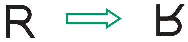
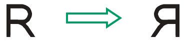
Parity and Plane Mirrors

In addition to bending or folding the light path, reflection from a **plane mirror** introduces a **parity** change in the image.

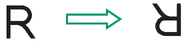
Invert – Image flip about a horizontal line.



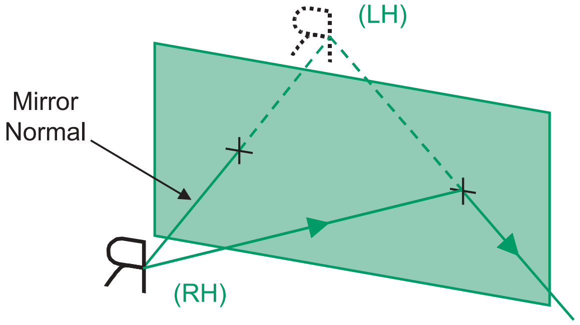
Revert – Image flip about a vertical line.



An inversion plus a reversion is equivalent to a 180° **image rotation**; no parity change.



An image seen by an even number of reflections maintains its parity. An odd number of reflections changes the parity. Parity is determined by looking back against the propagation direction towards the object or image in that optical space; let the light from the object or image come to you.



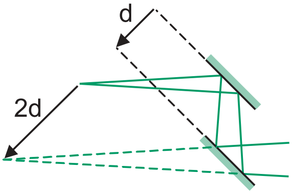
Each ray from an object obeys the law of reflection at a plane mirror surface, and a virtual image of the object is produced.

The rules of plane mirrors:

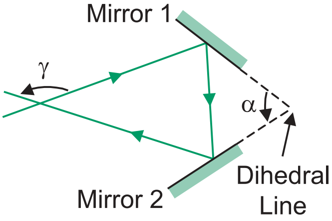
- The line connecting an object point and its image is perpendicular to the mirror and is bisected by the mirror.
- Any point on the mirror surface is equidistant from a given object point and its image point.
- The image parity is changed on reflection.

Systems of Plane Mirrors

The rules of plane mirrors are used sequentially at each mirror in a **system of plane mirrors**. Two **parallel plane mirrors** act as a **periscope** and displace the line of sight. There is no parity change, and all image rays are parallel to the corresponding object rays. The image is displaced by twice the perpendicular separation of the mirrors.



The **dihedral line** is the line of intersection of two **non-parallel plane mirrors**. In a plane perpendicular to the dihedral line (a **principal section**), the projected ray path is deviated by twice the angle between the mirrors (the **dihedral angle** α). This deviation is independent of the input angle.



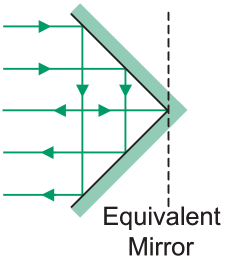
$$\gamma = 2\alpha$$

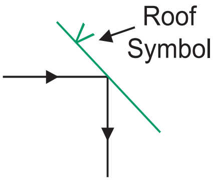
$\alpha < 90°$: The input and output rays cross.

$\alpha > 90°$: The input and output rays diverge.

The projection of the ray paths into a plane containing the dihedral line shows a simple reflection at the dihedral line.

When the dihedral angle is 90°, the input and output rays are anti-parallel. This **roof mirror** can replace any flat mirror to insert an additional reflection or parity change. An equivalent plane mirror is formed at the dihedral line. All rays through the roof mirror have the same optical path.

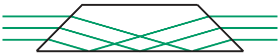


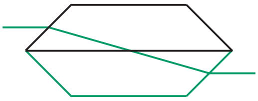


The dihedral line is often in the plane of the drawing, and the presence of a roof mirror is indicated by a "V" at the equivalent mirror or dihedral line.

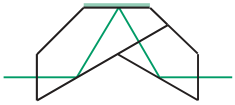
Image Rotation and Erection Prisms

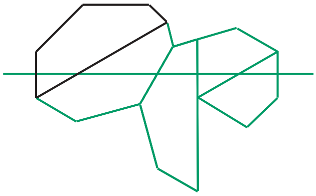
Image Rotation Prisms – as the prism is rotated by θ about the optical axis, the image rotates by twice that amount (2θ). **Dove prism** (1 R) – because of the tilted entrance and exit faces of the prism, it must be used in collimated light.



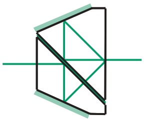


Reversion or K prism (3 R) – the upper face must be coated.





Pechan prism (5 R) – a small air gap provides a TIR surface inside the prism. This compact prism supports a wide FOV.



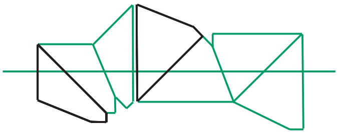
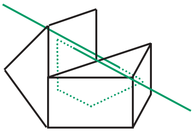
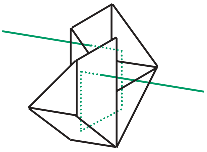


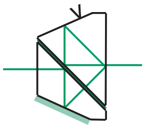
Image Erection Prisms – These prisms are inserted in an optical system to provide a fixed 180° image rotation.

Porro system (4 R) – two Porro prisms. This prism accounts for the displacement between the objective lenses and the eyepieces in binoculars.



Porro-Abbe system (4 R) – a variation of the Porro system where the sequence of reflections is changed.

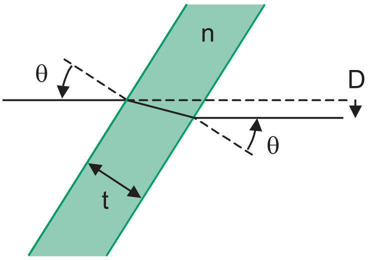




Pechan-roof prism (6 R) – a roof is added to a Pechan prism. This prism is used in compact binoculars and provides a straight-through line of sight.

Plane Parallel Plates

A ray passing through a **plane parallel plate** is displaced but not deviated; the input and output rays are parallel.



$$D = t\sin\theta\left[1 - \sqrt{\frac{1-\sin^2\theta}{n^2-\sin^2\theta}}\right]$$

$$D \approx t\theta\left(\frac{n-1}{n}\right)$$

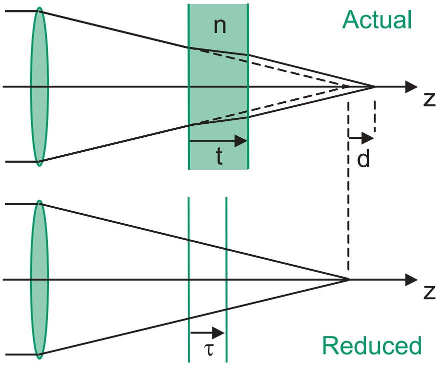
(in air)

An image formed through a plane parallel plate is longitudinally displaced, but its magnification is unchanged.

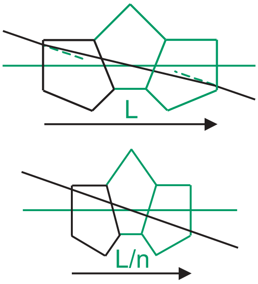
$$d \approx \left(\frac{n-1}{n}\right)t$$

$$d \approx \frac{t}{3} \quad \text{for} \quad n = 1.5$$

$$\tau = t - d = \frac{t}{n}$$



The **reduced thickness** τ gives the air-equivalent thickness of the glass plate. A **reduced diagram** shows the amount of air path needed to fit the plate in the system, and no refraction is shown at the faces of the plate. A **reduced tunnel diagram** shortens the length of a tunnel diagram by $1/n$ to show the air-equivalent length of the prism. Reduced diagrams can be placed directly onto system layout drawings to determine the required prism aperture sizes for a given FOV. Note that the OPL increases greatly when a prism or glass plate is inserted.

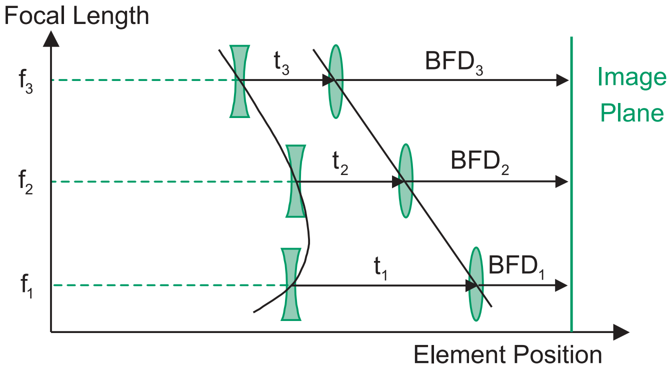


Zoom Lenses

A **zoom lens** is a variable focal length objective with a fixed image plane. The simplest example consists of two lens elements or groups (powers ϕ_1 and ϕ_2) where both the system focal length f and BFD vary with element spacing t.

$$\phi = \frac{1}{f} = \phi_1 + \phi_2 - \phi_1\phi_2 t \qquad BFD = f + d' = f - \frac{\phi_1}{\phi}t$$

The pair of elements is moved relative to the fixed image plane to maintain focus as the focal length is varied. The element positions are shown for a **reverse telephoto zoom**. This configuration is attractive due to its large BFD.



As the separation approaches the sum of the element focal lengths ($f_1 + f_2$), the system becomes afocal ($f \to \infty$). The zoom range of the analogous **telephoto zoom** is limited by its BFD as the rear element can run into the image plane when the element separation approaches f_1.

A mechanical cam provides the complicated lens motions required for these **mechanically compensated** zoom lenses. Zoom lenses often use multiple groups of moving elements. A common three group configuration uses a fixed front element and moving second and third groups.