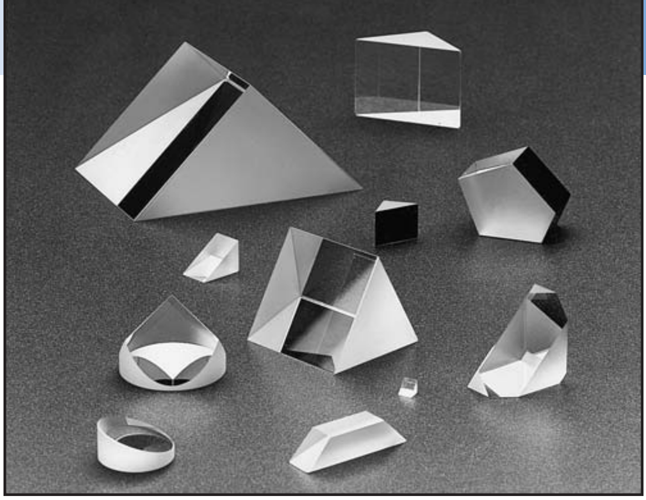

Prisms

Prisms are blocks of optical material whose flat, polished sides are arranged at precisely controlled angles to each other. Prisms may be used in an optical system to deflect or deviate a beam of light. They can invert or rotate an image, disperse light into its component wavelengths, and be used to separate states of polarization.

PRISM ORIENTATION

The orientation of a prism determines its effect on a beam of light or an image.

A viewer looks through a prism at an object and sees a virtual image (see Figure 1.37). This image may be displaced from the original object, or, if a dove prism is used, it may coincide with the object. Furthermore, image orientation may differ from the object; in the case of a right-angle prism, the image is reversed.

A real image (see Figure 1.38) can be formed only if imaging optics are present in the system. Without imaging optics, the image is virtual. A virtual image has the same orientation as the real image shown, but it can be viewed by the observer only by looking back through the prism system.

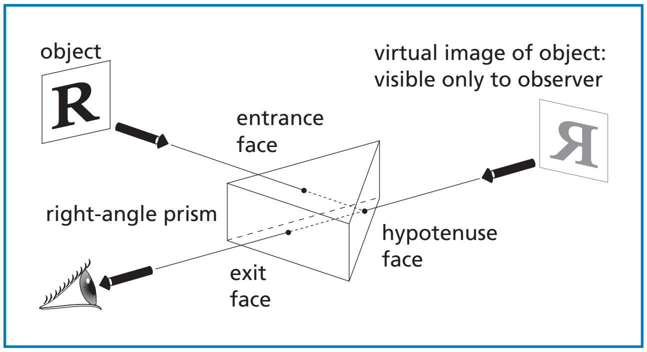

Figure 1.37 **Virtual imaging using a prism**

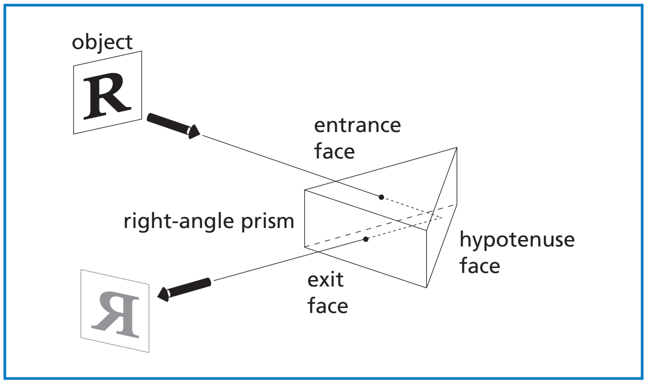

Figure 1.38 **Real imaging using a prism**

TOTAL INTERNAL REFLECTION

Rays incident upon a glass/air boundary (i.e., an internal reflection) at angles that exceed the critical angle are reflected with 100-percent efficiency regardless of their initial polarization state. The critical angle is given by

$$\theta_c(\lambda) = \arcsin\frac{1}{n_\lambda} \tag{1.67}$$

and depends on the refractive index, which is a function of wavelength. If, at some wavelength, the refractive index should fall to less than $\sqrt{2} = 1.414$, the critical angle will exceed 45 degrees, and total internal reflection (TIR) will fail for a collimated beam internally incident at 45 degrees on the hypotenuse face of a right-angle prism. Reflectance decreases rapidly at angles of incidence smaller than the critical angle.

The index of BK7 is sufficiently high to guarantee the TIR of a collimated beam at 45 degrees internal incidence over the visible and near-infrared region. The possibility of significant TIR failure with convergent or divergent beams should be kept in mind if polarization is important. TIR can also fail if the hypotenuse face is not kept extremely clean. Even an almost invisible fingerprint can lead to TIR failure. An aluminum- or silver-coated hypotenuse is recommended for applications where the right-angle prism is frequently handled, or where convergent or divergent beams are used. There is a slight loss of reflectance at all internal angles with the coating, and no critical angle exists.

ABERRATIONS FOR PRISMS

Prisms will introduce aberrations when they are used with convergent or divergent beams of light. Using prisms with collimated or nearly collimated light will help minimize aberrations. Conjugate distances that include prisms should be long.

DISPERSING PRISMS

Dispersing prisms are used to separate a beam of white light into its component colors. Generally, the light is first collimated and then dispersed by the prism. A spectrum is then formed at the focal plane of a lens or curved mirror. In laser work, dispersing prisms are used to separate two wavelengths following the same beam path. Typically, the dispersed beams are permitted to travel far enough so the beams separate spatially.

A prism exhibits magnification in the plane of dispersion if the entrance and exit angles for a beam differ. This is useful in anamorphic (one-dimensional) beam expansion or compression, and may be used to correct or create asymmetric beam profiles.

As shown in Figure 1.39, a beam of width W_1 is incident at an angle α on the surface of a dispersing prism of apex angle A. The angle of refraction at the first surface, β, the angle of incidence at the second surface, γ, and the angle of refraction exiting the prism, δ, are easily calculated:

$$\beta = \sin^{-1}((\sin\alpha) / \eta)$$
$$\gamma = A - \beta$$
$$\delta = \sin^{-1}(\eta \sin\gamma)$$

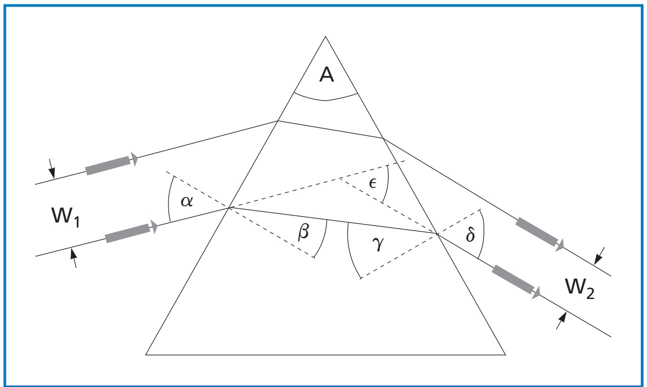

Figure 1.39 **Diagram of dispersing prism**

The beam deviation, ϵ, is of greatest importance. It is the angle the exit beam makes with its original direction.

$$\epsilon = \alpha + \delta - A \quad (1.68)$$

The magnification W_2/W_1 is given by:

$$M = \frac{\cos\delta\cos\beta}{\cos\alpha\cos\gamma} \quad (1.69)$$

The resolving power of a prism spectrometer angle α, the angular dispersion of the prism is given by:

$$\frac{d\delta}{d\lambda} = \left(\frac{\sin A}{\cos\delta\cos\beta}\right)\left(\frac{d\eta}{d\lambda}\right) \quad (1.70)$$

If the spectrum is formed by a diffraction limited focal system of focal length f, the minimum spot size is dx ~ $f\lambda$/ W. This corresponds to a minimum angular resolution dδ ~ λ/w for a beam of diameter w. The diffraction limited angular resolution at a given beam diameter sets the limit on the spectral resolving power of a prism. Setting the expression for dδ equal to the minimum angular resolution, we obtain:

$$RP = \frac{\lambda}{d\lambda} = \left(\frac{w_2 \sin A}{\cos\delta\cos\beta}\right)\left(\frac{d\eta}{d\lambda}\right) \quad (1.71)$$

where RP is the resolving power of the prism.

At a given wavelength, the beam deviation ϵ is a minimum at an angle of incidence:

$$\alpha_{\text{min dev}} = \sin^{-1}[\eta \sin(A/2)] \quad (1.72)$$

where η is the prism index of refraction at that wavelength. At this angle, the incident and exit angles are equal, the prism magnification is one, and the internal rays are perpendicular to the bisector of the apex angle.

By measuring the angle of incidence for minimum deviation, the index of refraction of a prism can be determined. Also, by proper choice of apex angle, the equal incident and exit angles may be made Brewster's angle, eliminating losses for p-polarized beams. The apex angle to choose is:

$$A = \pi - 2\theta_B \quad (1.73)$$

If, in addition, the base angles of the prism are chosen as Brewster's angle, an isosceles Brewster prism results.

Another use is illustrated next.

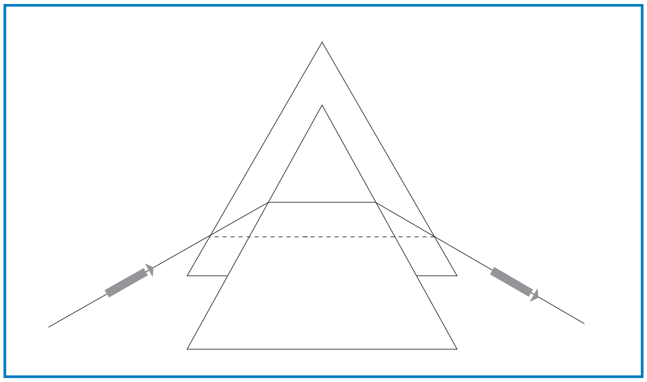

Figure 1.40 **Translation of a prism at minimum deviation**

At minimum deviation, translating a prism along the bisector of the apex angle does not disturb the direction of the output rays. See Figure 1.40. This is important in femtosecond laser design where intracavity prisms are used to compensate for group velocity dispersion. By aligning a prism for minimum deviation and translating it along its apex bisector, the optical path length in material may be varied with no misalignment, thus varying the contribution of the material to overall group velocity dispersion. Finally, it is possible to show that at minimum deviation

$$\mathrm{RP} = \left(b_2 - b_1\right)\frac{d\eta}{d\lambda} \qquad (1.74)$$

where the relevant quantities are defined in Figure 1.41.

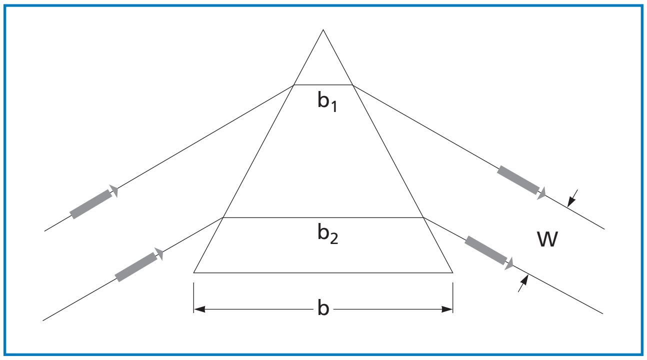

Figure 1.41 **Ray path lengths of a prism at minimum deviation**

If the beam is made to fill the prism completely, $b_1 = 0$, and $b_2 = b$, the base of the prism. So, we have the classical result that the resolving power of a prism spectrometer is equal to the base of the prism times the dispersion of the prism material.

As an example, consider CVI Melles Griot EDP-25-F2 prism, operating in minimum deviation at 590 nm. The angle of incidence and emergence are both then 54.09° and $d\eta/d\lambda$ is $-0.0854\ \mu m^{-1}$ for F2 glass at 590 nm. If the 25-mm prism is completely filled, the resolving power, $\lambda/d\lambda$, is 2135. This is sufficient to resolve the Sodium D lines.

PELLIN BROCA PRISMS

In a Pellin Broca prism, an ordinary dispersing prism is split in half along the bisector of the apex angle. Using a right angle prism, the two halves are joined to create a dispersing prism with an internal right angle bend obtained by total internal reflection, as shown in Figure 1.42.

In principle, one can split any type of dispersing prism to create a Pellin Broca prism. Typically the Pellin Broca prism is based on an Isosceles Brewster prism. Provided the light is *p*-polarized, the prism will be essentially lossless.

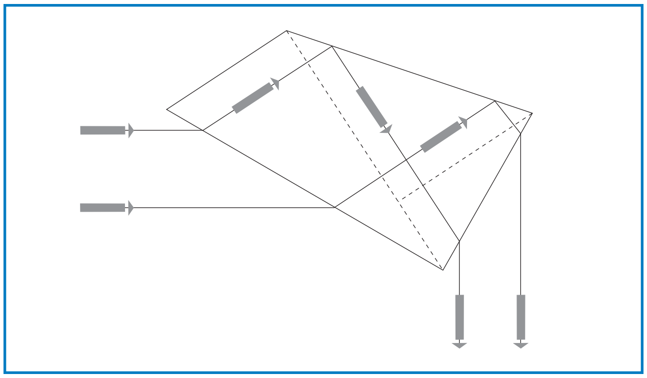

Figure 1.42 **One of the wavelengths deviates at exactly 90° to its initial direction**

Suppose wavelengths λ_1 and λ_2 are superimposed in a collimated beam, as at the output of a harmonic generating crystal, the diagram in Figure 1.42 suggests that it is always possible to find a rotation of the prism in its plane that ensures that one of the two wavelengths will operate at minimum deviation when refracting at the input face of the first of the half-dispersing prisms. This means that it will enter the right angle prism normal to one of its faces, be turned exactly 90°, be presented to the second half-dispersing prism in minimum deviation, and hence exit the Pellin Broca prism deviated at exactly 90° to its initial direction.

A simple dispersing prism always deviates the longer wavelength less than the shorter wavelength. In a Pellin Broca prism, whether the longer wavelength is deviated more or less depends on the orientation of the prism. This is an important consideration when designing a high power Pellin Broca beam separator, as shown in Figures 1.43 and 1.44.

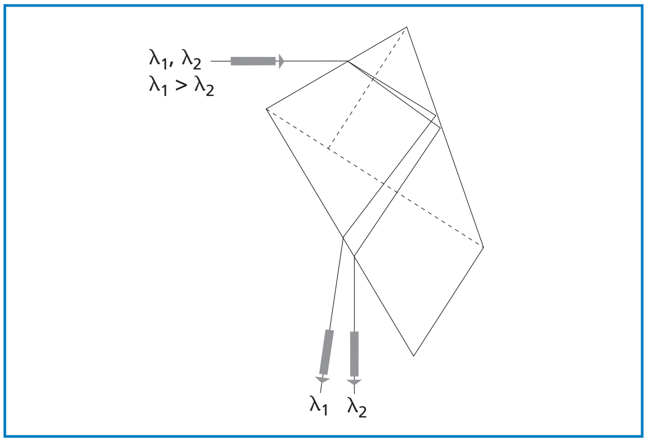

Figure 1.43 **Longer wavelength is deviated more than the shorter wavelength**

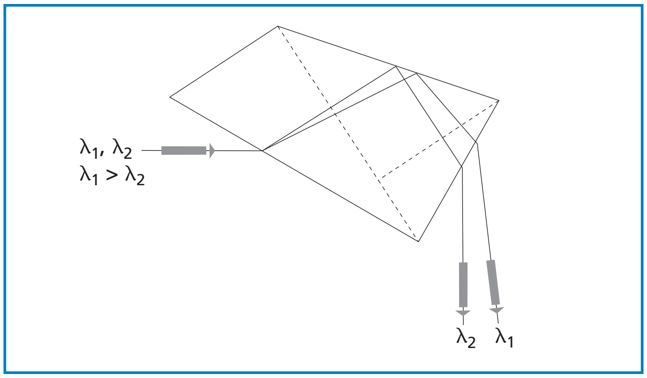

Figure 1.44 **Longer wavelength is deviated less than the shorter wavelength**

CVI Melles Griot offers Brewster angle Pellin Brocca prisms in a number of sizes and materials. BK7 prisms are used in the visible and near IR, and is the least expensive. UV-grade fused silica Pellin Broca prisms are used from 240 nm to 2000 nm. Excimer-grade prisms are used in the 180-nm to 240-nm region. Crystal-quartz Pellin Broca prisms are specifically designed for high-power Q-switched 266-nm laser pulses at fluence levels of 50 mJ/cm^2. Fused silica prisms track (i.e., suffer internal catastrophic damage) above this fluence, probably due to self-focusing.

PORRO PRISMS

A Porro prism, named for its inventor Ignazio Porro, is a type of reflection prism used to alter the orientation of an image. In operation, light enters the large face of the prism, undergoes total internal reflection twice from the 45° sloped faces, and exits again through the large face. An image traveling through a Porro prism is rotated by 180° and exits in the opposite direction offset from its entrance point, as shown in Figure 1.45. Since the image is reflected twice, the handedness of the image is unchanged. Porro prisms have rounded edges to minimize breakage and facilitate assembly.

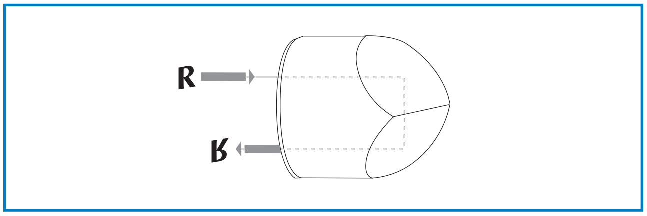

Figure 1.45 **Porro prisms retroreflect and invert the image**

Porro prisms are most often used in pairs, forming a double Porro prism, as shown in Figure 1.46. A second prism, rotated 90° with respect to the first, is placed such that the beam will traverse both prisms. The net effect of the prism system is a beam parallel to but displaced from its original direction, with the image rotated 180°. As before, the handedness of the image is unchanged.

Double Porro prism systems are used in small optical telescopes to reorient an inverted image and in many binoculars to both re-orient the image and provide a longer, folded distance between the objective lenses and the eyepieces.

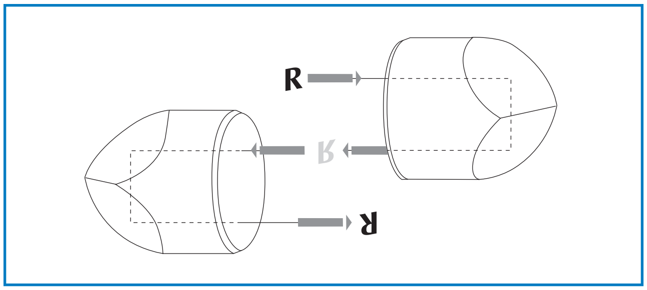

Figure 1.46 **Double porro prism results in a beam parallel to but displaced from its original direction, with the image rotated 180°**