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Modern Optical Engineering

The Design of Optical Systems

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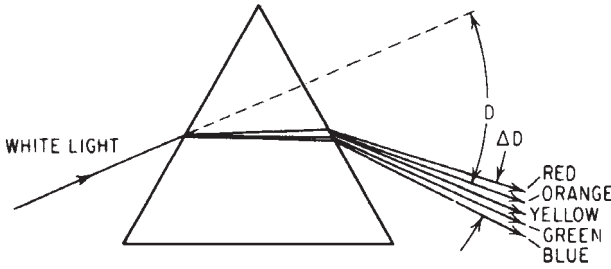


Figure 4.2 The dispersion of white light into its component wavelengths by a refracting prism (highly exaggerated).

almost at normal incidence to the prism faces. Under these conditions, we can write

$$\begin{aligned}
 i'_1 &= \frac{i_1}{n} \\
 i_2 &= A - i'_1 = A - \frac{i_1}{n} \\
 i'_2 &= ni_2 = nA - i_1 \\
 D &= i_1 + i'_2 - A = i_1 + nA - i_1 - A
 \end{aligned}$$

and finally

$$D = A(n - 1) \quad (4.8a)$$

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

$$D = A(n - 1) \left[1 + \frac{I^2(n + 1)}{2n} + \dots \right] \quad (4.8b)$$

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.

The dispersion of a “thin” prism is obtained by differentiating Eq. 4.8a with respect to n , which gives $dD = Adn$. If we substitute A from Eq. 4.8a, we get

$$dD = D \frac{dn}{(n - 1)} \quad (4.9)$$

Now the fraction $(n - 1)/\Delta n$ is one of the basic numbers used to characterize optical materials. It is called the reciprocal relative dispersion,

Abbe V number, or V -value. Ordinarily n is taken as the index for the helium d line ($0.5876\ \mu\text{m}$) and Δn is the index difference between the hydrogen F ($0.4861\ \mu\text{m}$) and C ($0.6563\ \mu\text{m}$) lines, and the V -value is given by

$$V = \frac{n_d - 1}{n_F - n_C} \quad (4.10)$$

Making the substitution of $1/V$ for $dn/(n - 1)$ in Eq. 4.9, we get

$$dD = \frac{D}{V} \quad (4.11)$$

which allows us to immediately evaluate the chromatic dispersion produced by a thin prism.

4.4 Minimum Deviation

The 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 $I_1 = I'_2 = \frac{1}{2}(A + D)$ and $I'_1 = I_2 = A/2$, so that if we know the prism angle A and the minimum deviation angle D_0 it is a simple matter to compute the index of the prism from

$$n = \frac{\sin I_1}{\sin I'_1} = \frac{\sin \frac{1}{2}(A + D_0)}{\sin \frac{1}{2}A} \quad (4.12)$$

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

4.5 The Achromatic Prism and the Direct Vision Prism

It is occasionally useful to produce an angular deviation of a light beam without introducing any chromatic dispersion. This can be done by combining two prisms, one of high-dispersion glass and the other of low-dispersion glass. We desire the sum of their deviations to equal $D_{1,2}$ and the sum of their dispersions to equal zero. Using the equations for "thin" prisms (Eqs. 4.8 and 4.11), we can express these requirements as follows:

$$\text{Deviation } D_{1,2} = D_1 + D_2 = A_1 (n_1 - 1) + A_2 (n_2 - 1)$$