Waveplates (Retarders)

Meadowlark Optics offers some of the best retardance accuracy measurements in Linear, Circular, and Elliptical Retarders. True Zero Order, Compound Zero Order, Wide Angular Field Of View, Achromatic, and Superachromatic types are available through our catalog along with Custom Athermal Crystalline, Wide Angular Field Of View, Achromatic Linear, Achromatic Circular, and Elliptical Retarders.

Retarders are used in applications where control or analysis of polarization states is required. Our retarder products include innovative polymer and liquid crystal materials as well as commonly used quartz. Other crystalline materials such as magnesium fluoride are also available upon request. Please call for a custom quote.

A retarder (or waveplate) is an optical device that resolves a light wave into two orthogonal linear polarization components and produces a phase shift between them. The resulting light wave is generally of a different polarization form. Ideally, retarders do not polarize, nor do they induce an intensity change in the light beam, they simply change its polarization form.

All standard catalog Meadowlark Optics retarders are made from birefringent, uniaxial materials having two different refractive indices – the extraordinary index ne and the ordinary index no. The difference between the two indices defines the material birefringence.

Light traveling through a retarder has a velocity v dependent upon its polarization direction given by

$v = c/n$

where c is the speed of light in a vacuum and n is the refractive index parallel to that polarization direction. By definition,

$ne > no$ for a positive uniaxial material.

For a positive uniaxial material, the extraordinary axis is referred to as the slow axis, while the ordinary axis is referred to as the fast axis. Light polarized parallel to the fast axis travels at a higher velocity than light parallel to the orthogonal slow axis.

In the figure that follows, a plane polarized light wave incident on a birefringent material is vectorially decomposed into two orthogonal components vibrating along the fast and slow axes. Plane polarized light is oriented at 45° relative to the fast axis of the retarder. The orthogonal polarization components travel through the material with different velocities (due to birefringence) and are phase shifted relative to each other producing a modified polarization state. The transmitted light leaves the retarder elliptically polarized.

Retardance (in waves) is given by:

$d = bt/\lambda$

where:

b=birefringence (ne – no)

λ = wavelength of incident light (in nanometers)

t = thickness of birefringent element (in nanometers)

Retardance can also be expressed in units of length, the distance that one polarization component is delayed relative to the other. Retardance is then represented by:

$d, = d\lambda = bt$

where d, is the retardance (in nanometers).

This equation illustrates that retardance is strongly dependent upon both incident wavelength and retarder thickness.

All retarders suffer small retardance oscillations as a function of wavelength when a coherent light source is used. This etalon effect can be substantial, depending upon the thickness and surface reflections of the retarder.

Retarder Types

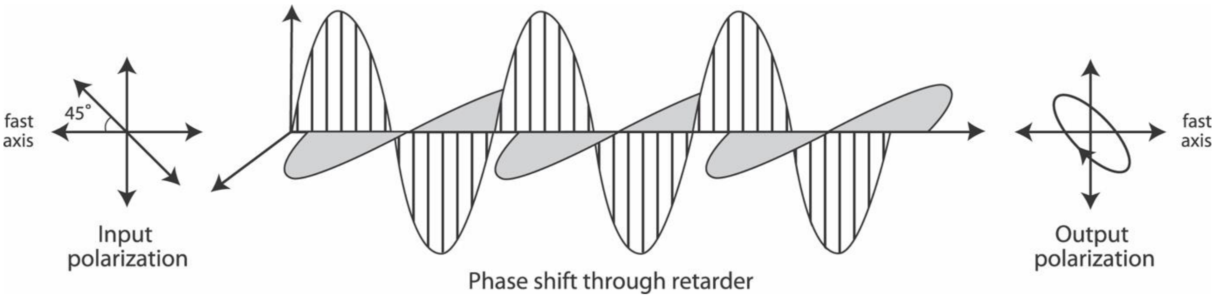
Birefringence is common in materials with anisotropic molecular order such as crystals (both solid and liquid) and oriented polymers. Crystalline retarders are often made of mica, calcite, or most commonly, quartz.

Retarders can be multiple-order (having several waves of retardance), compound zero-order, or true zero-order. True zero-order retarders are often preferred for the most demanding applications requiring retardance stability with wavelength, temperature and angle of incidence. A true zero-order retarder is thin and must have a low birefringence to be manufactured easily.

A review of several retarder types is presented below.

Quartz has a birefringence of ~0.0092 in the visible region. From the equations shown above, a true zero-order quartz quarter waveplate for 550 nm operation is only 15 mm thick. Such a thin, fragile retarder presents handling difficulties in both fabrication and mounting.

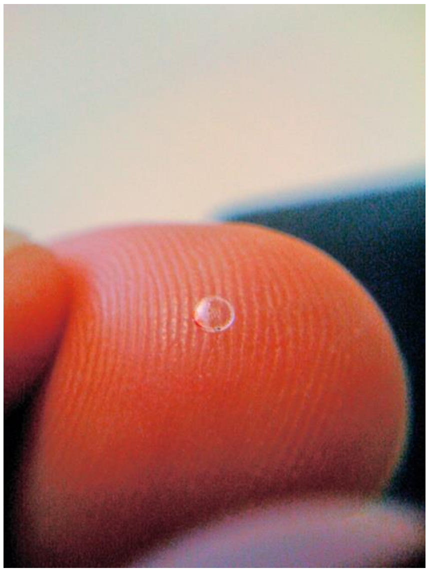
More commonly, multiple-order quartz retarders having a whole number of waves plus the desired fractional retardance (typically quarter- or half-wave) are offered. Precision polishing of the quartz substrate provides excellent surface and transmitted wavefront quality. However, multiple-order retarders can be extremely sensitive to incident angle, wavelength and temperature. As a rule of thumb, the retardance (in waves) for a 1 mm thick quartz retarder varies by about -0.5% per °C. Quartz retarders are sometimes preferred for their durability and high transmission properties.



A compound zero-order quartz retarder improves performance by combining two multiple-order quartz waveplates with the desired retardance difference. The fast axis of one plate is aligned with the slow axis of the other, cancelling the large retardance values and leaving only the desired fractional retardance difference (typically quarter- or half-wave). Thermal stability of compound zero-order quartz retarders is improved as temperature effects of the two retarders cancel.

Mica, a natural mineral, is cleaved to precise thicknesses offering true zero-order retarders. However, cleaving is difficult over large apertures and does not offer the necessary tolerance or spatial uniformity required for most applications. Also, the long term supply of optical quality mica is uncertain.

Polymer materials offer a lower birefringence than quartz and can therefore be made into true zero-order retarders of reasonable thickness. They are much less sensitive to incidence angle than either multiple- or compound zero-order quartz retarders. Birefringence dispersion (or variation with wavelength) varies with each polymer material. This factor is an important consideration when manufacturing polymer retarders.



Meadowlark custom 2mm polymer waveplate

Meadowlark Optics protects the polymer material using a proprietary lamination process between optically flat windows. This assembly provides the transmitted wavefront quality necessary for precision optical applications.

We precisely orient and layer several polymer sheets to make ***achromatic polymer retarders***. These polymer stacks are then laminated between optical flats. Achromatic polymer retarders offer the versatility needed for broadband applications with demanding performance requirements. When a retarder must have the same retardance at two wavelengths that are separated by a span too large for an achromatic retarder, then a ***dual wavelength retarder*** may be the answer. Some versions of dual wavelength retarders can also provide different specified retardances at two different wavelengths.

Meadowlark selection of dual wavelength retarders

Liquid crystal retarders are electrically variable waveplates. Retardance is altered by applying a variable, low voltage waveform. These retarders are made by placing a thin liquid crystal layer between parallel windows spaced a few microns apart. Different liquid crystal materials range in birefringence from 0.05 to 0.26, enabling fabrication of thin, true zero-order retarders in the visible to near infrared region.

Fresnel Rhombs use total internal reflection to create a phase shift between two orthogonal polarization components. Fresnel rhombs make excellent achromatic retarders.

Other tunable birefringent retarders use electro-optic crystals such as ***KD*P (potassium dideuterium phosphate).*** This material is used in ***Pockels cell retarders*** which operate at megahertz frequencies but require very high voltage for retardance control.