Retarder Principles

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 n_e and the ordinary index n_o. 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, $n_e > n_o$ 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 figure 2-1, 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:

$$\delta = \beta t / \lambda$$

where:

- β = birefringence ($n_e - n_o$)
- 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:

$$\delta' = \delta\lambda = \beta t$$

where δ' 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 on the previous page, a true zero-order quartz quarter waveplate for 550 nm operation is only 15 µm 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.

Retarder Principles

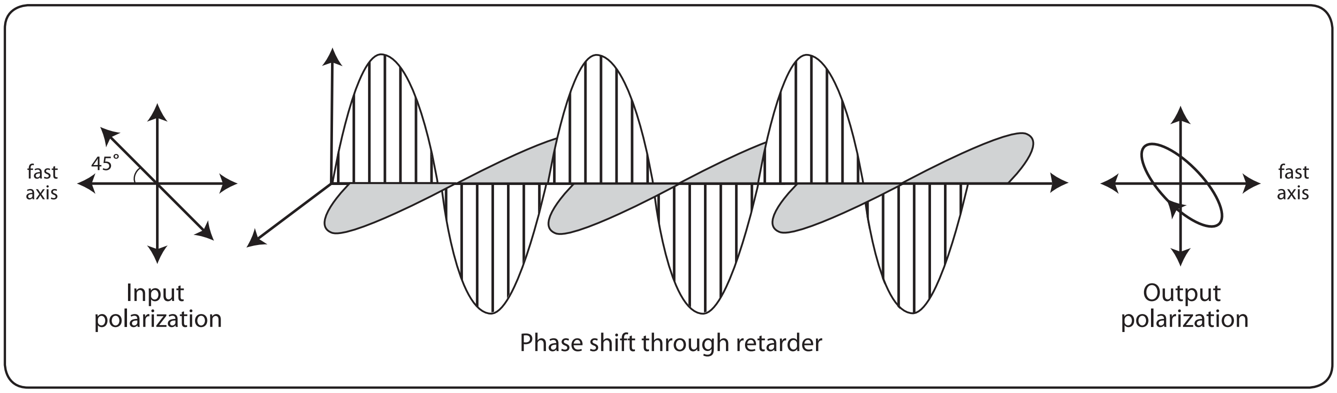


Fig. 2-1 Phase retardation

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 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 orent 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.

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. A more complete description of reflection retarders can be found in the references listed on page 5.

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.

Note that a compound zero-order quartz retarder does not provide improved field of view over a multiple-order retarder, only a true zero-order retarder does.

Polarization Control with Polymers

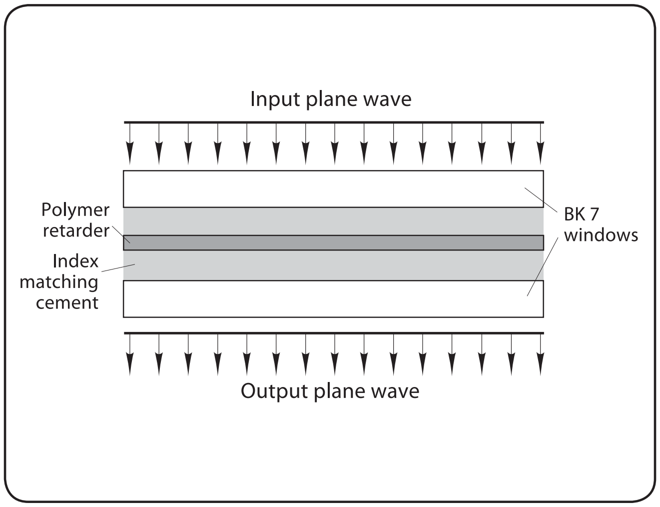


Fig. 2-2 Polymer retarder assembly

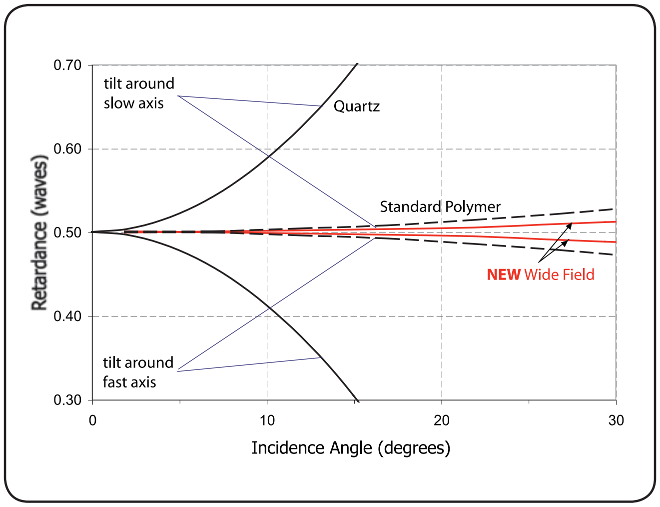


Fig. 2-3 Half-wave retarder performance versus incidence angle

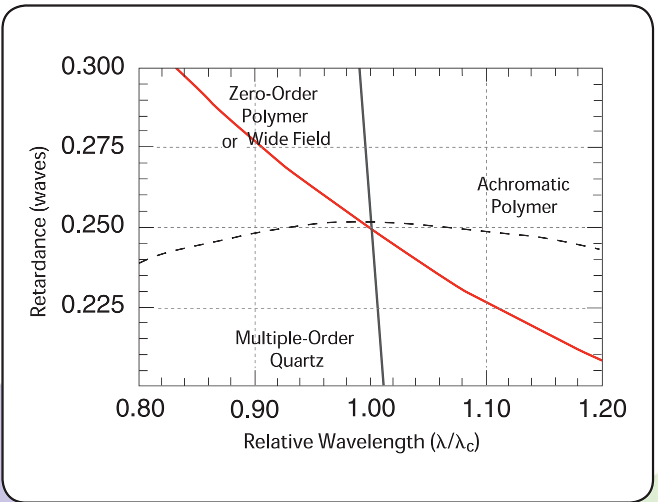


Fig. 2-4 Wavelength performance of common quarter-wave retarders

Naturally-occurring crystalline materials (calcite, mica and quartz) have traditionally been the birefringent materials of choice for retarders. Today's applications require performance versatility beyond the limitations of those crystals.

Meadowlark Optics specializes in the use of birefringent polymers and liquid crystals for polarization control in precision optical applications. These innovative materials offer a unique combination of high performance and cost-effectiveness.

Birefringent Polymers

Our polymer retarder assembly consists of birefringent polymer material laminated between two precision polished, optically flat BK 7 windows. Antireflection coatings and index matching optical cement help to maximize transmission in the visible to near infrared region. This construction (shown in figure 2-2) ensures excellent transmitted wavefront quality, while minimizing beam deviation and surface reflection losses.

Polymer retarders offer excellent angular field-of-view since they are true zero-order retarders. Figure 2-3 compares the change in retardance as a function of incidence angle for polymer and quartz retarders. A polymer retarder changes by less than 1% over a ± 10° incidence angle.

Retardance accuracy with wavelength change is often a key concern. For example, an off-the-shelf diode laser has a center wavelength tolerance of ± 10 nm. Changes with temperature and drive conditions cause wavelength shifts which may alter performance. Meadowlark Optics polymer retarders maintain excellent retarder performance even with minor shifts in the source wavelength.

We also produce achromatic retarders with excellent retardance accuracy over a very broad wavelength range. Basic construction of achromatic retarders is the same as that for zero-order polymer retarders shown in figure 2-2. A comparison of different retarder types and their dependence on wavelength is shown in figure 2-4.

The temperature sensitivity of laminated polymer retarders is about 0.04% per °C, allowing operation over moderate temperature ranges without significantly degrading retardance accuracy. We can also thermally calibrate polymer retarders for specific operating temperatures.

Large aperture quartz retarders are difficult to fabricate and become cost-prohibitive beyond two inches in diameter. Meadowlark Optics polymer retarders with large apertures can be fabricated for a reasonable price. Please call for a custom quotation.

Custom sizes and retardances are available. Please contact your Meadowlark Optics sales engineer for assistance.

Polarization Manipulation with Retarders

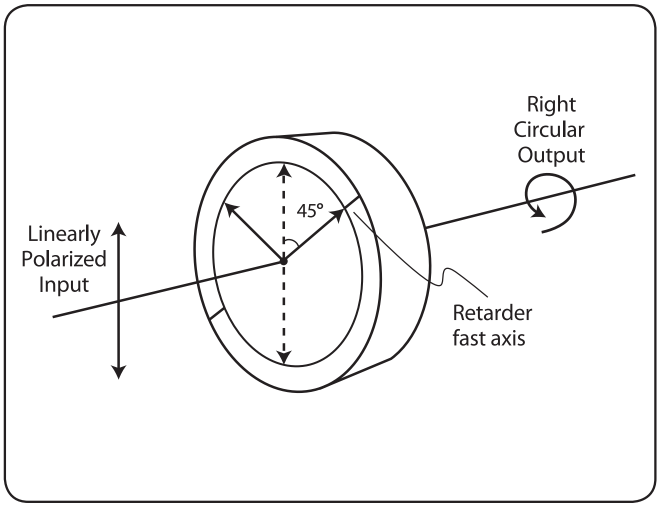


Fig. 2-5 A quarter-wave retarder converts linearly polarized light to circularly polarized light, or vice versa

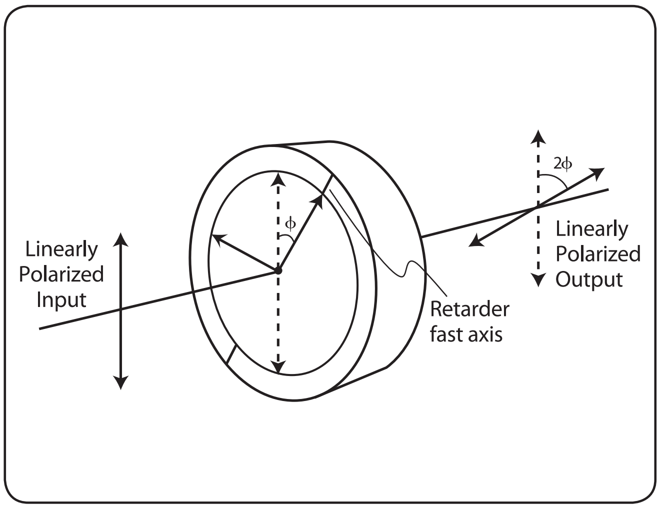


Fig. 2-6 A half-wave retarder rotates linearly polarized light by 2ϕ.

Micro Retarders

PolyWave is a high birefringence polymer that enables ultra-thin retarders.

Micro retarders passed rigid environmental testing with no change in retardance after many months of exposure to extreme conditions.

- Meadowlark Optics produces these retarders with dimensions less than 1 mm. The edges can be cut to allow the retarder to be used to within 15 µm of the edge.
- Due to the high birefringence of the PolyWave material, the total thickness of a 1550 nm half-wave retarder is only approximately 15 µm and a quarter-wave retarder is approximately 8 µm thick.

A retarder (or waveplate) alters the polarization of light in a manner that depends on the retardance and the angle between the retarder fast axis and the input plane of polarization. Examples of the most common waveplates follow.

Quarter-Wave Retarder

A quarter-wave retarder is used to convert light between circular and linear polarization forms. It changes linearly polarized light to circularly polarized light, when the angle between the input polarization and the retarder fast axis is 45°.

In figure 2-5, linearly polarized light is converted to right-hand circular polarized light by the quarter-wave retarder. Upon exiting the quarter-wave retarder, light polarized parallel to the slow axis is retarded by 1/4 wave relative to light polarized along the fast axis. When recombined, the exit light is circularly polarized.

Similarly, this retarder orientation will convert input right-hand circular polarized light to vertical linearly polarized light for a reversed direction of travel.

Optical Isolator

A quarter-wave retarder is often combined with a linear polarizer to form an optical isolator, used to eliminate undesired reflections. A common application prevents unwanted reflected light from re-entering a laser cavity. Please see page 19 for a discussion of Optical Isolators.

Half-Wave Retarder

Half-wave retarders are sometimes called polarization rotators. A half-wave retarder flips the polarization direction of incoming light about the retarder fast axis. When the angle between the retarder fast axis and the input plane of polarization is 45°, horizontal polarized light is converted to vertical. A half-wave retarder rotates a linear polarized input by twice the angle between the retarder fast axis and the input plane of polarization, as shown in figure 2-6.

A half-wave retarder can also be used to change the handedness of a left-circular polarized beam to right-circular polarized, or vice versa. A half-wave retarder is also conveniently used to change the polarization direction where mechanical rotation of a large laser is impractical.

Full-Wave Retarder

Full-wave retarders are valuable components for eliminating unwanted polarization changes in an optical system. Many optical components, especially metal mirrors, alter the polarization state by introducing unwanted phase shifts. For example, a linearly polarized input beam becomes elliptically polarized upon reflecting off of a metal surface. Ellipticity can be accurately corrected by using a full-wave retarder and tilting it about either the fast or slow axis, to change its retardance slightly.

Polarization Analysis Example

General Analysis

Several methods exist for computing and analyzing the polarization states of an optical system. Two common ways of evaluating a system involve Mueller and Jones calculus where the polarization of a light beam and the effects of optical components on that polarization form are represented by simple means.

In the general case, polarizing properties of an optical component are represented by a matrix. A vector describes the polarization form of the incident beam. Multiplying the matrix and vector, the resulting vector represents the polarization characteristics of light that has propagated through the component.

The Stokes vector S describes light polarization as:

$$S = \begin{vmatrix} I \\ Q \\ U \\ V \end{vmatrix}$$

where:

- I = total light intensity,
- Q = intensity difference between horizontal and vertical linearly polarized components,
- U = intensity difference between linearly polarized components oriented at ± 45° and
- V = intensity difference between right and left circular components.

The Mueller matrix M for a waveplate with retardance δ (in degrees) and arbitrary fast axis orientation ϕ (measured from the horizontal) is expressed as:

$$M = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & C_2^2 + S_2^2 \cos\delta & S_2C_2(1-\cos\delta) & -S_2 \sin\delta \\ 0 & S_2C_2(1-\cos\delta) & S_2^2 + C_2^2 \cos & C_2 \sin\delta \\ 0 & S_2 \sin\delta & -C_2 \sin\delta & \cos\delta \end{vmatrix}$$

where:

$C_2 \equiv \cos(2\phi)$ and
$S_2 \equiv \sin(2\phi)$

The light output S' is calculated by:

$$S' = MS.$$

An Example

A simple analysis using a horizontal linearly polarized beam incident on a quarter wave retarder is shown below.

Horizontal linearly polarized input light has a Stokes vector given by:

$$S = \begin{vmatrix} 1 \\ 1 \\ 0 \\ 0 \end{vmatrix}$$

The Mueller matrix representation for a quarter-wave retarder with its fast axis at 45° relative to the incoming polarization is:

$$M = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{vmatrix}$$

Multiplying the input Stokes vector S by the component Mueller matrix M results in:

$$S' = \begin{vmatrix} 1 \\ 0 \\ 0 \\ 1 \end{vmatrix}$$

This vector represents 100% right circular polarized light.

The references shown on page 3 provide detailed and comprehensive descriptions of polarization theory. Also, our engineers are happy to help you with any questions you may have regarding your application.

NEW

Compound Zero Order Quartz Retarders

Key Benefits

- **Tolerates high temperature**
- **High CW laser damage threshold**
- **Tip tunable retardance**
- **Good UV transmission**

We provide air spaced compound zero order quartz retarders for special applications where higher damage threshold, or better UV transmission than normal is required. These retarders combine two multiple order quartz retarders with their optic axis directions perpendicular to one another.The net retardance of the pair is the difference in the retardance of these two retarders. The net retardance is as insensitive to temperature changes as a true zero order quartz retarder but is as sensitive to angle of incidence as a multiple order quartz retarder of the thickness of the sum of the two quartz pieces. Angle tuning of retardance permits adjustment for use at a wavelength nearby the design wavelength.

SPECIFICATIONS	
Retarder Material	Crystal quartz, 2 pieces
Retardance accuracy	
Above 300 nm **Below 300 nm**	± λ/300 ± λ/200
Transmitted Wavefront Distortion (at 632.8 nm over central 8mm diameter)	≤ λ/10
Reflectance (per surface)	≤ 0.25% at normal incidence
Surface Quality	20-10 scratch and dig
Beam Deviation	≤ 10 arc sec
Diameter Tolerance	± 0.005 in.
Standard Wavelengths	266, 308, 355, 488, 514.5, 532 and 1064 nm
Temperature Range	-20° C to +80° C
Recommended Safe Operating Limit	1 MW/cm² CW at 1064 nm 2 J/cm² for a 10 nsec pulse at 1064 nm

ORDERING INFORMATION

Unmounted				
Diameter (in.)	*Clear Aperture (in.)*	*Thickness (in.)*	*λ/4 Wave Part No.*	*λ/2 Wave Part No.*
1.00	0.80	0.23	ZQ-100-λ	ZH-100-λ

Please include the standard wavelength λ in nanometers when ordering. Custom sizes or center wavelengths can be specified for your application.

Custom sizes are available. Please contact your Meadowlark Optics sales engineer for assistance

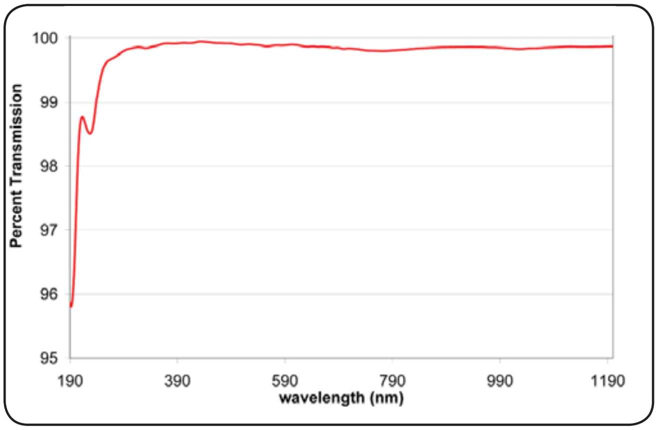


Fig. 2-7 Zero Order Quartz Retarder waveplate internal transmission

Precision Retarders

Key Benefits

- **True zero-order retarders**
- **Excellent off-axis performance**
- **Unequaled measurement accuracy**
- **Less temperature dependence than quartz waveplates**
- **Lower cost than compound zero-order quartz waveplates**
- **Better angular acceptance than compound zero-order quartz waveplates**

Meadowlark Optics specializes in precision polymer retarders for the visible to near infrared region. Our Precision Retarders have the highest optical quality and tightest retardance tolerance of all polymer retarders. These true zero-order Precision Retarders consist of a birefringent polymer cemented between two precision polished, optically flat BK 7 windows. The retarder fast axis is conveniently marked for quick and easy reference.

Precision Retarders are supplied with a broadband antireflection coating. Optical transmittance of a Precision Retarder is typically greater than 97%.

The retardance δ at a wavelength λ that is different from the center wavelength λ_C is given by:

$$\delta \approx \delta_C(\lambda_C / \lambda)$$

where δ_C is the retardance at λ_C.

This relationship is very important when using sources which vary in wavelength from their nominal value. Figures 2-8 and 2-9 show the retardance behavior as a function of relative wavelength for a quarter- and half-wave retarder, respectively. The Mueller calculus described on page 24 can be used to calculate the transmitted polarization state based upon the retardance differences from the ideal case.

Since polymer retarders are true zero-order devices, they offer the significant advantage of improved angular performance. You can expect less than 1% retardance change over ±10° incidence angle.

Meadowlark Optics has developed precision ellipsometric techniques that can measure retardance to λ/1000.

Our metrology for these measurements is the best in the industry. You can have absolute confidence that the calibration measurements supplied with your retarder are of the highest accuracy obtainable.

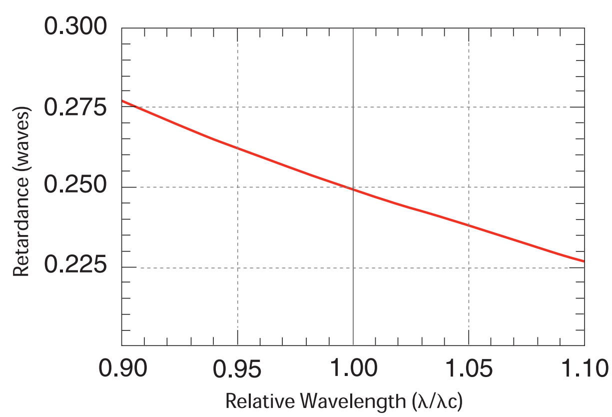


Fig. 2-8 Quarter-wave Precision Retarder performance

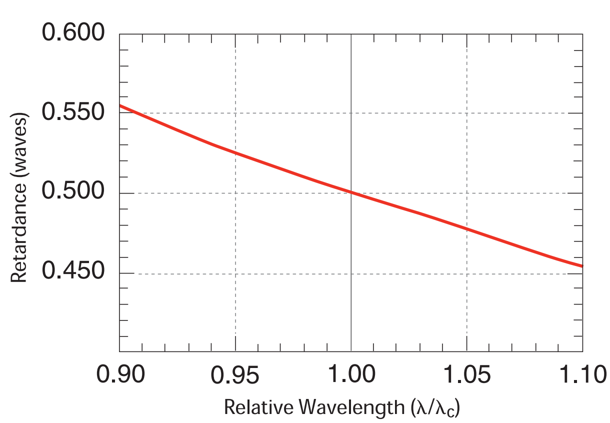


Fig. 2-9 Half-wave Precision Retarder performance

Precision Retarders

PROBLEM

"My laser center wavelength varies by a few nanometers, but I need my retarder to be a nearly perfect quarter-wave of retardance for each wavelength in order to give maximum isolation. I'll go broke if I have to purchase 10 retarders spaced at 0.5 nm intervals. Is there another way?"

SOLUTION

0.5 nanometers exceeds even our tight tolerance on retardance! Try angle tuning your retarder. A 10° tilt can change the retardance by about 1.25 nm or 0.002 waves of retardance at 632.8 nm. Remember to tilt about the fast or slow axis of your retarder, likely at ±45° to your optical bench. See our Application Note about retarders at www.meadowlark.com.

Another solution is to use a liquid crystal variable retarder, page 48.

PROBLEM

"I purchased a compound zero-order retarder for use in an imaging system where I need a good field of view. Do these really have the field of view of a true zero-order retarder?"

SOLUTION

This is a common misconception. In fact, compound zero-order retarders are twice as bad as the multi-order retarders they are made from! If you need a good field of view, you must use a true zero-order retarder. See our Application Note at www.meadowlark.com.

SPECIFICATIONS	
Retarder Material	Birefringent Polymer
Substrate Material	BK 7 Grade A, fine annealed
Standard Wavelengths	532, 632.8, 670, 780, 850, 1064 and 1550 nm
Custom Wavelengths	400-1800 nm (specify)
Standard Retardances	λ/4 and λ/2
Retardance Accuracy	≤ λ/350
Transmitted Wavefront Distortion (at 632.8 nm)	≤ λ/5
Surface Quality	40-20 scratch and dig
Beam Deviation	≤ 1 arc min
Reflectance (per surface)	≤ 0.5% at normal incidence
Diameter Tolerance	
Mounted Unmounted	±0.005 in. +0/-0.010 in.
Thickness Tolerance	±0.020 in.
Temperature Range	20° C to 50° C
Recommended Safe Operating Limit	500 W/cm^2, CW 600 mJ/cm^2, 20 ns, visible 4 J/cm^2, 20 ns, 1064 nm

Custom retardance values and sizes are available. Please call for a quote.

ORDERING INFORMATION				
Mounted				
Diameter (in.)	*Clear Aperture (in.)*	*Thickness (in.)*	*λ/4 Wave Part No.*	*λ/2 Wave Part No.*
1.00	0.40	0.25	NQM-050-λ	NHM-050-λ
1.00	0.70	0.35	NQM-100-λ	NHM-100-λ
2.00	1.20	0.50	NQM-200-λ	NHM-200-λ
Unmounted				
Diameter (in.)	*Clear Aperture (in.)*	*Thickness (in.)*	*λ/4 Wave Part No.*	*λ/2 Wave Part No.*
0.50	0.40	0.13	NQ-050-λ	NH-050-λ
1.00	0.80	0.26	NQ-100-λ	NH-100-λ
2.00	1.60	0.51	NQ-200-λ	NH-200-λ

Please specify your center wavelength λ in nanometers when ordering.

Custom size retarders with improved transmitted wavefront distortion and/or beam deviation are available. Your requirements for custom shapes and sizes are also welcome. Please call for a quote.

Meadowlark Optics one and two inch diameter retarders conveniently fit our Rotary Mounts. Please refer to page 43 for more information.

Commercial Retarders

Key Benefits

- **Economical choice**
- **Excellent performance**

Commercial Retarders are our most affordable line of zero-order waveplates. They are suitable for applications where transmitted wavefront quality is less critical.

These retarders use commercial quality glass windows and are designed as a low-cost alternative to our Precision Retarders described on pages 30-31. Basic construction is the same as described on page 26.

Both quarter- and half-wave retarders are available for popular wavelengths in the visible and near infrared regions. All Meadowlark Optics retarders have their fast axis conveniently marked.

SPECIFICATIONS	
Retarder Material	Birefringent Polymer
Substrate Material	Commercial Quality Glass
Standard Wavelengths	532, 632.8, 670, 780, 850, 1064 and 1550 nm
Custom Wavelengths	400-1800 nm (specify)
Standard Retardance	λ/4 and λ/2
Retardance Accuracy	≤ λ/50
Transmitted Wavefront Distortion (at 632.8 nm)	≤ 3λ
Surface Quality	80-50 scratch and dig
Beam Deviation	≤ 3 arc min
Reflection (per surface)	≤ 0.5% at normal incidence
Diameter Tolerance	
Mounted Unmounted	±0.005 in. +0/-0.015 in.
Temperature Range	-20° C to +50° C
Recommended Safe Operating Limit	500 W/cm², CW 600 mJ/cm², 20 ns, visible 4 J/cm², 20 ns, 1064 nm

ORDERING INFORMATION

Mounted				
Diameter (in.)	*Clear Aperture (in.)*	*Thickness (in.)*	*λ/4 Wave Part No.*	*λ/2 Wave Part No.*
1.00	0.40	0.25	RQM-050-λ	RHM-050-λ
1.00	0.70	0.35	RQM-100-λ	RHM-100-λ
2.00	1.20	0.50	RQM-200-λ	RHM-200-λ

Unmounted				
Diameter (in.)	*Clear Aperture (in.)*	*Thickness (in.)*	*λ/4 Wave Part No.*	*λ/2 Wave Part No.*
0.50	0.40	0.13	RQ-050-λ	RH-050-λ
1.00	0.80	0.26	RQ-100-λ	RH-100-λ
2.00	1.60	0.51	RQ-200-λ	RH-200-λ

Please specify your center wavelength λ in nanometers when ordering.

Meadowlark Optics one and two inch retarders conveniently fit our Rotary Mounts. Please refer to page 43 for details.

Custom sizes and retardance values are available.

Wide Field Retarders

Key Benefits

- **Unmatched off-axis performance**
- **Standard and custom wavelength retarders**
- **Mounted and unmounted versions available**
- **Off-axis performance ideal for uncollimated light applications**

Meadowlark Optics now offers Wide Field Retarders, the latest innovation in near zero-order polymer retarder technology. At their design wavelength, Wide Field Retarders provide a consistent retardance value over a wide acceptance angle, out to 30° or more.

Standard quarter- and half-wave designs are available for common wavelengths in the visible to near infrared region. Figure 2-10 shows the Wide Field Retarder performance as a function of incidence angle for the half-wave design. Quarter-wave Wide Field Retarder performance is shown in figure 2-11.

Multilayer broadband antireflection (BBAR) coatings are included as standard. Note that BBAR coating performance varies with incidence angle; these coatings perform best at (or near) normal incidence.

As with all Meadowlark Optics retarders, the fast axis is conveniently marked. Custom retardance values are available for wavelengths from 400-1800 nm. Please call for application assistance or to request a custom quotation.

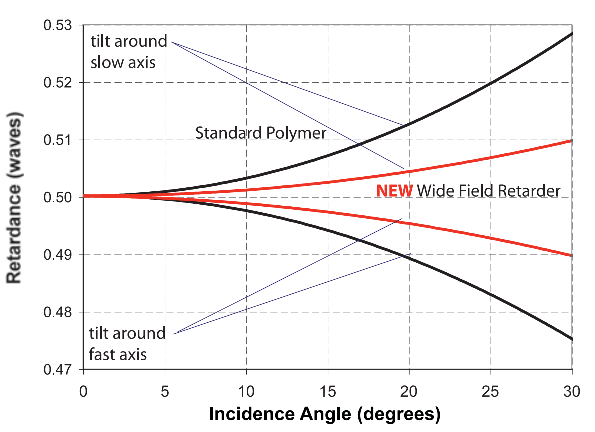


Fig. 2-10 Half-wave Wide Field Retarder performance versus incidence angle

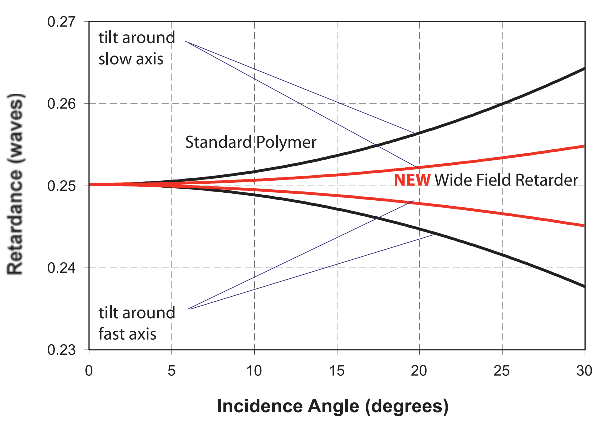


Fig. 2-11 Quarter-wave Wide Field Retarder performance versus incidence angle performance

Wide Field Retarders

SPECIFICATIONS	
Retarder Material	Birefringent Polymer
Substrate Material	BK 7 Grade A, fine annealed
Standard Wavelengths	532, 632.8, 670,780,850, 1064 and 1550 nm
Custom Wavelengths	400-1800 nm (specify)
Standard Retardance	λ/4 and λ/2
Retardance Accuracy	≤ λ/250 at normal incidence at the center of the part
Retardance Change (at 30° tilt)	
Half-wave Quarter-wave	≤ λ/100 ≤ λ/200
Transmitted Wavefront Distortion (at 632.8 nm)	≤ λ/2
Surface Quality	60-40 scratch and dig
Beam Deviation	≤ 1 arc min
Reflectance (per surface)	
At normal incidence At 30° incidence	≤ 0.5% ≤ 1.0%
Diameter Tolerance	
Mounted Unmounted	±0.005 in. +0/-0.010 in.
Temperature Range	0° C to 40° C

ORDERING INFORMATION				
Mounted				
Diameter (in.)	*Clear Aperture (in.)*	*Thickness (in.)*	*λ/4 Wave Part No.*	*λ/2 Wave Part No.*
1.00	0.40	0.25	WQM-050-λ	WHM-050-λ
1.00	0.70	0.35	WQM-100-λ	WHM-100-λ
2.00	1.20	0.50	WQM-200-λ	WHM-200-λ
Unmounted				
Diameter (in.)	*Clear Aperture (in.)*	*Thickness (in.)*	*λ/4 Wave Part No.*	*λ/2 Wave Part No.*
0.50	0.40	0.14	WFQ-050-λ	WFH-050-λ
1.00	0.80	0.28	WFQ-100-λ	WFH-100-λ
1.50	1.20	0.40	WFQ-150-λ	WFH-150-λ

Custom sizes and retardance values are available. Please contact your Meadowlark Optics sales engineer for a custom quote.

NEW

Dual Wavelength Retarders

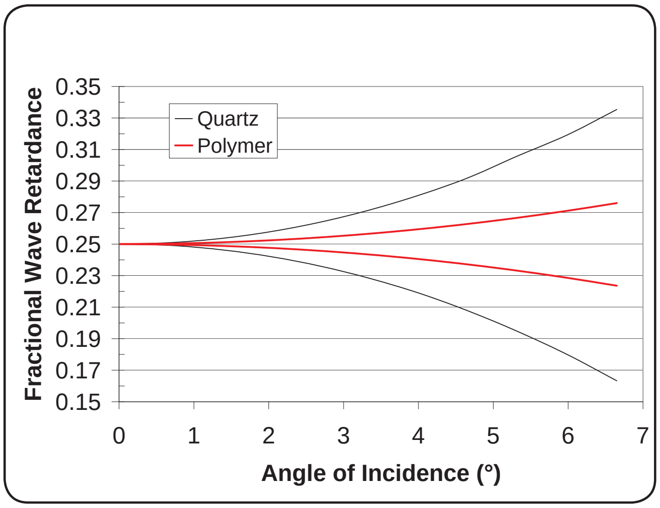


Fig. 2-12 Dual Wavelength Field of View

Dual wavelength retarders can provide the same retardance at two wavelengths that are separated in wavelength by more than the span covered by an achromatic retarder. They can also provide different specified retardances at two different wavelengths. Traditionally these retarders have been made using crystal quartz and are multiorder retarders at both wavelengths. Our dual wavelength retarders use polymers instead. They are usually much lower order and consequently have a slower change in retardance with angle of incidence as shown in the figure. On average the order is about 20% of that for a comparable quartz dual wavelength retarder. Call for a quote on a custom coating on these normally uncoated retarders. The retardance tolerance is ±0.01waves at both wavelengths. Many custom combinations not listed in the catalog are available. Please call for a quote on your custom requirement. Standard unmounted sizes are 0.50 inches and 1.00 inches.

SPECIFICATIONS	
Retarder Material	Birefringent Polymer
Substrate Material	BK 7 Grade A, fine annealed
Retardance Accuracy	≤ λ/100 at both wavelengths
Transmitted Wavefront Distortion (at 632.8 nm)	≤ λ/4
Reflectance (per surface on uncoated retarders only)	~ 4% at normal incidence
Diameter tolerance	+0/-0.010 in.
Beam Deviation	≤ 1 arc min
Thickness	
Half inch diameter One inch diameter	0.14 in. 0.27 in.
Temperature Range	design dependant

Custom anti-reflection coatings to provide less than 0.5% reflection at both wavelengths are available. Please call your Meadowlark Optics sales engineer for a quote.

Key Benefits

- **Low order**
- **Wide angular field**
- **Broad wavelength coverage**

QUESTION

"I have a need for a quarter (or half) wave retarder at two different wavelengths. Which do I order, the Precision Achromatic Retarder or the Dual Wavelength Retarder?"

ANSWER

Dual wavelength retarders are primarily for use at two different wavelengths separated by 20% apart. If the wavelengths are both covered by one of our standard achromatic retarder wavelength ranges (please see the Specifications Box for Precision Achromatic Retarders on page 37), we recommend purchasing a Precision Achromatic Retarder. We can also do custom achromatic retarder wavelength ranges. Please contact your Meadowlark Optics sales engineer for assistance and a custom quote.

If the wavelength difference between the two is greater than 30 to 35 % of the lower wavelength, then we recommend a Dual Wavelength Retarder. Please contact your Meadowlark Optics sales engineer for assistance so that we can design for you the required Dual Wavelength Retarder or if you need any help at all.

QUESTION

"I need a Dual Wavelength Retarder with two non-standard retardances at two non-standard wavelengths. Can you help me?"

ANSWER:

While not all retardance and wavelength combinations are available, we can manufacture tens of thousands of different combinations for our Dual Wavelength Retarders. Please contact your Meadowlark Optics sales engineer for assistance and a custom quote.

Dual Wavelength Retarders

ORDERING INFORMATION

Available Combinations				
First Retardance	*Second Retardance*	*Diameter (in.)*	*First Wavelength*	*Second Wavelength*
Quarter wave Half wave Full wave	Quarter wave Half wave Full wave	0.50 1.00	488 nm 514.5 nm 632.8 nm 780 nm 976 nm 1064.1 nm	488 nm 514.5 nm 632.8 nm 780 nm 976 nm 1064.1 nm

HOW TO ORDER DUAL WAVELENGTH RETARDERS

To order dual wavelength retarders, five pieces of information are required (with their symbols in brackets):

1. The First (or lower) wavelength [λ_1] in nanometers
2. The Second (or higher) wavelength [λ_2] in nanometers
3. The retardance at the first wavelength [R_1], where:
   a. Q = Quarter Wave Retardance
   b. H = Half Wave Retardance
   c. F = Full Wave Retardance
4. The retardance at the second wavelength [R_2]
   a. Q = Quarter Wave Retardance
   b. H = Half Wave Retardance
   c. F = Full Wave Retardance
5. The outside diameter, 0.50 in. or 1.00 in. [*D*] where
   a. 050 = 0.50 in.
   b. 100 = 1.00 in.

The part number is then created by these five pieces of data and the letter "D" to start it off.

$$\mathbf{D\ R_1\ R_2} - D - \lambda_1/\lambda_2$$

And we have 10,000 combinations!

Example 1:

A dual wavelength retarder is requested with a full wave of retardance at 488 nm and a half wave of retardance at 976 nm. The outside diameter is 0.50 in. The part number is then:

DFH – 050 – 0488/0976

Example 2:

A dual wavelength retarder is requested with a quarter wave of retardance at 514.5 nm and a quarter wave of retardance at 1064.1 nm. The outside diameter is 1.00 inches. The part number is then:

DQQ – 100 – 0514/1064

Please note that the decimal is not included in the part number.

Precision Achromatic Retarders

Meadowlark Optics Precision Achromatic Retarders are designed to provide a nearly constant retardance over a broad wavelength region. Standard quarter- and half-wave devices are available for common wavelength regions in the visible and near infrared.

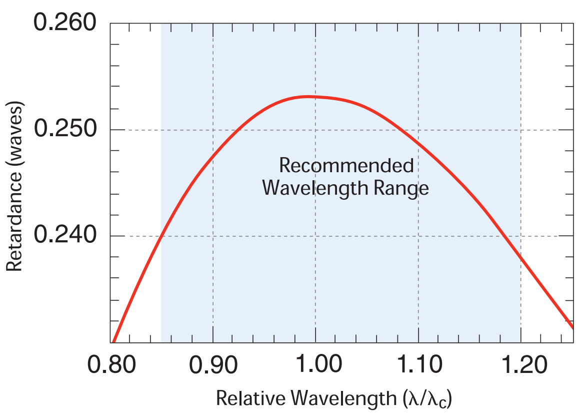


Fig. 2-13 Quarter-wave Achromatic Retarder performance

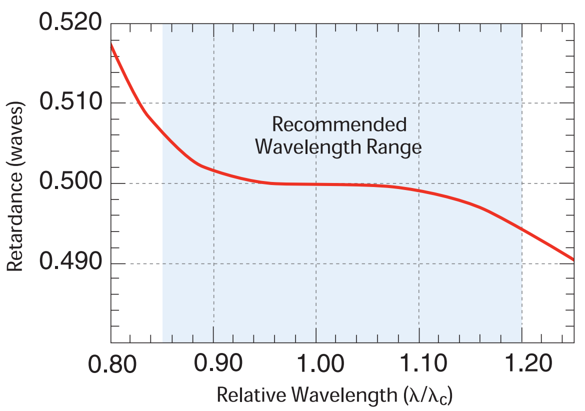


Fig. 2-14 Half-wave Achromatic Retarder performance

Our Precision Achromatic Retarders consist of carefully aligned birefringent polymer sheets laminated between precision polished, optically flat BK 7 windows. Assembly is quite similar to the assembly of our Precision Retarders.

Optical transmittance varies slightly from the Precision Retarder because several polymer layers are used in each Achromatic Retarder.

We provide retardance accurate to λ/100 for all wavelengths in the operating range. Achromatic retarders are an excellent choice for applications requiring broad wavelength use.

Key Benefits

- **Broad spectral range**
- **Superior field of view**

SPECIFICATIONS	
Retarder Material	Birefringent Polymer Stack
Substrate Material	BK 7 Grade A, fine annealed
Standard Wavelength (nm)	**Operating Range (nm)**
545	485 - 630
630	555 - 730
720	630 - 835
840	735 - 985
1060	920 - 1240
1400	1200 - 1650
Retardance	λ/4 and λ/2
Retardance Accuracy	≤ λ/100
Transmitted Wavefront Distortion (at 632.8 nm)	≤ λ/4
Surface Quality	40-20 scratch and dig
Beam Deviation	≤ 1 arc min
Reflectance (per surface)	≤ 0.5% at normal incidence
Diameter Tolerance	
Mounted	±0.005 in.
Unmounted	+0/-0.010 in.
Thickness Tolerance	±0.020 in.
Temperature Range	-20° C to +50° C
Recommended Safe Operating Limit	500 W/cm², CW 300 mJ/cm², 10 ns, visible 500 mJ/cm², 10 ns, 1064 nm

ORDERING INFORMATION				
Mounted				
Diameter (in.)	*Clear Aperture (in.)*	*Thickness (in.)*	*λ/4 Wave Part No.*	*λ/2 Wave Part No.*
1.00	0.40	0.25	AQM-050-λ	AHM-050-λ
1.00	0.70	0.35	AQM-100-λ	AHM-100-λ
Unmounted				
Diameter (in.)	*Clear Aperture (in.)*	*Thickness (in.)*	*λ/4 Wave Part No.*	*λ/2 Wave Part No.*
0.50	0.40	0.14	AQ-050-λ	AH-050-λ
1.00	0.80	0.28	AQ-100-λ	AH-100-λ

Please include the standard wavelength λ in nanometers when ordering. Custom sizes or center wavelengths can be specified for your application.

Custom sizes are available. Please contact your Meadowlark Optics sales engineer for assistance.

Bi-Crystalline Achromatic Retarders

Key Benefits

- **High damage threshold**
- **Volume pricing**
- **Superior IR performance**

Meadowlark Optics is pleased to offer a selection of quarter- and half-wave achromatic retarders that span the UV, visible, near IR and IR portions of the spectrum. Two multi-order crystalline retarders, one made of crystalline quartz and the other magnesium fluoride, are combined in a subtractive mode to give an effective zero-order waveplate. By a careful choice of waveplate thicknesses, retardance dispersion is balanced to give a nearly constant retardance (in waves) over a broad range of wavelengths.The useable wavelength range is defined to give a retardance value within λ/100 of the nominal value. Custom designs with larger achromatic ranges or deeper UV wavelengths are available on request.

Bi-Crystalline Achromats are similar in achromatic performance to our polymer achromats in the visible, but they excel in the IR. They have higher power handling capability than our polymer achromats and can withstand higher storage temperatures. Their field of view is narrow compared to polymer achromats. Typically, they cannot be expected to meet their retardance accuracy for rays whose incidence angles exceed 1.5°. If you must have the performance of a Bi-Crystalline Achromat and a large field of view, call us. We have a proprietary design that can be your polarization solution.

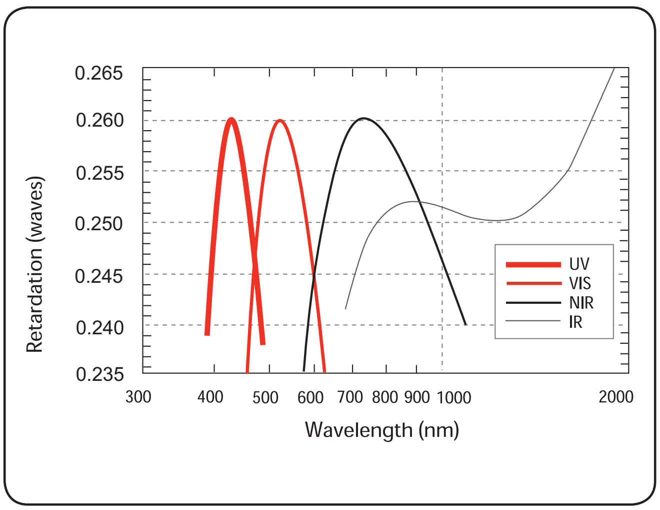


Fig. 2-15 Quarter-Wave Bi-Crystalline Achromatic Retarder performance

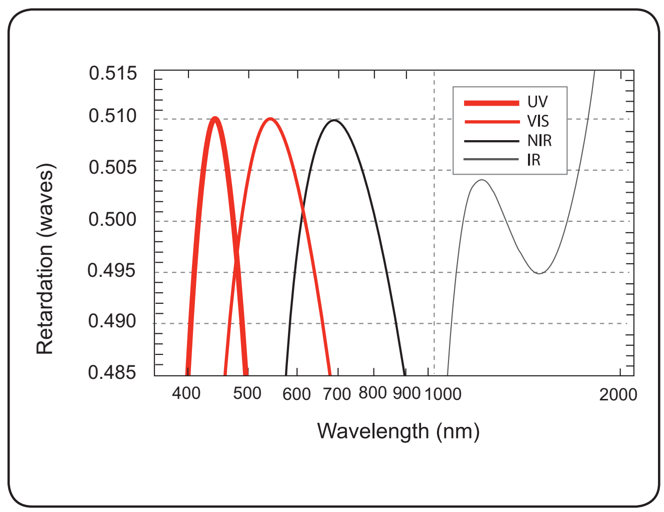


Fig. 2-16 Half-Wave Bi-Crystalline Achromatic Retarder performance

Bi-Crystalline Achromatic Retarders

SPECIFICATIONS		
Materials	Quartz and Magnesium Fluoride	
Retardance	λ/4 or λ/2	
Retardance Accuracy	≤ λ/100 over wavelength range	
Temperature Coefficient of Retardance	< λ/500 per °C	
Wavelength Range	Quarter Wave	Half Wave
Ultraviolet	395-465 nm	412-475 nm
Visible	475-590 nm	500-650 nm
Near Infrared	600-900 nm	600-840 nm
Infrared	690-2050nm	1190-1660 nm
Transmitted Wavefront Distortion (at 632.8 nm)	≤ λ/4	
Reflectance (per surface)	≤ 0.5% at normal incidence	
Surface Quality	40-20 scratch and dig	
Beam Deviation	≤ 1 arc min	
Temperature Storage Range	-40° C to +75° C	
Recommended Safe Operating Limit	2 J/cm², 10 ns, 1064 nm	

ORDERING INFORMATION			
Mounted			
Diameter (in.)	*Clear Aperture (in.)*	*λ/4 Wave Part No.*	*λ/2 Wave Part No.*
1.00	0.40	CQM-050	CHM-050
Unmounted			
0.50	0.40	CQ-050	CH-050

We offer standard Bi-Crystalline Achromatic Retarders to cover 4 regions of the spectrum (see graph): UV, VIS, NIR, IR. Please specify wavelength region when placing your order.

Polarizers
Retarders
Mounting Hardware
Liquid Crystal Devices
Liquid Crystal Controllers

Retarder Selection Chart

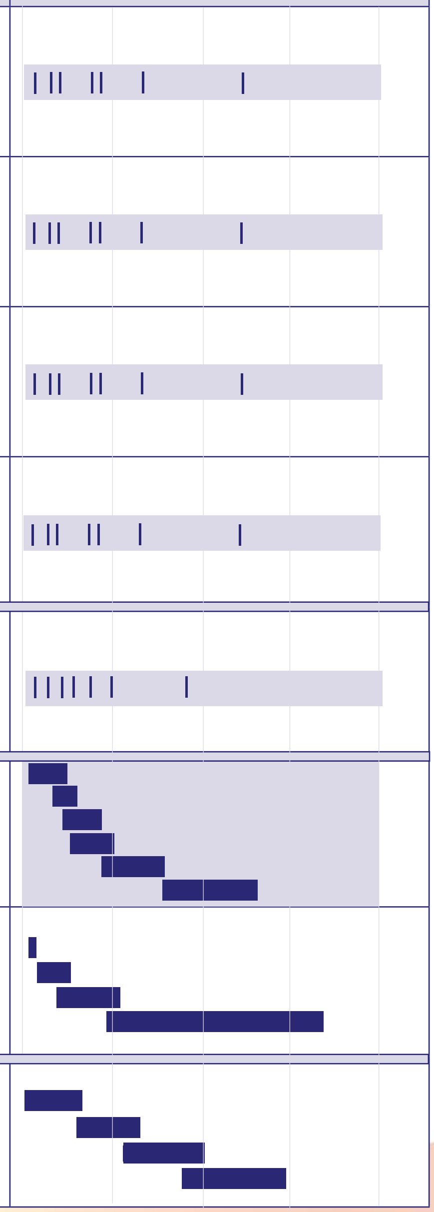
Retarder Selection

When selecting a retarder, key performance features must be considered. These features include wavelength dependence, temperature sensitivity, acceptance angle, response time and aperture size. Our Retarder Selection Chart provides an at-a-glance review of standard retarders.

Meadowlark Optics is a leader in retarder metrology among commercial companies. Our proprietary measurement techniques provide you with extremely accurate calibration measurements for every retarder we ship.

Meadowlark Optics engineers are happy to assist you in the process of selecting a retarder.

Retarder Type	Page	Product Features	Wavelength Range 500 1000 1500 2000
Precision	30	• most popular retarder type • large, custom clear apertures available • insensitive to small wavelength variations	
Commercial	32	• most economical retarder choice • insensitive to small wavelength variations	
Wide Field	33	• unmatched on-axis performance • ideal for uncollimated light applications • standard and custom wavelength versions	
Dual Wavelength	35	• low order • wide angular field • broad wavelength coverage	
Compound Zero Order Quartz	29	• tolerates high temperature • high CW laser damage threshold • tip tunable retardance	
Precision Achromatic	37	• industry-leading design • excellent broadband operation • custom wavelength ranges available	
Bi-Crystalline Achromatic	38	• superior infrared performance • high power handling capability • excellent broadband operation • optic axis independent of wavelength	
Liquid Crystal Variable	48	• unmatched versatility • electrically controlled retardance • custom retardance ranges available	



standard products   custom options

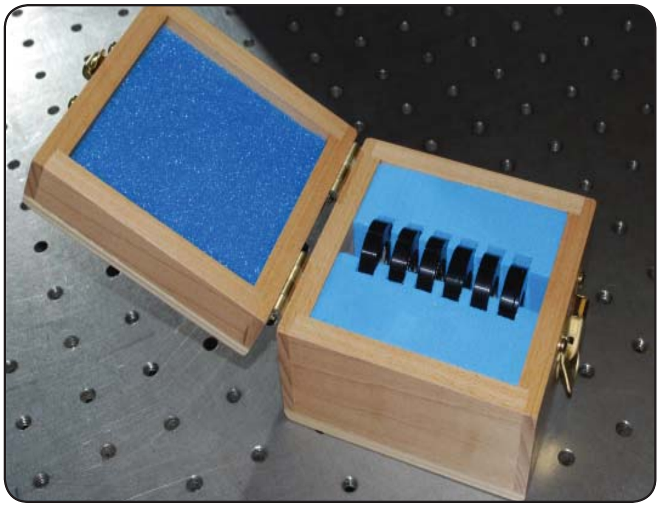
Retarder Selection Chart

- Polymer retarders offer much better field of view than either multiple-order or compound zero-order quartz retarders (Figure 2-4, pg. 26).
- Large clear apertures are cost effective using polymer retarders.
- Polymer retarders are less sensitive to wavelength change than multiple-order quartz retarders (Figure 2-4, pg. 26).
- By design, our achromatic retarders offer much lower retardance variation with wavelength than any other birefringent retarder (Figure 2-4, pg. 26)
- Zero-order polymer retarders are lower in cost than compound zero-order quartz retarders.
- Liquid Crystal retarders offer real-time, continuous control of retardance with no moving parts.
- We offer polymer and liquid crystal retarders in nonstandard sizes and for custom wavelengths and retarder values.
- Multiple-order quartz retarders are preferred for high power laser applications and can be designed for dual-wavelength operation.

Retardance Accuracy	Reflectance (maximum per surface)	Beam Deviation (maximum)	Transmitted Wavefront Distortion (maximum at 632.8 mn)	Acceptance Angle	Clear Aperture (diameter)
± λ/350	0.5%	1 arc min	λ/5	± 10°	0.40, 0.70, 0.80, 1.20
± λ/50	0.5%	3 arc min	3λ	± 10°	0.40, 0.70, 0.80, 1.20
± λ/250	0.5%	1 arc min	λ/2	± 30°	0.40, 0.70, 0.80, 1.20
± λ/100	~ 4%	1 arc min	λ/4	± 5°	0.40, 0.70, 0.80
Above 300 nm: ± λ/300 Below 300 nm: ± λ/200	0.25%	10 arc sec	λ/4	± 1°	0.40, 0.80
± λ/100	0.5%	1 arc min	λ/4	± 5°	0.40, 0.70, 0.80
± λ/100	0.5%	1 arc min	λ/4	± 1°	0.40
tunable with ± λ/500 resolution	0.5%	2 arc min	λ/4	± 2° to 10° (dependent upon applied voltage)	0.37, 0.70 1.60

Polarizer and Retarder kits available, see page 42.

Polarizer/Retarder Sets



Key Benefits

- **Convenient box set**
- **Precise components**

Meadowlark Optics Polarizer/Retarder sets include either a VIS, NIR1 or NIR2 linear polarizer and several precision retarders as described on pages 30-31 within the same wavelength range as the polarizer. By using different combinations, a variety of different polarization states can be accurately and reproducibly created. For example, a linear polarizer with a quarter-wave retarder at 45 degrees can be used to make circularly polarized light. The parts are 1" diameter, 0.7" clear aperture and are packaged in a protective wooden box. Each component is mounted in a black anodized aluminum ring.

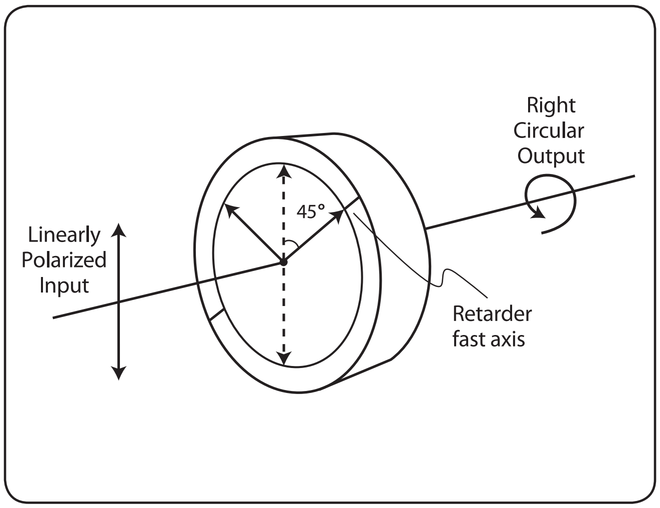


Fig. 2-17 A quarter-wave retarder converts linearly polarized light to circularly polarized light, or vice versa

For polarizer specifications please refer to page 7.
For retarder specifications please refer to page 31.

ORDERING INFORMATION

Item	*Part Number*
PRS1 sets include a polarizer and one retarder.	
VIS Polarizer/Retarder Set	PRS1-VIS-λ
NIR1 Polarizer/Retarder Set	PRS1-NIR1-λ
NIR2 Polarizer/Retarder Set	PRS1-NIR2-λ
PRS3 sets include a polarizer and three retarders.	
VIS Polarizer/Retarder Set	PRS3-VIS-λ_1/ λ_2/ λ_3
NIR1 Polarizer/Retarder Set	PRS3-NIR1-λ_1/ λ_2/ λ_3
NIR2 Polarizer/Retarder Set	PRS3-NIR2-λ_1/ λ_2/ λ_3
PRS5 sets include a polarizer and five retarders.	
VIS Polarizer/Retarder Set	PRS5-VIS-λ_1/ λ_2/ λ_3/ λ_4/ λ_5
NIR1 Polarizer/Retarder Set	PRS5-NIR1-λ_1/ λ_2/ λ_3/ λ_4/ λ_5
NIR2 Polarizer/Retarder Set	PRS5-NIR2-λ_1/ λ_2/ λ_3/ λ_4/ λ_5

Please specify your wavelength(s) λ in nanometers when ordering. Half wave and quarter wave retarders are available over the following regions:

VIS: 400 - 700 nm
NIR1: 650 - 850 nm
NIR2: 800 - 1700 nm