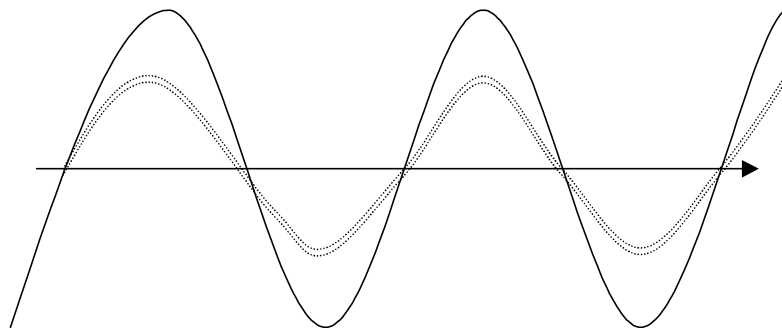


Fig. 2. Rays of light add when they occupy the same path, have the same wavelength, and are in phase.

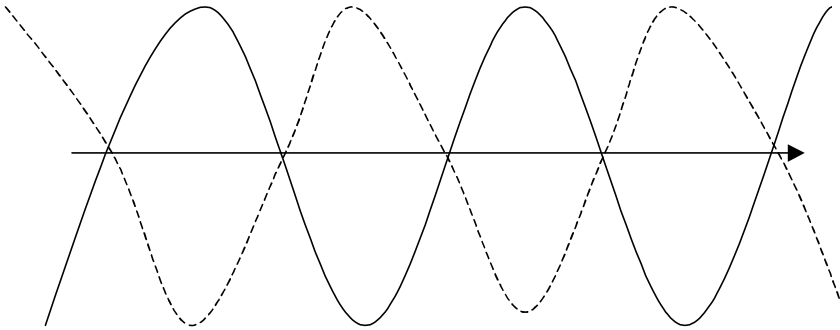


Fig. 3. Two rays of light interfere when they occupy the same path, have the same wavelength, and are opposite in phase.

The effects are exploited in science and industry through the fact that different transparent substances have different refractive indices depending upon the speed at which light travels through them. Here are a few examples:

Material	Refractive Index
Air	1.00
Crown Glass	1.52
Magnesium Fluoride	1.38
Zinc Sulfide	2.30

Whenever a light ray travelling in one medium meets another medium of different refractive index, part of the light is reflected from the boundary surface and part passes into the new medium. If the second material has a higher refractive index than the first one, the reflected ray changes phase by $\frac{1}{2}$ wavelength. On the other hand, if the second material has a lower refractive index, the reflected ray does not change in phase.

Thin Film

Now consider a ray of light travelling in air and striking a film of material having a higher refractive index than air, as in **Figure 4**. The thickness of the film and the wavelength has been greatly exaggerated for illustrative purposes. The part of the light reflected from point A changes phase by half a wavelength. Another part of the ray is reflected from B with no change of phase because the third material has a lower refractive index than the second does. As this ray emerges at point C, it is out of phase with ray **a** by $\frac{1}{2}$ wavelength.

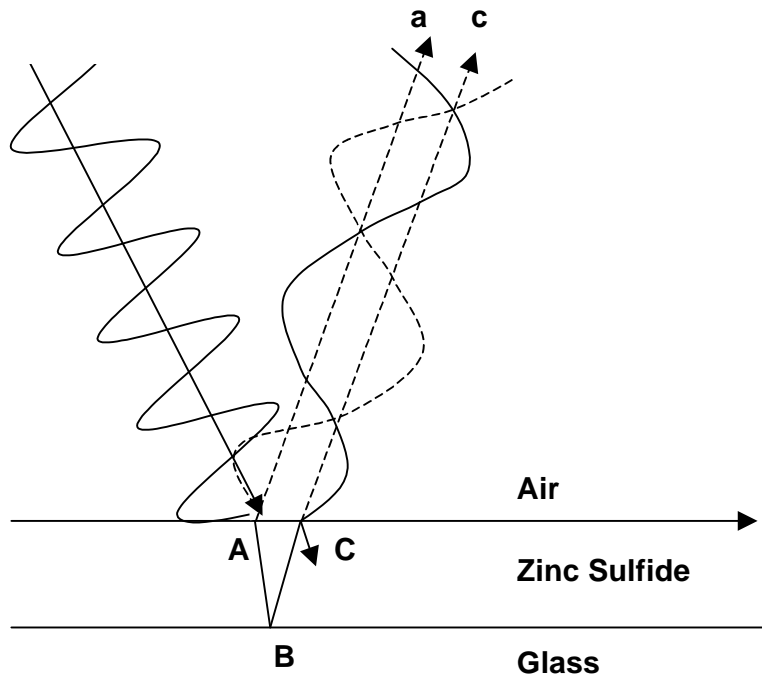


Fig. 4. Interference of reflected light when the film thickness is equal to the wavelength of the light

When the thickness of the film is very small compared to the wavelength of the light, and we are principally concerned with rays striking the surfaces more nearly at right angles, the paths of rays **a** and **c** will coincide for practical purposes and interference will occur. It will not be total because ray **c** will have less energy than ray **a**. There are cases where the film thickness is not small compared to the wavelength of the light. If the film has a thickness of $\frac{1}{2}$ wavelength, the wave **c** will leave point C without change of phase because it has traveled through the film twice. As in the case of the very thin film, it will interfere with ray **a**.

When the film has a thickness equal to $\frac{1}{4}$ wavelength, the ray **c** will be reflected with change of phase, and will therefore add to ray **a**, increasing the brightness of the reflection. These results also occur when the thickness is multiple of $\frac{1}{4}$ wavelength. As a general rule, therefore, for a particular wavelength of light, a film of higher refractive index than its adjacent materials will reflect part of the light when the film thickness is an odd multiple of $\frac{1}{4}$ wavelength, and will not reflect it when the film thickness is an even multiple of $\frac{1}{4}$ wavelength. For example, if the film thickness is equal to three-quarters of a wavelength, interference will occur.

Non-reflecting Films

This principle is used in coating the lenses of cameras, binoculars, and other optical devices. Since the principle depends upon an exact relationship between the film thickness and the wavelength of the light, maximum control can be exercised at only one wavelength. Although in non-reflecting films the maximum effect occurs at only one wavelength, there is a region on both sides of the critical wavelength in which reflections are reduced. In binoculars

and range finders the wavelength band is usually chosen in the yellow-green region of the spectrum where the eye is most sensitive. See **Figure 5** for the response curve of the average human eye.

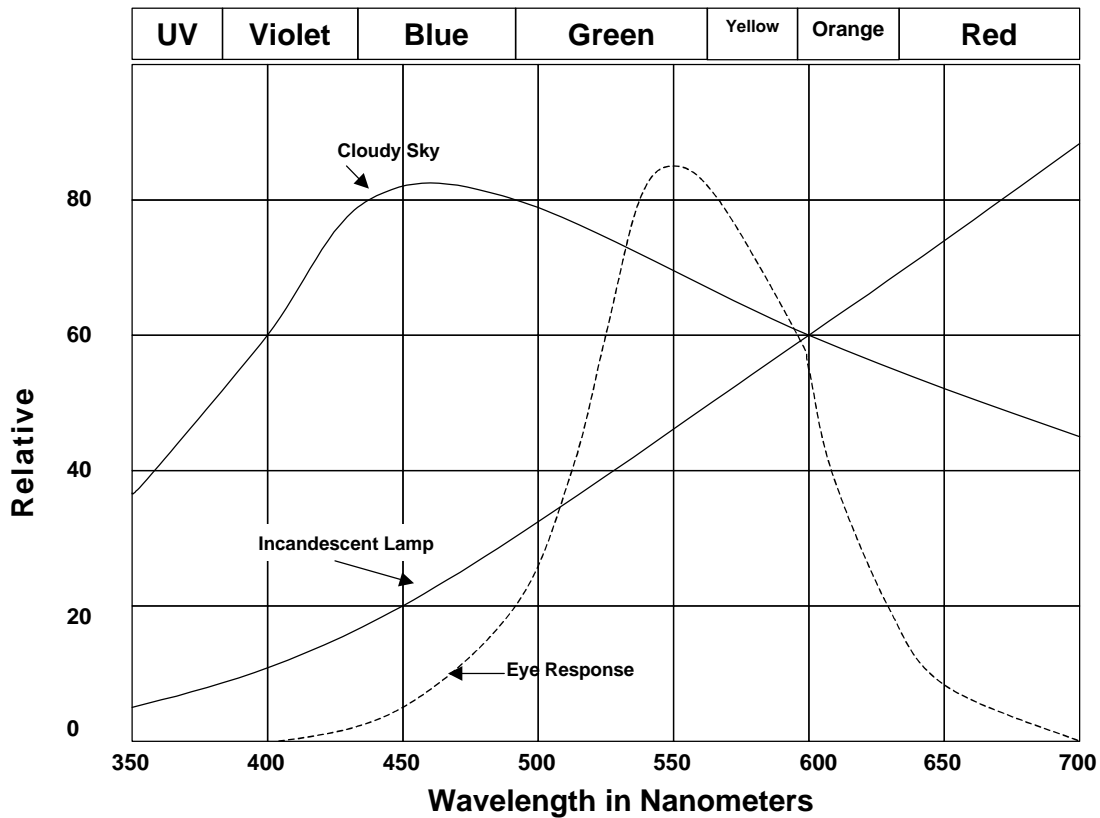


Fig. 5. Spectral energy distribution from an incandescent lamp and a cloudy sky, compared with the response of the average human eye.

Dichroic Lamps

Often the goal is to increase reflections rather than reduce them, while keeping the selective nature of the process. Multiple layers having the proper thickness and refractive indices can reflect most of the energy in one band of wavelengths while transmitting the energy at other wavelengths. This principle is used in dichroic lamps to greatly reduce the amount of heat in the projected beam.

Figure 6 shows the energy distribution from an incandescent lamp, extended beyond the visible range. Note that most of the energy (80%) is emitted in the infrared region, 12.5% in the UV range and only 6.5% are used to produce light. The dichroic lamp has an optical multi-layer coating, which reflects visible light and transmits invisible infrared radiation as shown schematically in **Figure 7**. Of course, the heat must be removed from the lamp housing, but the advantages of keeping it out of the beam are obvious. Therefore, luminaires using dichroic reflector lamps should be ventilated or otherwise designed to provide adequate cooling of the socket and wiring adjacent to the bulb.

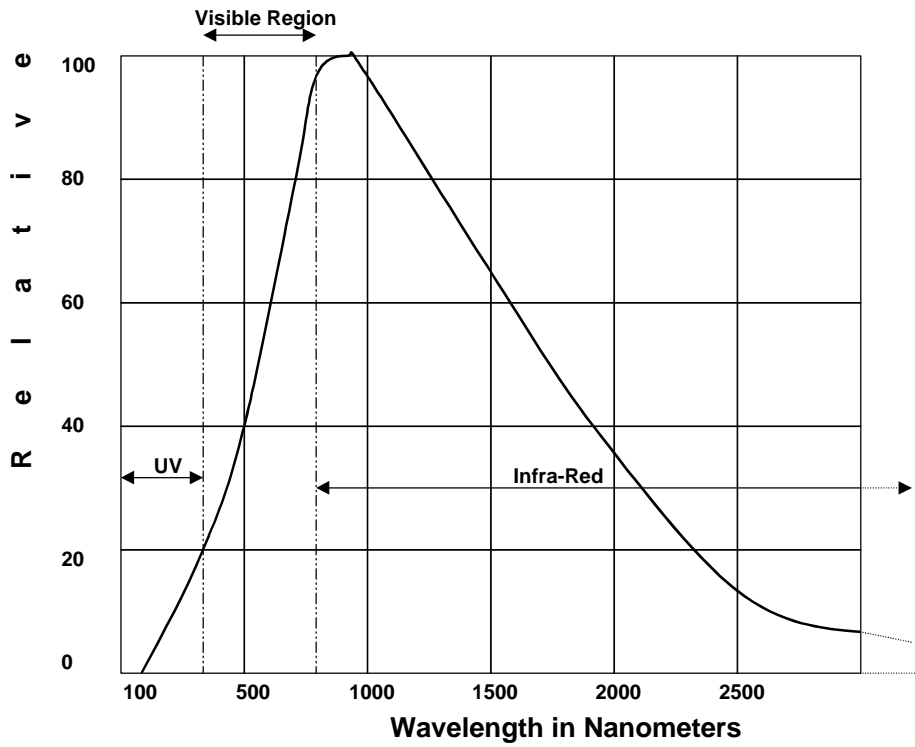


Fig. 6. An incandescent lamp emits much more energy than is included in the visible region. The energy to the right of the visible region is invisible infra-red (radiated heat) and to the left is UV.

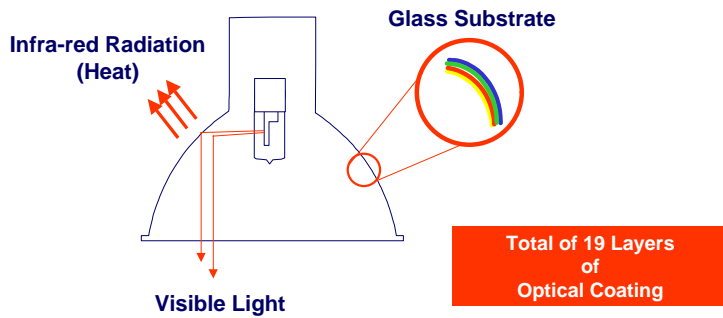


Fig. 7. The dichroic reflector reflects most of the visible light and allows most of the heat (IR radiation) to pass through and out the back of the lamp.