PH 301

ENGINEERING OPTICS

Lecture_Optical Components_10

Optical components: Reflective, refractive & diffractive systems; Mirrors, prisms, gratings, filters, polarizing components.

Mirrors

Dielectric mirrors offer higher reflectivity over a broad spectral range of up to several hundred nanometers. Their coating is more durable making them easier to clean & more resistant to laser damage.

λ = 350-1100 nm

Flatness $\lambda/10$

Flatness $\lambda/10$

High performance super mirror

Dielectric coated square mirror

Elliptical mirror

D-shaped mirror

Wavelength region: **VIS, NIR, Broadband, IR, UV**

Mirror shape: **D-shaped, elliptical, round, square**

Material: **Borofloat (Borosilicate glass), Fused silica,**
N-BK7 (optical borosilicate crown glass), UV grade fused silica,
Zerodur (glass ceramic)

Parabolic mirrors

- Off-axis parabolic mirrors are segments of a full paraboloid with a circular cross-sectional aperture.
- Optical axis is folded 90° & displaced from mechanical axis, giving unobstructed access.
- Parabolic mirrors allow *achromatic collimation or focusing* of light from UV to near IR.
    - Low scatter for UV applications
    - Achromatic focusing & collimation
    - UV-IR & NIR-IR coating options
    - Light-weight with integral mount

Retroreflectors

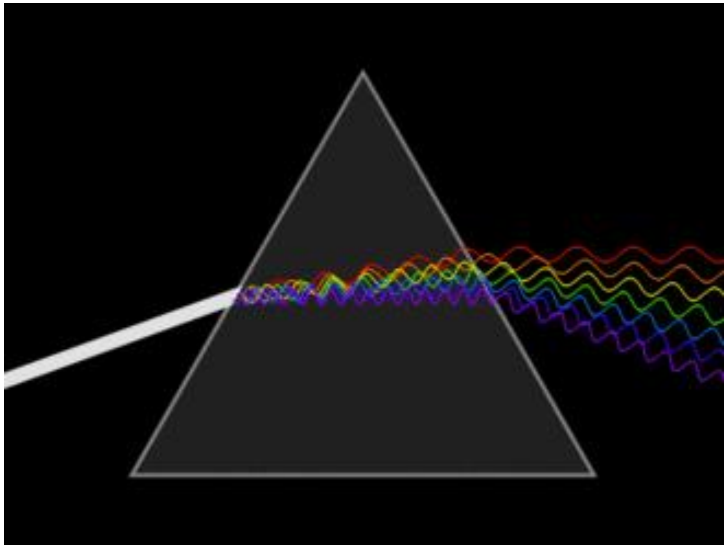
- Use front surface reflection,
- are achromatic, &
- require no wavelength-dependent refraction-offset.

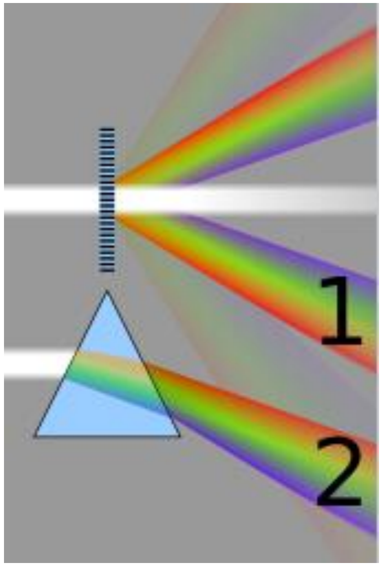
Optical Mirror Mounts






Prisms



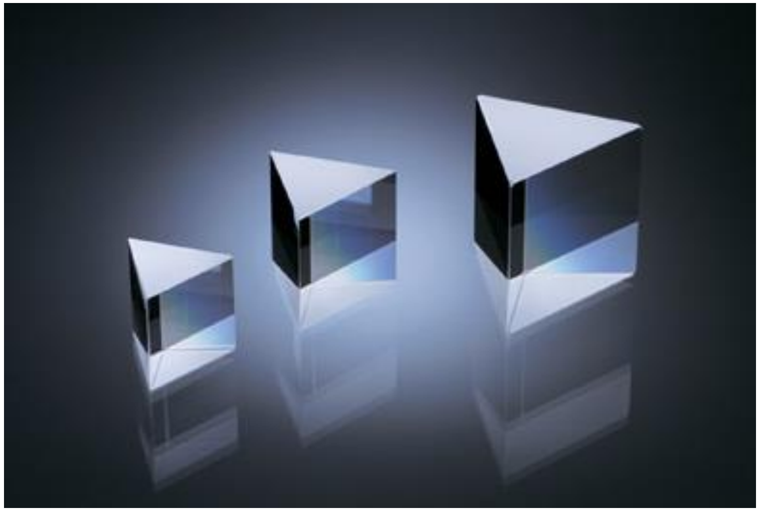


Before Isaac Newton, it was believed that white light was colorless & that prism itself produced color. Newton's experiments demonstrated that all the colors already existed in light in a heterogeneous fashion, & that "corpuscles" (particles) of light were fanned out because particles with different colors traveled with different speeds through prism.

Young & Fresnel combined Newton's particle theory with Huygens' wave theory to show that color is the visible manifestation of light's wavelength.

Prisms

An optical prism uses flat surfaces with an angle between them to refract light.



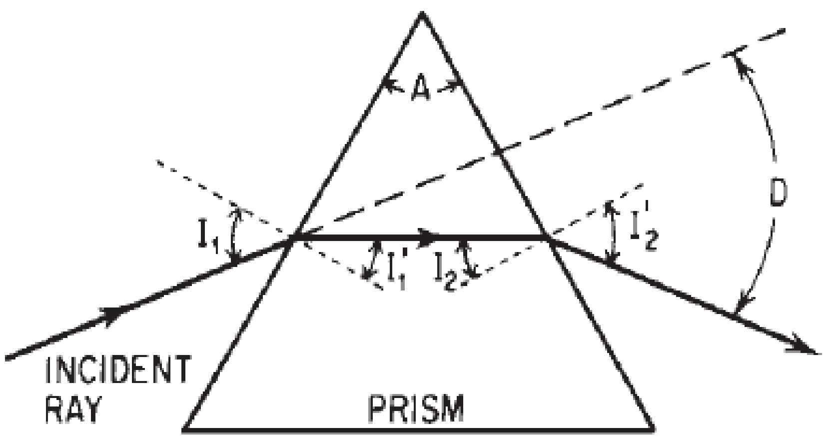
Types of prisms

1. **Dispersive prisms**: to break up light into its constituent spectral colors
2. **Reflective prisms**: to reflect light (to flip, invert, rotate, deviate, or displace)
3. **Beam splitting prisms**: splitting a beam into two or more beams
4. **Polarizing prisms**: split a beam of light into components of varying polarization
5. **Deflecting prisms**: deflect a beam of light by a fixed angle (beam steering)

Prisms

In spectral instruments (spectroscopes, spectrographs, spectrophotometers, etc.) their function is to disperse the light or radiation; that is, to separate different wavelengths.

In other applications, prisms are used to displace, deviate, or reorient a beam of light or an image. In this type of use, the prism is carefully arranged so that it will *not separate* the different colors.



Deviation of a light ray by a refracting prism

Dispersing Prisms

A light ray strikes 1st surface at an angle of incidence I_1 & is refracted downward, making an angle of refraction I'_1 with normal to surface. Ray is thus deviated through an angle of $(I_1 - I'_1)$ at this surface.

At 2nd surface, ray is deviated through an angle $(I'_2 - I_2)$.

Total deviation of the ray is

$$D = (I_1 - I_1') + (I_2' - I_2)$$

From geometry of Figure,

$$\angle I_2 = I_1 + I_2' - A$$

where A is vertex angle of prism.

To compute deviation produced by prism, apply Snell's law:

$$n \sin I_1' = 1 \sin I_1$$

$$\sin I_1' = \frac{1}{n} \sin I_1$$

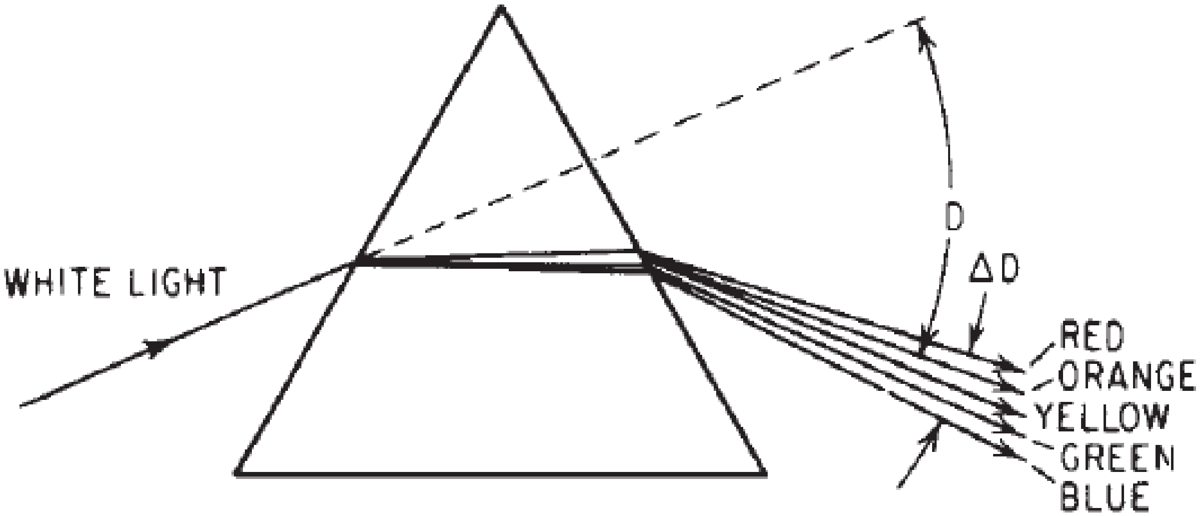
$$I_2 = A - I_1'$$

$$\sin I_2' = n \sin I_2$$

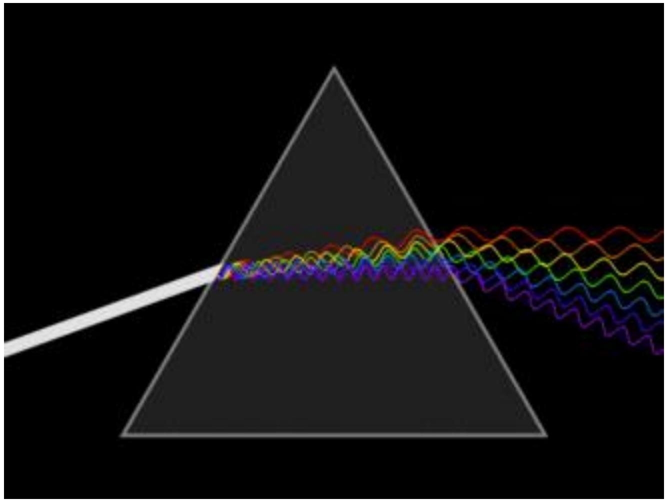
$$D = I_1 - A + \arcsin[(n^2 - \sin^2 I_1)^{1/2} \sin A - \cos A \sin I_1]$$

Deviation is a function of prism index & it will increase as index is raised.

For optical materials, r.i. is higher for short wavelengths (blue light) than for long wavelengths (red light). Therefore deviation angle will be greater for blue light than red.



Dispersion of white light into its component wavelengths by a refracting prism.



Variation of deviation angle with wavelength is called dispersion of prism.

$$D = I_1 - A + \arcsin[(n^2 - \sin^2 I_1)^{1/2} \sin A - \cos A \sin I_1]$$

Differentiation the Eq. with respect to *n*, expression for dispersion can be found.

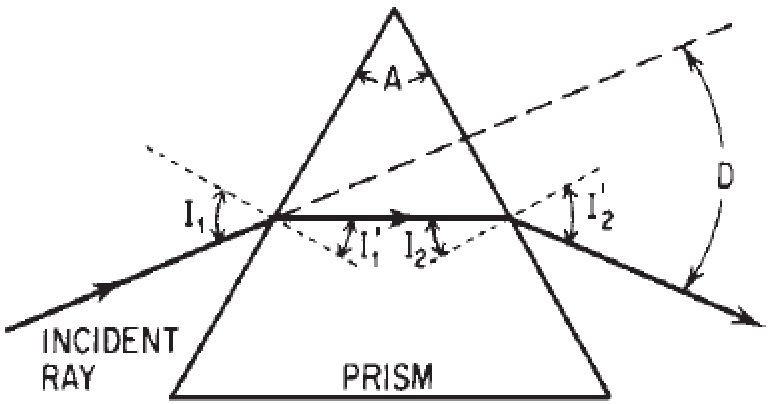
$$dD = \frac{\cos I_2 \tan I_1' + \sin I_2}{\cos I_2'} dn$$

Angular dispersion with respect to wavelength,

$$\frac{dD}{d\lambda} = \frac{\cos I_2 \tan I_1' + \sin I_2}{\cos I_2'} \frac{dn}{d\lambda}$$

$\frac{dn}{d\lambda}$ **= Index dispersion of prism material.**

Thin Prism



Deviation of a light ray by a refracting prism

If all angles involved in a prism are very small, we can substitute angle itself for its sine. This case occurs when prism angle *A* is small & when ray is almost at normal incidence to prism faces.

Under these conditions,

$$I_1' = \frac{I_1}{n}$$

$$I_2 = A - I_1' = A - \frac{I_1}{n}$$

$$I_2' = nI_2 = nA - I_1$$

$$D = I_1 + I_2 - A = I_1 + nA - I_1 - A$$

$$D = A(n-1)$$

If prism angle *A* is small but angle of incidence *I* is not small, we get following approximate expression for *D* (neglecting powers of *I* larger than 3),

$$D = A(n-1)\left[1 + \frac{I^2(n+1)}{2n} + \ldots\right]$$

These expressions are of great utility in evaluating the effects of a small prismatic error in the construction of an optical system since it allows the resultant deviation of the light beam to be determined quite readily.

Dispersion of a thin prism is obtained by differentiating following Eq. with respect to *n*.

$$D = A(n-1) = An - A$$

$$\frac{dD}{dn} = A$$

$$dD = Adn = D\frac{dn}{(n-1)}$$

$$\Rightarrow \qquad dD = D\frac{dn}{(n-1)}$$

Minimum Deviation

Deviation of a prism is a function of the initial angle of incidence *I_1*. It can be shown that the deviation is at a minimum when the ray passes symmetrically through the prism. In this case,

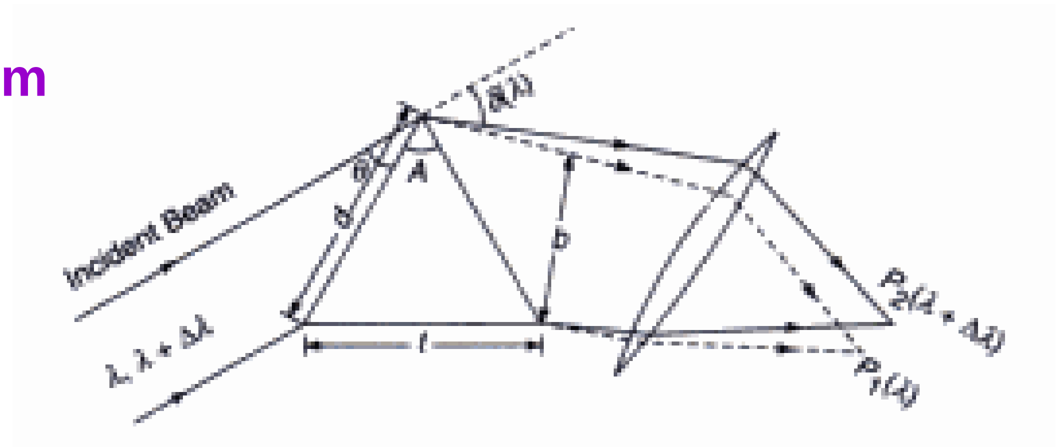
$$I_1 = I_2' = \frac{1}{2}(A + D) \quad \& \qquad I_1' = I_2 = A/2$$

so that if we know the prism angle *A* & minimum deviation angle *D_0* it is a simple matter to compute index of prism from

$$n = \frac{\sin I_1}{\sin I_1'} = \frac{\sin 1/2(A + D_0)}{\sin 1/2A}$$

This is a method for precise measurement of index, since minimum deviation position is readily determined on a spectrometer. This position for prism is also approximated in most spectral instruments because it allows largest diameter beam to pass through a given prism & also produces smallest amount of loss due to surface reflections.

Resolving power of a prism



$$n(\lambda) = \frac{\sin \frac{A+\delta(\lambda)}{2}}{\sin \frac{A}{2}}$$

$$\frac{dn}{d\lambda} = \frac{1}{\sin \frac{A}{2}} \cos\left[\frac{A+\delta(\lambda)}{2}\right] \frac{1}{2} \frac{d\delta}{d\lambda}$$

Resolving power, R

$$R = \frac{\lambda}{\Delta\lambda} = t\frac{dn}{d\lambda}$$

Cauchy formula: Wavelength dependence of r.i.

$$n = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \ldots\ldots.$$

Negative sign implies that r.i. decreases with increase in wavelength.

$$\frac{dn}{d\lambda} = -\left[\frac{2B}{\lambda^3} + \frac{4C}{\lambda^5} + \ldots.\right]$$