PRISM POTPOURRI

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The number of optical applications employing prisms is nearly as great as the number of prism designs on record. Sorting out the prism designs can be tricky, since two prisms may have the same optical effect on an incident beam.

What is a prism, anyway? It is a solid piece of optically transparent material with planar exterior surfaces, one or more of which may be silvered. Depending upon the geometry of the prism and the angle of incidence of the impinging beam, refraction and reflection within the prism will invert, reverse and/or displace the incident beam. Normally, interactions at two or more prism surfaces are required to produce the desired effect.

In addition to refraction at entrance and exit surfaces and intermediate air gaps, prisms modify incident light by reflection, either from silvered faces or by total internal reflection (TIR) from an uncoated face. Prisms must be kept scrupulously clean; even a nearly invisible fingerprint on an uncoated surface can frustrate TIR, deflecting the image out of the optical system prematurely.

And what is next to cleanliness? Collimation, that's what. Using prisms (other than constant deviation prisms) in converging or diverging beams will introduce aberrations not present in collimated optical systems. While these aberrations can be compensated for elsewhere in the optical system, it is simpler and generally cheaper to collimate the input beam. Conjugate distances that include prisms should be long.

Right-Angle Prisms

Perhaps the simplest of the imaging prisms is the 45°-45°-90° prism (**Fig. 1**). It is often preferred to an inclined mirror in applications involving severe acoustic or inertial loads because it is easier to mount and deforms less than a mirror. Very high transmission can be achieved by using the hypotenuse face in TIR mode and anti-reflection-coating the entrance and exit faces. Alternatively, the hypotenuse face can be coated with either metallic or dielectric coatings and used in an external reflection mode. In either case, the beam is deflected through a 90° angle.

Porro Prisms

The porro prism is a special case of a 45°-45°-90° right-angle prism, where the beam is incident perpendicularly on the hypotenuse face. Two total internal reflections invert the image. The porro prism is widely used as an erecting element in telescopes and binoculars, frequently with two porros mounted hypotenuse-to-hypotenuse with roof edges perpendicular, as shown in **Fig. 2**.

When mounting two porro prisms in this manner, the roof edges must be exactly 90° to one another. Any deviation from this value will result in the outgoing image being rotated through twice the angular mounting error. Note that in this configuration, the image is inverted, reversed and displaced from its original path.

Roof (or Amici) Prisms

Complicating the isosceles right triangle prism picture is the roof prism, a prism whose hypotenuse face has been ground down on the outer (long) edges to form a 90° TIR roof. Its shape is further complicated by the common practice of trimming away glass not contributing to the useful aperture, to reduce size and weight.

The roof prism finds application in situations that demand both right-angle deflection and image erection (a combination of left-to-right reversion and top-to-bottom inversion, equivalent to a 180° rotation about the optical axis), as in some instrument viewfinders. The image reversal depicted in **Fig. 3** comes from two TIR reflections (not shown), one from each side of the roof.

Penta-prisms

Roof and right-angle prisms are not the only 90° deviation prisms. The penta-prism also deviates an image by 90°, but does it by going "the long way around" (a 270° deviation). The penta-prism neither inverts nor reverses the image as it is deviated by 90° (**Fig. 4**). Further, this is a constant deviation prism — every ray transmitted by the useful aperture is deviated 90°, regardless of the angles between these rays and the optical axis. However, the internal geometry of the prism precludes TIR operation, requiring reflective coatings on the active surfaces.

Because of its constant deviation property, the penta-prism is especially important in applications where prism orientation cannot be precisely controlled (*e.g.*, because of vibration). This prism is commonly used in optical tooling, alignment, rangefinding, surveying and other instrumental applications. For example, reflection normal to the surface of a calm pool of mercury, seen through a penta-prism, establishes an accurate horizontal reference.

Dove Prisms

Dove prisms are used as image rotators in a variety of optomechanical systems. As the prism is rotated about the

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optical axis, the image passing through will rotate at twice the prism's angular rate (see **Fig.** 5). Because the ray path through the prism is quite long (prism length is typically five times its height), collimation of the input beam is particularly important.

The useful aperture of a Dove prism can be conveniently doubled by silvering the hypotenuse face and cementing this face to the hypotenuse face of an identical, but uncoated, Dove prism. Overall transmission for the double-Dove is slightly reduced by the substitution of the metallic reflecting film for the usual TIR surface.

Pechan Prisms

On occasions when the Dove prism cannot be used (*e.g.*, in converging or diverging beams), the Pechan prism (**Fig.** 6) is sometimes employed. Like the Dove prism, the Pechan is used as a derotation prism, with the image rotating at twice the angular rate of the prism. The air gap must be maintained with a uniform spacing, lest nonnormal incidence lead to image aberrations. (*Ed. note: Beware! This is one of at least three prism designs sometimes referred to as Schmidt prisms.)*

Wedge Prisms

Wedge prisms are used as beam-steering elements in optical systems, playing a role in optics analogous to that of the wobble plate in mechanics. The (minimum) deviation of deflection D experienced by a ray in passing through a thin wedge of apex angle A is approximately given by $D=(n-1)A$, where n is the refractive index and the incident ray is assumed to be perpendicular to the first face.

The "power" (Δ) of a prism is measured in prism diopters, which are in turn defined as the number of 1 cm deflections measured at a distance of 1 m from the prism. Thus, $\Delta = 100 \tan (D)$.

By combining two wedges of equal power, in near contact, and independently rotating them about an axis roughly paralleling the normals of their adjacent faces, a ray passing through the combination can be steered within a narrow cone about the path of the undeviated ray (see **Fig.** 7). The angular radius of this cone is approximately *2D*. Wedge prisms are most frequently used for laser beam steering and schlieren system calibration.

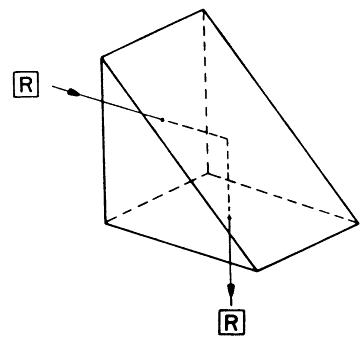

Fig. 1. Right-angle prism.

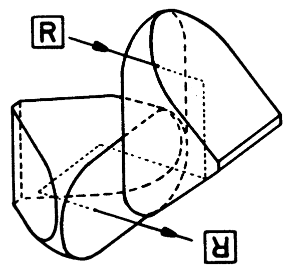

Fig. 2. Two porro prisms, as used in binoculars.

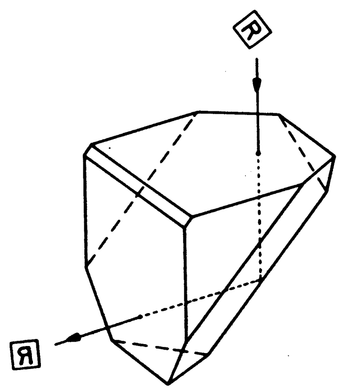

Fig. 3 Roof (or Amici) prism.

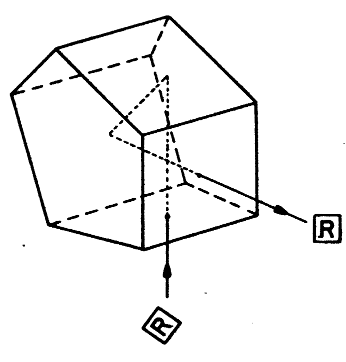

Fig. 4. Penta-prism.

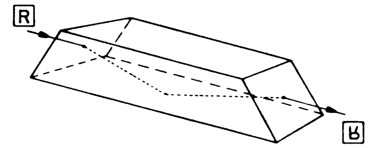

Fig. 5. Dove prism.

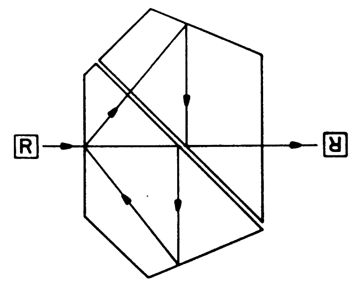

Fig. 6. Pechan prism.

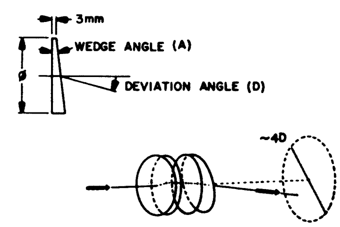

Fig. 7. Wedge prisms used for beam steering.

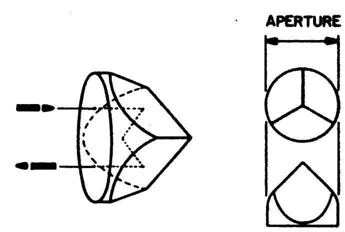

Fig. 8. Corner cube.

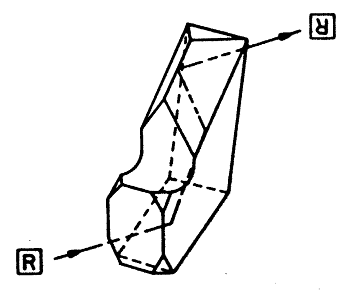

Fig. 9. Leman prism.

Retroreflectors

The trihedral retroreflector (corner cube) has the property that any ray entering the effect aperture will be reflected and emerge from the entrance/exit face parallel to itself (Fig. 8). A uniform incident beam, exactly filling the effective aperture, is reflected exactly back on itself. These properties are, within the acceptance angle limits associated with TIR requirements, independent of the retroreflector's orientation. Corner cubes therefore find frequent application in situations where orientation is difficult or impossible to control, where a mirror would be unsatisfactory.

It is usually possible to choose a retroreflector orientation such that acceptance angle limitations are, for all practical purposes, nonexistent. It is always possible to guarantee, by appropriate orientation of neighboring reflectors in a retroreflector array, that part of the array will be functional even at very large angles of incidence. All acceptance angle limitations can be removed, at the cost of a several-percent reduction in reflective efficiency, by applying reflective coatings to the rear reflecting surfaces, and thereby avoiding TIR failure.

Other Imaging Prisms

In addition to the prisms mentioned above, there are several other lesser-known beam deviation prisms in limited use. These include the Abbe, Leman and rhomboid prisms. Taken in turn, the Abbe (not shown) inverts and reverses an image but does not deviate the optic axis. It consists of either two or three pieces, cemented together. It resembles two Dove prisms, with the hypotenuse of the first resting atop the entrance face of the second and what would have been the exit face of the first ground down to a 90° TIR roof. The Leman prism inverts, reverses and displaces the beam laterally by *3A*, where *A* is the height of the input face (Fig. 9). The rhomboid prism merely displaces the beam laterally by the length of the prism (Fig. 10).

Dispersing Prisms

Several types of prisms with triangular cross sections are used for spectrally dispersing an input beam. This function is based on the nonlinear behavior of the index of refraction of glass as a function of wavelength, resulting in an angular dispersion as a function of wavelength. Perhaps most widely known is the equilateral 60° prism (sometimes called a Schmidt prism) used in high school physics demonstrations.

An important special case of the dispersing prism is the Brewster prism (which also admittedly takes advantage of a polarization effect that will be described later). The apex angles of these isosceles prisms are chosen so that, for a particular wavelength, rays at minimum deviation (which travel parallel to the prism base while inside it) both enter and exit the prism at Brewster's angle. Light of this wavelength, which is linearly polarized so that within the prisms the electric field vector is orthogonal to the prism base, enters and exits at Brewster's angle essentially without reflection losses.

These prisms are primarily used for wavelength selection in tunable dye, argon ion, HeSe and HeNe laser systems (Fig. 11). These systems tend to oscillate at several wavelengths simultaneously, or tend to concentrate their output in the wavelengths of highest gain. Brewster prisms are indispensable when one wishes to have all of the laser output at a wavelength of comparatively low gain. Tuning is accomplished by tilting the prism slightly.

If an isosceles Brewster prism is cut in half along the plane passing through the apex and perpendicular to the base, two Littrow prisms are formed. The surfaces resulting from bisection are customarily coated with a high reflectance multilayer dielectric film designed for near-normal incidence at and near the design wavelength. The Littrow prism is used as the planar element of a hemispherical laser resonator or as a coupling element (Fig. 12). Tuning is again accomplished by tilting.

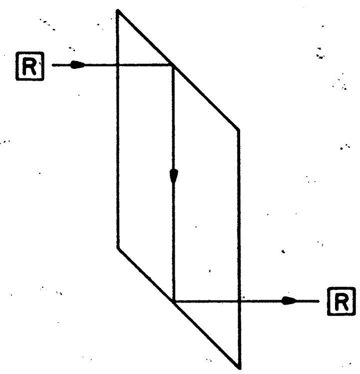

Fig. 10. Rhomboid prism.

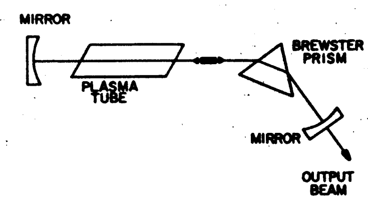

Fig. 11. Brewster prism used as wavelength selector.

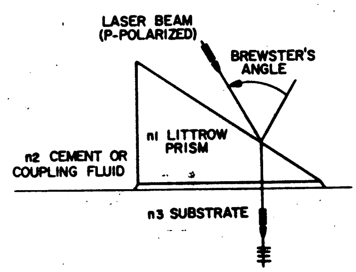

Fig. 12. Littrow prism used as coupler.