

ESCO PRODUCTS



HANDBOOK OF

STANDARD & CUSTOM

OPTICAL COMPONENTS

Esco Products, Inc.

HANDBOOK OF STANDARD AND CUSTOM OPTICAL COMPONENTS

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- *Can I use BK7, or does my application require fused silica?*
- *What are the consequences of using a biconvex lens instead of a plano-convex lens?*
- *Which type of neutral density filter best suits my application, metallic coated or solid glass?*
- *Do I need $\lambda/10$, or will $\lambda/2$ be precise enough?*

Do you often ask yourself questions like this? Many of our customers do, and that is precisely why we have assembled this handbook. Esco Products manufactures one of the most complete lines of standard optical elements in the world today. We are also a leading manufacturer of custom optical components. With the huge variety of parts we build, we want to ensure that our customers can easily locate the part they need, feel comfortable that it has the quality they require, and will receive it in a timely manner, at a price they can afford.

Our reputation precedes us. Esco is a proven manufacturing leader of fused silica and fused quartz optics. We have the largest selection of standard optical windows in the industry. And we carry the most complete line of off-the-shelf and custom Schott filter glasses.

It doesn't stop there. Our opticians possess all the skills that are necessary to produce high accuracy elements in low quantities. We also have the capacity to produce high volume, American-made components at competitive prices.

We are pleased that you have looked to Esco Products as a reliable supplier of precision optical components. We hope that this handbook demonstrates our commitment to excellence, answers many of your questions and gives you a clearer understanding of why Esco Products is an industry leader.



ZERODUR® is a registered trademark of SCHOTT GLASWERKE of Mainz, Germany

PYREX® is a registered trademark of CORNING INCORPORATED, Corning, NY

OPTICAL MATERIALS

Fused Silica / Quartz

Both fused quartz and fused silica are at least 99.7% silicon dioxide. Fused quartz is manufactured from the melting and refusing of crushed natural crystalline quartz. Fused silica is a synthetic material fused from various chemicals in a very controlled environment.

STANDARD MATERIALS

Esco does not manufacture optical materials. We select the most favorable materials from the marketplace and utilize them for our optics.

OPTICAL CHARACTERISTICS

Bubbles and Inclusions are the most common visible defects that are associated with optical materials. Bubbles are trapped air spaces. Inclusions can be trapped particles of refractory. Occurrences of either is limited to larger and thicker optics.

Esco typically screens out most internal defects unless they are absolutely unavoidable.

The chart to the right shows the maximum size and quantity of internal defects that an optic may have within the material type and size range.

Homogeneity refers to the variation in the index of refraction across the entire aperture of the optic. Unless you have a critical imaging or high powered laser application this is generally not an issue with our materials.

Striae refers to localized visible variations in the index of refraction shaped like thin threads. Grade A means none visible. Grade B implies almost visible. Grade C means visible to the naked eye. These defects are selected out of Esco's optics unless they are unavoidable,

Fused quartz and fused silica have nearly identical properties except that fused silica has much better deep UV transmission than does fused quartz. The deeper UV transmission is the result of the elimination of most impurities in the synthesizing process.

You can be confident that we have chosen the best performing most cost-effective materials for our components. In addition to the standard grades offered in the

Fused silica dominates the marketplace for optical applications at the present time. Esco's current stock is nearly 100% fused silica. Fused quartz is only readily available in non-optical grade IR material.

handbook, our technical sales department will be happy to suggest and offer intermediate grades of materials that best meet the requirements of your unique application.

Bubbles & Inclusions						
ESCO Material	up to 1.0" dia.		from 1.0" to 2.0" dia.		from 2.0" to 3.0" dia.	
	Max. Dia. (inches)	Max. Qty. per pc.	Max. Dia. (inches)	Max. Qty. per pc.	Max. Dia. (inches)	Max. Qty. per pc.
S1-UVA	0.006	0	0.008	1	0.010	1
S1-UVB	0.008	1	0.015	1	0.015	1
A1	0.010	1	0.015	1	0.020	2
G1	0.030	3	0.040	3	0.060	3
I2-IR	0.010	3	0.015	3	0.020	3
BK-7	0.006	0	0.006	0	0.010	1

* These specifications are worst case conditions.
 * Materials can be selected and guaranteed to customer's requirements.
 * Bubbles less than the maximum diameter count as a fraction of the allowed limit.
 * Bubbles less than 0.004" are regarded as undetectable.

Fluorescence in optics is the emission of light caused by an exposure to UV light. Fused quartz will have a strong blue fluorescence. Standard fused silica will not fluoresce unless

the source of UV light is intense such as that from an excimer laser beam. UV laser applications require the use of excimer grade fused silica in order to minimize this problem.

Material Code	Type	Striae per MIL-G-174A	Index Variation $\Delta n(x10^{-6})$
S1-UVA	Fused Silica	A	6
S1-UVB	Fused Silica	A	10
A1	Fused Quartz or Fused Silica	B	10
G1	Fused Quartz or Fused Silica	C-D	20
I2-IR	Fused Quartz	A	4
BK7	Optical Glass	A	10

Ultraviolet Grades

S1-UVA and S1-UVB

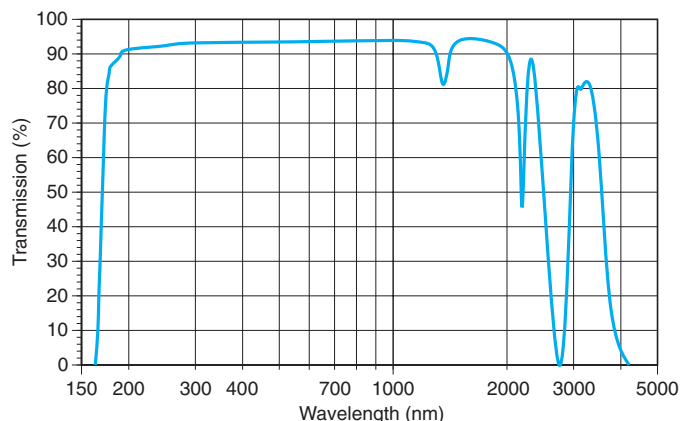
These extremely pure fused silica materials offer good transmittance down into the deep UV. They provide outstanding homogeneity, making them ideal for applications demanding superior wavefront performance. As fused silica materials, they show no fluorescence or discoloration when exposed to radiation shorter than 290 nm. S1-UVA has slightly better homogeneity and fewer and smaller bubbles than S1-UVB. Unless otherwise specified, the UV grade optical elements found in this handbook are manufactured out of S1-UVB.

Optimum Transmission Range:

- 170 nm–2.2 μm
- 2.9 μm –3.6 μm

Ideal Applications:

- Deep UV transmission elements
- Minimum scattering systems



Infrared Grade

I2-IR

This fused quartz material is virtually free of OH⁻ ions allowing it to provide superior transmittance in the 2.7 μm wavelength (“water band”) region. I2-IR is a high quality optical grade IR fused quartz with outstanding homogeneity and bubble characteristics. A commercial quality of IR quartz is also available, however it often contains many small bubbles and should only be used for non-imaging applications.

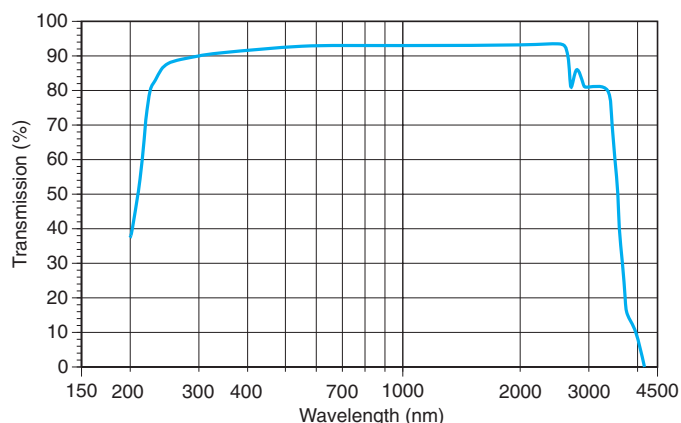
Optimum Transmission Range:

- 250 nm–3.6 μm

Ideal Applications:

I2-IR

- Superior optical quality IR transmission
- Solar simulation optics



Commercial Grades & Optical Grade

G1 & A1

In thin, small pieces, G1 fused quartz/silica material is virtually bubble-free. Elements built from larger pieces will most likely contain bubbles. Your application should not be sensitive to these inclusions. G1 provides good UV and visible transmission. In cases where simple light gathering and strong mechanical properties are the primary goals, G1 grade provides excellent performance at a low price.

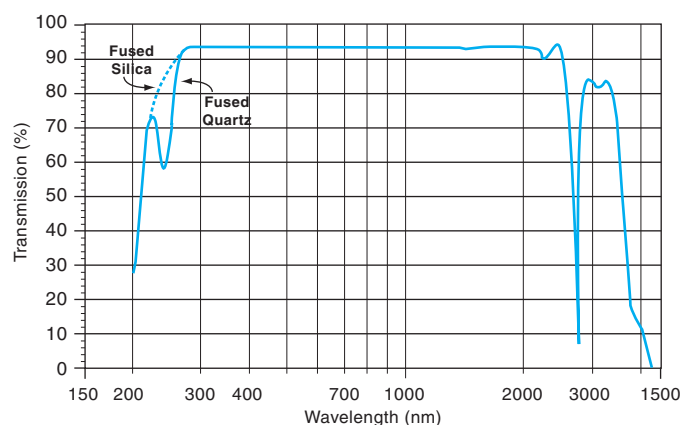
A1 is ideal for all but the most demanding optical applications. All the materials used in this grade are guaranteed to be Grade B or better, providing excellent optical and physical properties at a reasonable price. A1 is an ideal material for larger-sized optical components.

Optimum Transmission Range:

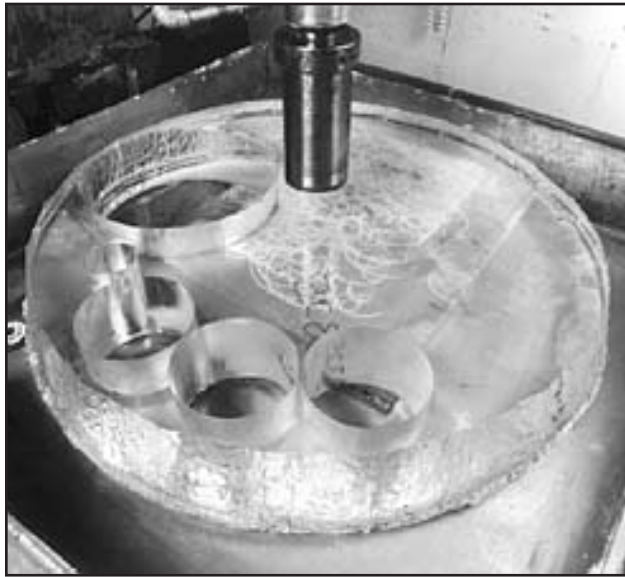
270 nm–2.5 μm

Ideal Applications:

- Condenser optics not concerned with scatter or distortion
- High temperature and pressure applications
- Optical flats, microscope slides and sight glasses



OPTICAL MATERIALS



INDICES OF REFRACTION

Wavelength, nm	Fused Quartz Fused Silica	BK7	Sapphire
213.86	1.53427	-	-
230.21	1.52005	-	-
239.94	1.51337	-	-
265.20	1.50000	-	1.83360
280.35	1.49403	-	1.82427
302.15	1.48719	-	1.81351
334.15	1.47976	-	1.80184
346.62	1.47746	-	1.79815
365.02	1.47452	1.53626	1.79358
404.66	1.46962	1.53024	1.78582
435.84	1.46669	1.52669	1.78120
546.07	1.46008	1.51872	1.77078
706.52	1.45516	1.51289	1.76303
852.11	1.45247	1.50981	1.75885
1013.98	1.45025	1.50731	1.75547
1529.52	1.44427	1.50094	1.74660
1970.09	1.43853	1.49500	1.73833
2325.42	1.43293	1.48929	1.73055
3243.90	1.41315	-	1.70437
3507.00	1.40566	-	1.69504
4954.00	-	-	1.62665
5577.00	-	-	1.58638

Optical Glass

BK7

For all standard optical glass components, or when optical glass is generically requested for custom elements, Esco Products uses normal quality BK7, a high quality optical glass that is used whenever the additional benefits of fused silica are not required. Since BK7 performs well in all chemical tests, no special handling is required, thus reducing manufacturing costs. It is a relatively hard material with extremely low bubble and inclusion content. BK7 provides excellent transmittance throughout the visible and near infrared spectra and down to 350 nm in the ultraviolet.

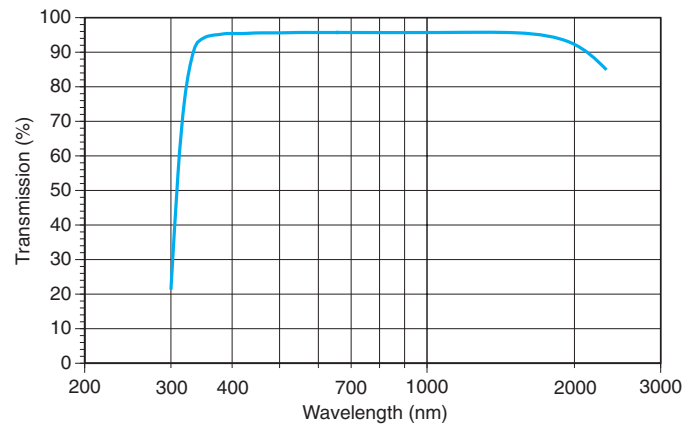
Optimum Transmission Range:

- 350 nm–2.0 μm

Ideal Applications:

- Optical imaging in the visible spectrum
- Laser optics
- Stable temperature environments

NOTE: Esco can work with any commercially available glass type. If there is a specific glass that is more highly suited to your particular application, please contact Esco at 1-800-922-ESCO (3726) to discuss the design details.



Low Expansion Materials

PYREX® (Corning 7740)

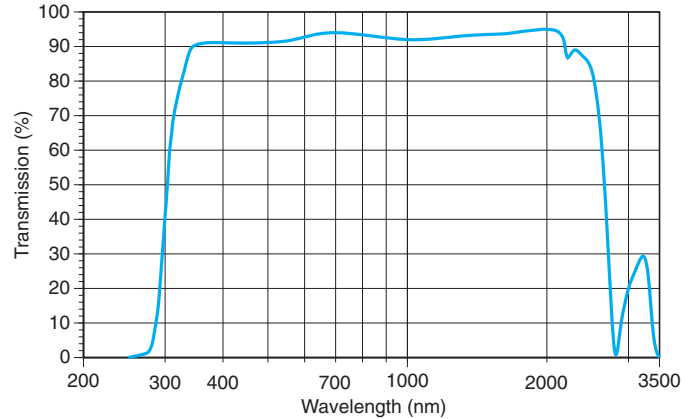
Pyrex® is a heat-resistant, low-expansion industrial borosilicate glass. This low-cost material provides good transmission and excellent thermal stability in non-critical imaging applications.

Optimum Transmission Ranges:

- 310 nm–2.6 μm

Ideal Applications:

- Non-imaging condensing systems needing a heat resistant material



ZERODUR® (Schott)

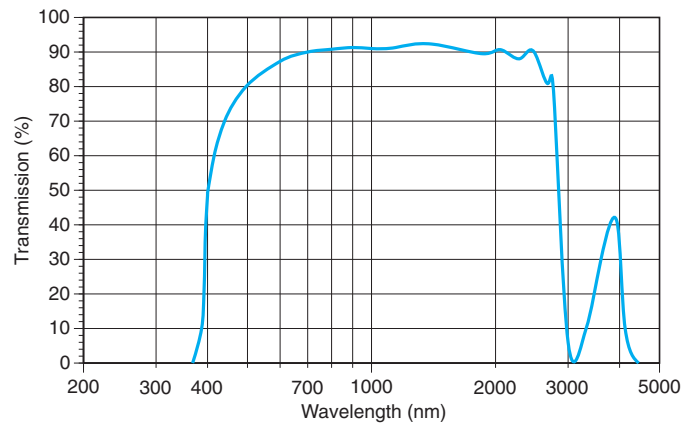
Zerodur® is a highly homogeneous, glass ceramic whose thermal and mechanical properties are extremely stable over a wide temperature range. This porous-free material is a carefully chosen, temperature-treated combination of a glass with a positive expansion coefficient and a quartz structure crystalline phase with a negative expansion coefficient. The resultant mixture provides a material with a near-zero coefficient of thermal expansion. Zerodur® provides outstanding homogeneity, but due to absorption near the blue end of the visible spectrum, is rarely used in refractive applications.

Optimum Transmission Ranges:

- None

Ideal Applications:

- High accuracy interferometer mirror substrates
- Large astronomical telescope mirrors
- Ring-laser gyroscope elements
- Laser resonator distance gauges



PHYSICAL AND OPTICAL PROPERTIES

	Fused Quartz/ Fused Silica	BK7	Pyrex®	Zerodur®	Sapphire
Maximum Temperature (Continuous, °C)	950/1000	350	230	600	2040*
Coefficient of Thermal Expansion (cm/cm • °C)	4.8	83	32.5	0.5	84
n _d (index at 589.3 nm)	1.458	1.517	1.474	1.542	1.768
v _d (Abbé number)	67.7	64.2	66.6	56.2	72.2

*melting point of crystalline structure

OPTICAL MATERIALS

SAPPHIRE

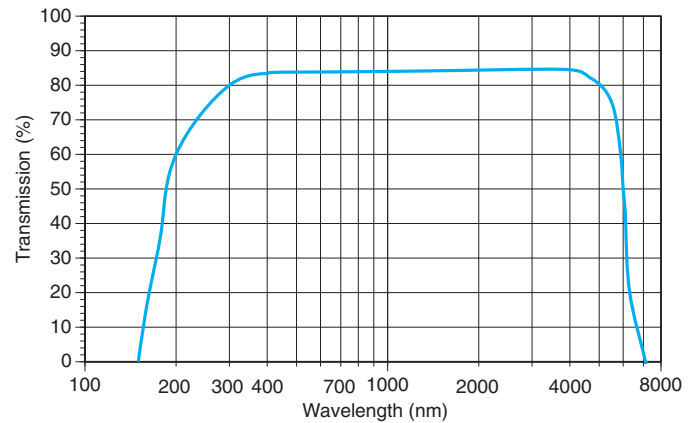
Synthetic sapphire is an anisotropic crystalline material composed of single crystal aluminum oxide (Al_2O_3). Esco works with only high quality, optical grade sapphire. It is essentially 100% pure. The various properties of sapphire are a function of the direction within the crystal with respect to the optic axis. It has an extremely wide transmission spectrum (150 nm to 6.0 μm). Its high melting point, good thermal conductivity and low thermal expansion provide excellent performance in high temperature environments. The extreme hardness of sapphire makes it difficult to polish using standard techniques. High optical quality finishes on sapphire are not always possible. Contact Esco for more information.

Optimum Transmission Range:

- 200 nm–5.0 μm

Ideal Applications:

- With PbS, PbSe and InSb detectors. Spectral transmittance matches spectral sensitivity of detectors
- Infrared, high temperature, high pressure, high thermal shock environments
- Scratch resistant elements used in rain resistance, bar code scanning applications



Mechanical Properties of Optical Materials



Thermal	Units	Fused Quartz	Fused Silica	BK7	Pyrex®	Sapphire	
Softening Point	°C	1730	1600	715	820	2040	
Annealing Point	°C	1180	1120	550	565		
Strain Point	°C	1075	1025	624	515		
Maximum Temperature (Continuous)	°C	1000	950	350	230	1100	
Maximum Temperature (Momentary)	°C	1300	1200		490		
Thermal Conductivity	@ 20° C		0.0033	0.0033	0.0026	0.0027	0.0065
	@ 200°C	$\frac{\text{cal} \cdot \text{cm}}{\text{cm}^2 \text{ sec } ^\circ\text{C}}$	0.0037	0.0037			
	@ 950° C		0.0064	0.0064			
Specific Heat	0°–100° C	$\frac{\text{cal}}{\text{g } ^\circ\text{C}}$	0.18	0.18	0.21	0.20	
	0°–900° C		0.25	0.25			
Coefficient of Thermal Expansion	-50°–0° C	$\frac{\text{cm}}{\text{cm } ^\circ\text{C}}$	2.7×10^{-7}	2.8×10^{-7}			
	0°–300° C		5.9×10^{-7}	5.9×10^{-7}	86×10^{-7}	33×10^{-7}	
	0°–900° C		4.8×10^{-7}	4.8×10^{-7}			90.3×10^{-7}
Strength/Hardness							
Moh Hardness			5.5–6.5	5.5–6.5	5	9	
Microhardness	kg/cm ²		9.4×10^4	9.4×10^4			
Knoop Hardness (100g load)	kg/mm ²		605	615	520	481	1525–2000
Density	g/cm ³		2.203	2.203			
Specific Gravity			2.203	2.201	2.53	2.23	3.98
Compressive Strength	kg/cm ²		1.13×10^4	1.13×10^4			2.04×10^4
Tensile Strength	kg/cm ²		500	500		282	7000
Torsional Strength	kg/cm ²		300	300			1.5×10^6
Bending Strength	kg/cm ²		680	680			
Young's Modulus	kg/cm ²		7.45×10^5	7.45×10^5	8.63×10^5	7×10^6	79×10^5
Shear Modulus	kg/cm ²		3.2×10^5	3.2×10^5			
Bulk Modulus	kg/cm ²		3.76×10^5	3.76×10^5			
Poisson's Ratio			0.17	0.17	0.208	0.2	0.02
Electrical							
Dielectric Strength	@ 20° C	kv/cm	250–400	250–400			480
	@ 500° C		150–200	150–200			
Dielectric Constant	(0–1MHz)		3.70	3.70		5.1	8.6–10.6
Dielectric Loss Tangent	1 MHz		1×10^{-4}	1×10^{-4}		2.6×10^{-2}	
	10 ² MHz		1×10^{-4}	1×10^{-4}			
	3×10^4 MHz		4×10^{-4}	4×10^{-4}			
Resistivity	@ 20° C	Ω/cm	1×10^{18}	1×10^{18}			
	@ 600° C		8×10^7	8×10^7			1×10^{11}
	@ 1000° C		1×10^6	1×10^6			1×10^6

All properties measured at 20° C unless otherwise specified.

COATINGS



The types of coatings that are typically used to control the reflective characteristics of optical elements used in the UV, visible and NIR spectra include:

Anti-reflective

- Single layer
- Multilayer, narrowband
- Multilayer, broadband

Reflective

- All-dielectric (MAX R)
- Metallic

Partially reflective (Beamsplitter)

Filter coatings

This section discusses Anti-reflective and Reflective coatings. All thin film coatings offered by Esco are created using vacuum deposition techniques.

Specifications on Beamsplitter coatings can be found on pages 47 and 49, and Filter coatings on page 45.

Custom Coatings

It is also possible to supply other coatings or different variations of the coatings described here. To discuss custom coating designs, please call Esco at 1-800-922-ESCO (3726).

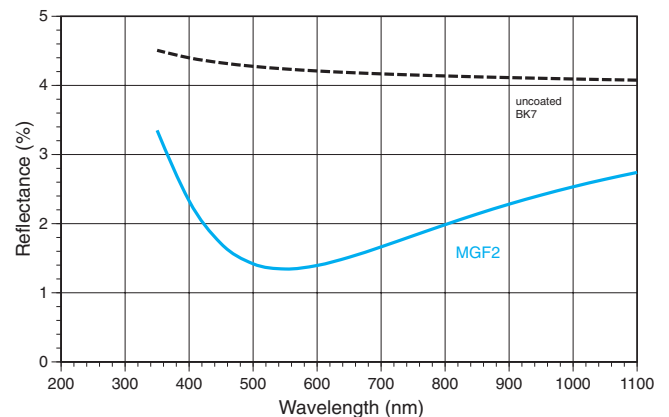
Anti-reflection Coatings

Anti-reflection, or "AR" coatings are the most common type of optical coating in the world. Applied to elements from eyeglasses and camera lenses, to components used in high-power laser systems, AR coatings are designed to minimize natural back reflections that could otherwise interfere with the preferred operation of an optical system. To meet the needs of a variety of users, Esco provides a comprehensive range of AR types. To discuss the coating that is best suited to your application, please call Esco.

Reflectivity (per surface):	~1.3% for mid-visible on BK7 2.00% max on BK7, 2.25% max on SiO ₂
Practical bandwidth:	~300 nm
Wavelength range:	200 nm to 1500 nm
Substrates:	Fused Quartz/Fused Silica (all grades) Any Optical Glass Other materials upon request Per MIL-C-48497A
Durability:	
ORDER AS:	MGF2
PLEASE SPECIFY:	Substrate material/Part number Surface(s) to be coated Wavelength range Angle of incidence

Single Layer MgF₂ (MGF2)

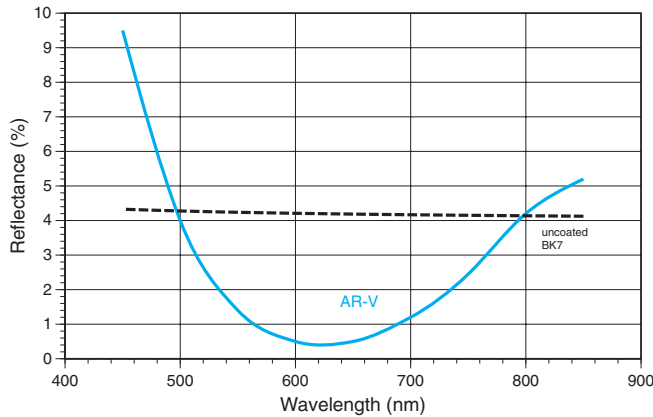
The index of refraction of magnesium fluoride is nearly ideal for the task of providing minimum reflectance with only a single layer film. When applied at high temperatures, MgF₂ becomes a hard, durable coating that meets all standard MIL requirements. It exhibits broadband characteristics and can be applied on a variety of substrates for use in spectral regions from the UV to the NIR. MgF₂ has the best performance:cost ratio of any anti-reflection coating.



Typical MGF2 coating shown for visible spectrum

Narrowband AR ("V") Coating (AR-V)

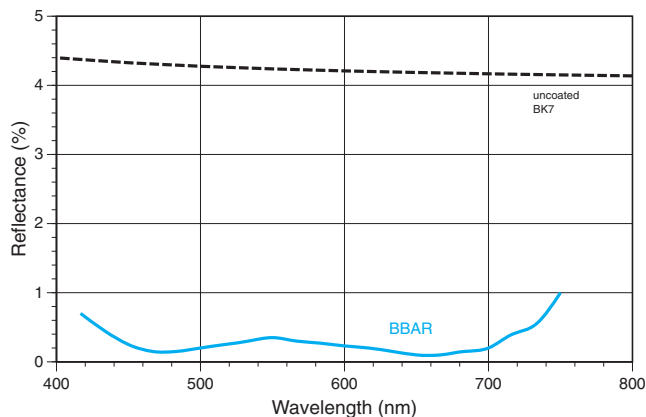
Commonly called a "V" coating because of its spectral shape, narrowband AR coatings are the simplest of the multilayer coatings and are used whenever the application involves a single wavelength. A "V" coating usually achieves reflectivity of <0.25% at the design wavelength.



Typical AR-V coating shown at 632.8 nm

Broadband Multilayer AR Coating (BBAR)

This coating provides the low reflectivity of a "V" coating combined with the broadband characteristics of a single layer coating. The trade-off is higher cost.



Typical BBAR coating shown for visible spectrum

Reflectivity (per surface): <0.25% at design wavelength
Practical bandwidth: Usually 12% of the design wavelength between 0.5% points
Wavelength range: 400 nm to 1500 nm
Substrates: Fused Quartz/Fused Silica (all grades)
 Any Optical Glass
 Other materials upon request
 Per MIL-C-48497A
Durability:
Variation: "V" coatings that minimize reflections at TWO wavelengths are also possible. For more information please call Esco.

ORDER AS: AR-V
PLEASE SPECIFY: Substrate material/Part number
 Surface(s) to be coated
 Design wavelength
 Angle of incidence

Reflectivity (per surface): <1% absolute, within practical bandwidth, <0.5% average
Practical bandwidth: ~280 nm, (420 nm–700 nm)
Wavelength range: 400 nm to 1500 nm
Angle of incidence: 0° ±15°
Substrates: Fused Quartz/Fused Silica (all grades)
 Any Optical Glass
 Other materials upon request
 Per MIL-C-48497A
Durability:

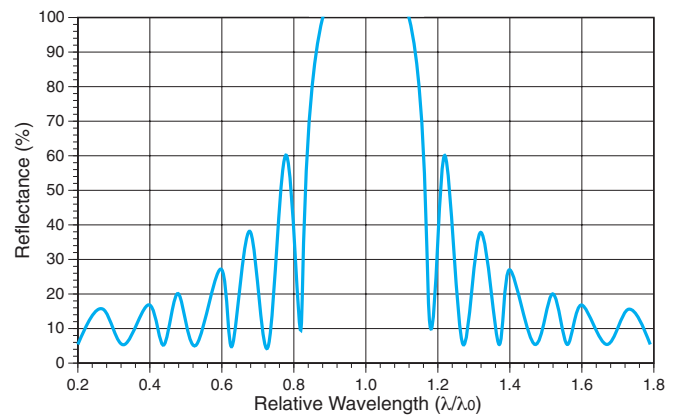
ORDER AS: BBAR
PLEASE SPECIFY: Substrate material/Part number
 Surface(s) to be coated
 Wavelength range
 Angle of incidence

Maximum Reflecting Dielectric Coatings

Typically used with lasers, Max R coatings provide nearly complete reflection over a specific spectral range, absorbing negligible incident energy. These high-purity coatings are very durable—designed to meet all standard MIL requirements. The trade-offs for high reflectivity (compared to metal reflectors) are: increased polarization sensitivity and increased cost.

Reflectivity:	>99.5% at design wavelength
Typical bandwidth:	~20% of design wavelength at 99% points
Wavelength range:	300 nm to 3000 nm
Angle of incidence:	0-45°
Substrates:	Fused Quartz/Fused Silica (all grades) BK7 Optical Glass Pyrex®/Zerodur® Other materials upon request
Durability:	Per MIL-C-48497A
ORDER AS:	MAX R (at specified wavelength)
PLEASE SPECIFY:	Wavelength (narrowband) Substrate material/Part number Surface to be coated Design wavelength Angle of incidence Polarization of incident energy

Narrowband Maximum Reflecting Coating (MAX R)



Metallic Reflectors

For most mirror applications, metallic coatings offer the best performance:cost ratio of any reflective coating. Many different metals can be evaporated for use as reflectors. The three most common and effective types are listed below. In addition, several dielectric coatings are available as overcoats. These layers are used to enhance reflectivity, durability and/or longevity of the underlying metal.



Aluminum-Silicon Monoxide (AL SIO)

Benefits

- General purpose Aluminum coating for use in the visible spectrum
- Inexpensive

Trade-offs

- Poor UV reflectance

Reflectivity: >85% average, 400 nm-800 nm

Wavelength range: 350 nm to 3000 nm

Substrates: Fused Quartz/Fused Silica (all grades)
BK7 Optical Glass
Pyrex®/Zerodur®
Other materials upon request
Per MIL-C-48497A

Durability:

ORDER AS:

AL SIO

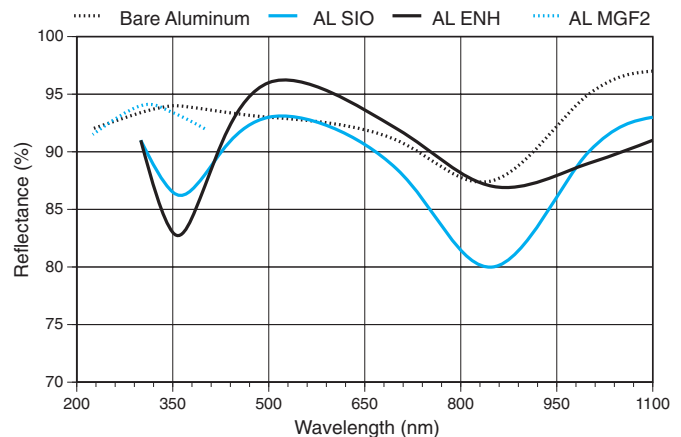
PLEASE SPECIFY:

Substrate material/Part number
Surface to be coated

Aluminum

Al-SiO, Al-MgF₂, Enhanced Aluminum

Bare aluminum provides excellent reflectivity from the UV to the IR. Unfortunately, it also oxidizes rapidly and use of a dielectric overcoat is usually required to prevent degradation. Since no overcoat is ideal for all applications, materials best suited to the intended application should be chosen.



Enhanced Aluminum (AL ENH)

Benefits

- Special Aluminum coating for higher reflectivity in the visible spectrum.

Trade-offs

- Poor out-of-band reflectivity

Reflectivity: >93% average, 450 nm-750 nm

Wavelength range: 400 nm to 800 nm

Substrates: Fused Quartz/Fused Silica (all grades)
BK7 Optical Glass
Pyrex®/Zerodur®
Other materials upon request
Per MIL-C-48497A

Durability:

ORDER AS:

AL ENH

PLEASE SPECIFY:

Substrate material/Part number
Surface to be coated

Aluminum-Magnesium Fluoride (AL MGF2)

Benefits

- General purpose Aluminum coating for use in the UV and visible spectra.
- Relatively inexpensive

Trade-offs

- Very poor durability, special care must be taken while handling or cleaning

Reflectivity: >85% average, 200 nm-800 nm

Wavelength range: 200 nm to 3000 nm

Substrates: Fused Quartz/Fused Silica (all grades)
BK7 Optical Glass
Pyrex®/Zerodur®
Other materials upon request

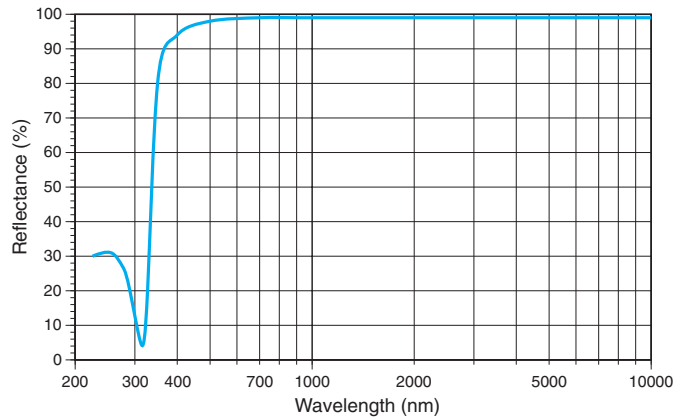
ORDER AS:

AL MGF2

PLEASE SPECIFY:

Substrate material/Part number
Surface to be coated

COATINGS



Silver (AG)

Benefits

- Excellent reflectivity from the visible to the far infrared
- Durable overcoat allows front surface use without risk of silver oxidation

Trade-offs

- Cost
- Poor UV reflectivity

Reflectivity:

>96% average, 400 nm-1000 nm
>98% absolute, 2.5 μm -12 μm

Wavelength range:

400 nm to 12 μm

Substrates:

Fused Quartz/Fused Silica

(all grades)

BK7 Optical Glass

Pyrex®/Zerodur®

Other materials upon request

Per MIL-C-48497A

Durability:

ORDER AS:

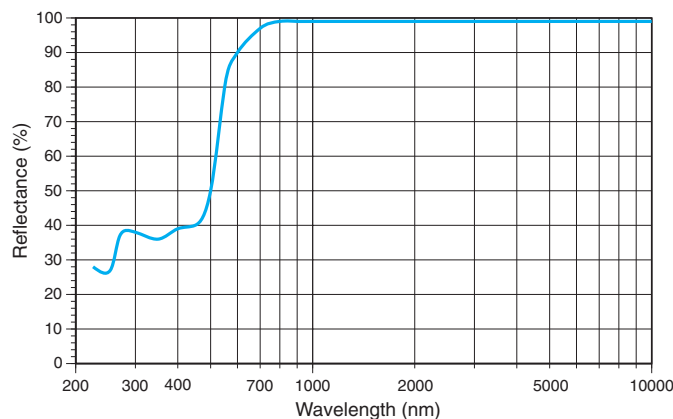
AG

PLEASE SPECIFY:

Substrate material/Part number

Surface to be coated

Wavelength range



Gold (AU)

Benefits

- Excellent reflectivity from the visible to the far infrared (best 2-12 μm)
- Low scatter surfaces

Trade-offs

- Cost
- Poor UV, visible reflectivity
- Poor durability. Contact Esco for details.

Reflectivity:

>95% average, 650 nm-1000 nm
>98% absolute, 2.5 μm -12 μm

Wavelength range:

650 nm to 12 μm

Substrates:

Fused Quartz/Fused Silica

(all grades)

BK7 Optical Glass

Pyrex®/Zerodur®

Other materials upon request

ORDER AS:

AU

PLEASE SPECIFY:

Substrate material/Part number

Surface to be coated (cannot be

used as rear surface reflector)

To ensure an accurate solution of these and other optical formulas, proper sign convention must be observed. The common illustrative convention (and the one used in this handbook) is to show light traveling from left to right. If this convention is used, then it follows that:

- The object distance, s_o , is + to a left of the lens and - to the right
- The image distance, s_i , is + to a right of the lens and - to the left
- A radius is + when its center of curvature is to the right of the surface, and is - when its center of curvature is to the left
- Lens thicknesses and indices of refraction are always positive

The transmitted, or refracted, component of a ray of light traveling from one optical medium to another follows a path that is described by [Snell's Law](#),

$$n_i \sin \theta_i = n_t \sin \theta_t$$

where n_i is the index of refraction of the incident medium, θ_i is the angle of incidence, n_t is the index of refraction of the transmitting medium and θ_t is the resulting transmission angle.

The [Reflectivity](#), ρ of a plane wave normal to an optical material is determined by the material's index of refraction, n

$$\rho = \left(\frac{n - 1}{n + 1} \right)^2$$

The percentage of light that an optical material allows to pass internally is known as its [Internal Transmittance](#), τ_i .

$$\tau_i = e^{-\alpha t}$$

where α is the absorption coefficient of the material and t is its thickness. The total [Transmittance](#), τ , is then given as

$$\tau = \frac{(1 - \rho)^2 e^{-\alpha t}}{1 - \rho^2 e^{-2\alpha t}}$$

A component's [Optical Density](#), D , is described by the equations where T is the ratio of the transmitted energy to the incident energy.

$$D = \log\left(\frac{1}{T}\right) \quad T = 10^{-D}$$

To determine the [Effective Focal Length](#), f , of a lens with a center thickness, t_c , the equation

$$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n - 1)t_c}{nR_1R_2} \right)$$

can be used, where R_1 , R_2 are the radii of curvature and n is the lens material's index of refraction.

If the thickness of a lens, t_c , is much smaller than the effective focal length ($<1:6$), then, an approximation is valid.

$$\frac{1}{f} = (n - 1) \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

The [Back Focal Length](#) can then be determined by using

$$\text{BFL} = f \left(1 - \frac{(n - 1)t_c}{nR_1} \right)$$

The equation

$$\frac{1}{f_r} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$

can be used to determine the [Resultant Focal Length](#) of a lens system made up of multiple elements, where f_1 and f_2 are the effective focal lengths of the individual lenses, d is the distance between them and f_r is the Resultant Focal Length.

The [Magnification](#), m of a finite conjugate system is given by

$$m = \frac{s_i}{s_o} = \frac{f}{s_o - f} = \frac{s_i - f}{f}$$

where s_i is the image distance and s_o is the object distance, both measured from the lens.

The [F-number](#) of a lens, $F/\#$, is the ratio of the focal length, f , of the lens system to the diameter, d , of its entrance pupil.

$$F/\# = \frac{f}{D} = \frac{1}{2 NA}$$

The thickness of a lens is total of the sagittal heights of each lens surfaces plus the edge thickness. The [Sagittal Height](#) of a lens surface, h , is given as:

$$h = R - \sqrt{R^2 - (d/2)^2}$$

where R is the radius of the surface and d is the diameter of the lens.

[Sight Glass Burst Pressure](#), P , is given as

$$P = \frac{3.48 M t^2}{k A}$$

where M is the tensile strength of the material, t is its thickness, A is the unsupported area and k is the safety factor (usually 10).

NOTE: Too many unknown factors affect burst pressure for ESCO to guarantee the accuracy of this formula. It should be considered only as an approximation.

BICONVEX LENSES

Standard

Biconvex lenses are symmetrical elements with positive focal lengths. They are designed for 1:1 finite conjugate imaging where aberrations such as coma, distortion and lateral chromatic exactly cancel and spherical aberration is at a minimum.

Biconvex lenses are ideal for finite conjugate imaging over a narrow spectral range. For imaging parallel light (infinite conjugate) or for collimation, plano-convex lenses should be used. For broadband situations where chromatic aberration would be a problem, achromats should be considered. For improved performance involving laser light, bestform lenses could be considered as well.

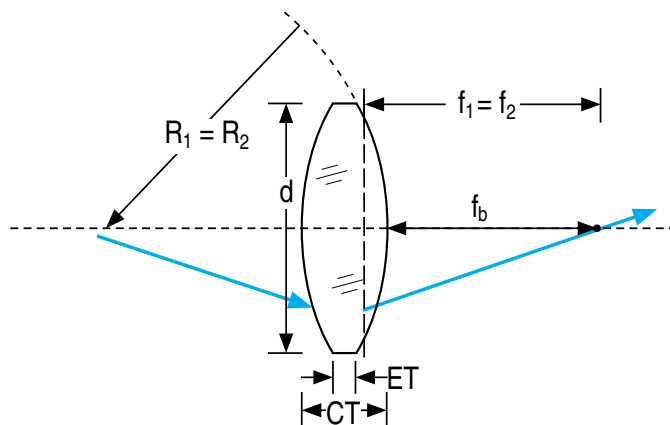
Esco manufactures biconvex lenses from most of the optical grade materials listed in this handbook. They are pitch polished to provide good surface quality and excellent low-cost imaging performance with a variety of light sources.

Specifications

Focal length tolerance: $\pm 3\%$
Diameter tolerance: ± 0.125 mm
Thickness tolerance: ± 0.5 mm
Design wavelength: 546 nm
Centration: $< 3'$
Surface quality: 60-40, scratch-dig
Edges: Fine ground and beveled

OPTICAL MATERIALS, pages 4-9
 OPTICAL COATINGS, pages 10-14

All dimensions are in mm unless otherwise specified.



BICONVEX LENSES

S1-UV Grade Fused Silica

P/N	f_{nom}	Diameter	f/#	CT	ET	EFL ₅₄₆	EFL ₂₅₀	BFL ₂₅₀
A1BI05005	12.7	12.7	1.0	5.3	1.5	13.7	12.6	10.7
A1BI05010	25.4	12.7	2.0	3.3	1.5	26.0	23.9	22.8
A1BI10010	25.4	25.4	1.0	9.0	1.5	27.1	25.1	21.7
A1BI05015	38.1	12.7	3.0	2.7	1.5	38.6	35.5	34.6
A1BI10015	38.1	25.4	1.5	6.3	1.5	39.3	36.1	34.0
A1BI15015	38.1	38.1	1.0	13.3	2.0	40.5	37.4	32.7
A1BI05020	50.8	12.7	4.0	2.4	1.5	51.2	47.1	46.3
A1BI10020	50.8	25.4	2.0	5.0	1.5	51.8	47.7	45.8
A1BI15020	50.8	38.1	1.3	10.1	2.0	52.6	48.5	45.0
A1BI20020	50.8	50.8	1.0	17.0	2.0	53.9	49.8	43.7
A1BI10030	76.2	25.4	3.0	3.8	1.5	77.0	70.8	69.4
A1BI15030	76.2	38.1	2.0	7.3	2.0	77.5	71.3	68.9
A1BI20030	76.2	50.8	1.5	11.5	2.0	78.2	72.1	68.1
A1BI10040	101.6	25.4	4.0	3.2	1.5	102.2	94.1	92.9
A1BI15040	101.6	38.1	2.7	5.9	2.0	102.6	94.5	92.5
A1BI20040	101.6	50.8	2.0	9.0	2.0	103.2	95.0	91.9
A1BI20060	152.4	50.8	3.0	6.6	2.0	153.6	141.3	139.1

BICONVEX LENSES (Continued)

G1 Commercial Grade Fused Quartz

P/N	f_{nom}	Diameter	f/#	CT	ET	EFL ₅₄₆	EFL ₃₀₀	BFL ₃₀₀
A4BI05005	12.7	12.7	1.0	5.3	1.5	13.7	12.9	11.0
A4BI05010	25.4	12.7	2.0	3.3	1.5	26.0	24.5	23.4
A4BI10010	25.4	25.4	1.0	9.0	1.5	27.1	25.6	22.3
A4BI05015	38.1	12.7	3.0	2.7	1.5	38.6	36.4	35.5
A4BI10015	38.1	25.4	1.5	6.3	1.5	39.2	37.0	34.8
A4BI15015	38.1	38.1	1.0	13.3	2.0	40.5	38.3	33.5
A4BI05020	50.8	12.7	4.0	2.4	1.5	51.2	48.3	47.5
A4BI10020	50.8	25.4	2.0	5.0	1.5	51.7	48.7	47.0
A4BI15020	50.8	38.1	1.3	10.1	2.0	52.6	49.7	46.1
A4BI20020	50.8	50.8	1.0	17.0	2.0	53.9	50.9	44.8
A4BI10030	76.2	25.4	3.0	3.8	1.5	76.9	72.5	71.2
A4BI15030	76.2	38.1	2.0	7.3	2.0	77.5	73.1	70.6
A4BI20030	76.2	50.8	1.5	11.5	2.0	78.2	73.8	69.8
A4BI10040	101.6	25.4	4.0	3.2	1.5	102.2	96.3	95.2
A4BI15040	101.6	38.1	2.7	5.9	2.0	102.6	96.8	94.8
A4BI20040	101.6	50.8	2.0	9.0	2.0	103.2	97.3	94.2
A4BI20060	152.4	50.8	3.0	6.6	2.0	153.6	144.8	142.5

BK7 Optical Glass

P/N	f_{nom}	Diameter	f/#	CT	ET	EFL ₇₈₀	EFL ₅₄₆	BFL ₅₄₆
A6BI05005	12.7	12.7	1.0	4.8	1.5	13.7	13.5	11.9
A6BI05010	25.4	12.7	2.0	3.1	1.5	26.2	25.9	24.9
A6BI10010	25.4	25.4	1.0	8.5	2.0	27.2	26.9	23.9
A6BI05015	38.1	12.7	3.0	2.5	1.5	39.0	38.5	37.7
A6BI10015	38.1	25.4	1.5	6.2	2.0	39.6	39.2	37.1
A6BI15015	38.1	38.1	1.0	11.8	2.0	40.6	40.2	36.1
A6BI05020	50.8	12.7	4.0	2.3	1.5	51.8	51.2	50.4
A6BI10020	50.8	25.4	2.0	5.1	2.0	52.3	51.7	49.9
A6BI15020	50.8	38.1	1.3	9.2	2.0	53.0	52.4	49.3
A6BI20020	50.8	50.8	1.0	15.1	2.0	54.0	53.4	48.2
A6BI10030	76.2	25.4	3.0	4.1	2.0	77.8	76.9	75.5
A6BI15030	76.2	38.1	2.0	6.7	2.0	78.2	77.3	75.1
A6BI20030	76.2	50.8	1.5	10.4	2.0	78.9	78.0	74.4
A6BI10040	101.6	25.4	4.0	3.5	2.0	103.4	102.2	101.0
A6BI15040	101.6	38.1	2.7	5.5	2.0	103.7	102.5	100.7
A6BI20040	101.6	50.8	2.0	8.2	2.0	104.2	103.0	100.2
A6BI20060	152.4	50.8	3.0	6.1	2.0	155.2	153.4	151.4

BICONVEX LENSES

Custom Biconvex Lenses

In addition to our standard lines of biconvex lenses, we also manufacture a variety of custom elements including *biconcave lenses*—negative focal length components with symmetrical concave radii of curvature. For more information on these and other custom products or applications, please contact Esco.

Sizes:

From 5.0 mm to 380.0 mm diameter

Materials:

Fused Quartz/Fused Silica (all grades)
Pyrex®
BK7 Optical Glass
Other materials upon request

Focal Lengths:

Any design greater than f/1.0 is possible. Research quantities of some custom focal lengths may be available off-the-shelf. Please contact Esco for more information.

Surface Quality:

Some applications may require surface qualities better than that of commercially available products. Esco can supply biconvex elements with surface quality better than laser grade, 10-5 or surface accuracies better than $\lambda/10$. Please inquire.

Tolerances:

The dimensional tolerances shown above are the standard tolerances used for off-the-shelf elements. Although Esco feels that these tolerances are in line with the typical uses for these parts, we can manufacture custom products with different tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Coatings:

Anti-reflection coatings that allow efficient energy throughput are available. For more information, see pages 10–11 or call Esco.



PLANO-CONVEX LENSES

Standard

Plano-convex lenses are positive focal length elements with one spherical surface and one flat surface. They are designed for infinite conjugate (parallel light) use or simple imaging in non-critical applications.

Plano-convex lenses are ideal all-purpose focussing elements. Yet for finite conjugate

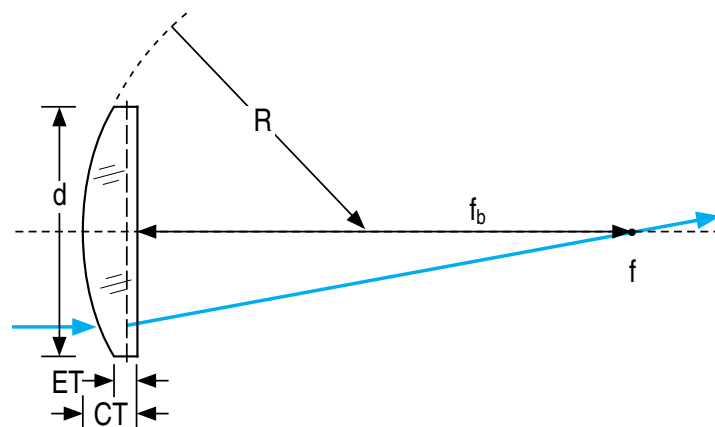
imaging with limited off-axis aberrations, biconvex lenses are often better suited. For broadband situations where chromatic aberrations would be a problem, or when spherical aberrations must be reduced to a minimum, achromats should be considered. For improved performance involving laser light, bestform lenses should be considered as well."

Esco manufactures plano-convex lenses from most of the optical grade materials listed in this handbook. They are pitch polished to provide good surface quality and excellent low-cost imaging performance with a variety of light sources.

Specifications

Focal length tolerance:	±3%
Diameter tolerance:	±0.125 mm
Thickness tolerance:	±0.5 mm
Design wavelength:	546 nm
Centration:	<3'
Surface Quality:	60-40, scratch-dig
Edges:	Fine ground and beveled
	OPTICAL MATERIALS, pages 4-9
	OPTICAL COATINGS, pages 10-14

All dimensions are in mm unless otherwise specified.



PLANO-CONVEX LENSES

S1-UV Grade Fused Silica

P/N	f_{nom}	Diameter	f/#	CT	ET	EFL ₂₅₀	BFL ₂₅₀
A105010	25.4	12.7	2.0	3.3	1.5	23.9	21.7
A105015	38.1	12.7	3.0	2.7	1.5	35.1	33.3
A110015	38.1	25.4	1.5	6.9	1.5	35.1	30.4
A105020	50.8	12.7	4.0	2.4	1.5	46.7	45.1
A110020	50.8	25.4	2.0	5.3	1.5	46.7	43.2
A115020	50.8	38.1	1.3	11.8	2.0	46.7	38.8
A105030	76.2	12.7	6.0	2.1	1.5	70.1	68.7
A110030	76.2	25.4	3.0	3.9	1.5	70.1	67.5
A115030	76.2	38.1	2.0	7.6	2.0	70.1	65.0
A120030	76.2	50.8	1.5	12.9	2.0	70.1	61.5
A105040	101.6	12.7	8.0	1.9	1.5	93.5	92.2
A110040	101.6	25.4	4.0	3.3	1.5	93.5	91.3
A115040	101.6	38.1	2.7	6.1	2.0	93.5	89.4
A120040	101.6	50.8	2.0	9.5	2.0	93.5	87.1
A110050	127.0	25.4	5.0	2.9	1.5	116.8	114.9
A115050	127.0	38.1	3.3	5.2	2.0	116.8	113.4
A120050	127.0	50.8	2.5	7.8	2.0	116.8	111.6
A110060	152.4	25.4	6.0	2.7	1.5	140.2	138.4
A115060	152.4	38.1	4.0	4.6	2.0	140.2	137.1
A120060	152.4	50.8	3.0	6.8	2.0	140.2	135.7
A110070	177.8	25.4	7.0	2.5	1.5	163.6	161.9
A115070	177.8	38.1	4.7	4.2	2.0	163.6	160.7
A120070	177.8	50.8	3.5	6.0	2.0	163.6	159.5

PLANO-CONVEX LENSES

S1-UV Grade Fused Silica (cont.)

P/N	f _{nom}	Diameter	f/#	CT	ET	EFL ₂₅₀	BFL ₂₅₀
A110080	203.2	25.4	8.0	2.4	1.5	186.9	185.4
A115080	203.2	38.1	5.3	4.0	2.0	186.9	184.3
A120080	203.2	50.8	4.0	5.5	2.0	186.9	183.3
A110100	254.0	25.4	10.0	2.2	1.5	233.7	232.2
A115100	254.0	38.1	6.7	3.6	2.0	233.7	231.3
A120100	254.0	50.8	5.0	4.8	2.0	233.7	230.5
A110120	304.8	25.4	12.0	2.1	1.5	280.4	279.0
A115120	304.8	38.1	8.0	3.3	2.0	280.4	278.2
A120120	304.8	50.8	6.0	4.3	2.0	280.4	277.5

G1 Commercial Grade Fused Quartz

P/N	f _{nom}	Diameter	f/#	CT	ET	EFL ₃₀₀	BFL ₃₀₀
A405010	25.4	12.7	2.0	3.3	1.5	24.5	22.3
A405015	38.1	12.7	3.0	2.7	1.5	35.9	34.1
A410015	38.1	25.4	1.5	6.9	1.5	35.9	31.2
A405020	50.8	12.7	4.0	2.4	1.5	47.9	46.2
A410020	50.8	25.4	2.0	5.3	1.5	47.9	44.4
A415020	50.8	38.1	1.3	11.8	2.0	47.9	39.9
A405030	76.2	12.7	6.0	2.1	1.5	71.8	70.4
A410030	76.2	25.4	3.0	3.9	1.5	71.8	69.2
A415030	76.2	38.1	2.0	7.6	2.0	71.8	66.7
A420030	76.2	50.8	1.5	12.9	2.0	71.8	63.2
A405040	101.6	12.7	8.0	1.9	1.5	95.8	94.5
A410040	101.6	25.4	4.0	3.3	1.5	95.8	93.6
A415040	101.6	38.1	2.7	6.1	2.0	95.8	91.7
A420040	101.6	50.8	2.0	9.5	2.0	95.8	89.4
A410050	127.0	25.4	5.0	2.9	1.5	119.7	117.8
A415050	127.0	38.1	3.3	5.2	2.0	119.7	116.2
A420050	127.0	50.8	2.5	7.8	2.0	119.7	114.5
A410060	152.4	25.4	6.0	2.7	1.5	143.7	141.9
A415060	152.4	38.1	4.0	4.6	2.0	143.7	140.5
A420060	152.4	50.8	3.0	6.8	2.0	143.7	139.1
A410070	177.8	25.4	7.0	2.5	1.5	167.6	165.9
A415070	177.8	38.1	4.7	4.2	2.0	167.6	164.7
A420070	177.8	50.8	3.5	6.0	2.0	167.6	163.5
A410080	203.2	25.4	8.0	2.4	1.5	191.5	190.0
A415080	203.2	38.1	5.3	4.0	2.0	191.5	188.9
A420080	203.2	50.8	4.0	5.5	2.0	191.5	187.8
A410100	254.0	25.4	10.0	2.2	1.5	239.4	238.0
A415100	254.0	38.1	6.7	3.6	2.0	239.4	237.0
A420100	254.0	50.8	5.0	4.8	2.0	239.4	236.2
A410120	304.8	25.4	12.0	2.1	1.5	287.3	285.9
A415120	304.8	38.1	8.0	3.3	2.0	287.3	285.1
A420120	304.8	50.8	6.0	4.3	2.0	287.3	284.4

PLANO-CONVEX LENSES

BK7 Optical Glass

P/N	f _{nom}	Diameter	f/#	CT	ET	EFL ₅₄₆	BFL ₅₄₆
A605010	25.4	12.7	2.0	3.1	1.5	26.0	24.0
A605015	38.1	12.7	3.0	2.6	1.5	38.1	36.4
A610015	38.1	25.4	1.5	6.1	1.5	38.1	34.1
A605020	50.8	12.7	4.0	2.3	1.5	50.8	49.3
A610020	50.8	25.4	2.0	4.8	1.5	50.8	47.7
A615020	50.8	38.1	1.3	10.2	2.0	50.8	44.1
A605030	76.2	12.7	6.0	2.0	1.5	76.2	74.9
A610030	76.2	25.4	3.0	3.6	1.5	76.2	73.8
A615030	76.2	38.1	2.0	6.9	2.0	76.2	71.6
A620030	76.2	50.8	1.5	11.3	2.0	76.2	68.8
A605040	101.6	12.7	8.0	1.9	1.5	101.6	100.4
A610040	101.6	25.4	4.0	3.1	1.5	101.6	99.6
A615040	101.6	38.1	2.7	5.6	2.0	101.6	97.9
A620040	101.6	50.8	2.0	8.5	2.0	101.6	96.0
A610050	127.0	25.4	5.0	2.7	1.5	127.0	125.2
A615050	127.0	38.1	3.3	4.8	2.0	127.0	123.8
A620050	127.0	50.8	2.5	7.1	2.0	127.0	122.3
A610060	152.4	25.4	6.0	2.5	1.5	152.4	150.7
A615060	152.4	38.1	4.0	4.3	2.0	152.4	149.5
A620060	152.4	50.8	3.0	6.2	2.0	152.4	148.3
A610070	177.8	25.4	7.0	2.4	1.5	177.8	176.2
A615070	177.8	38.1	4.7	4.0	2.0	177.8	175.2
A620070	177.8	50.8	3.5	5.6	2.0	177.8	174.1
A610080	203.2	25.4	8.0	2.3	1.5	203.2	201.7
A615080	203.2	38.1	5.3	3.7	2.0	203.2	200.7
A620080	203.2	50.8	4.0	5.1	2.0	203.2	199.8
A610100	254.0	25.4	10.0	2.5	1.5	254.0	252.6
A615100	254.0	38.1	6.7	3.4	2.0	254.0	251.8
A620100	254.0	50.8	5.0	4.5	2.0	254.0	251.0
A610120	304.8	25.4	12.0	2.0	1.5	304.8	303.5
A615120	304.8	38.1	8.0	3.2	2.0	304.8	302.7
A620120	304.8	50.8	6.0	4.1	2.0	304.8	302.1

Custom Plano-Convex Lenses

In addition to our standard lines of plano-convex lenses, we also manufacture a variety of custom elements including plano-concave lenses—negative focal length components with one concave surface. For more information on these and other custom products or applications, please contact Esco at 1-800-922-ESCO (3726).

Sizes:

From 5.0 mm to 380.0 mm diameter

Materials:

Fused Quartz/Fused Silica (all grades)
 Pyrex®
 BK7 Optical Glass
 Other materials upon request

Focal Lengths:

Nearly any focal length is possible. Research quantities of some focal lengths may be available off-the-shelf. Please contact Esco for more information.

Surface Quality:

Some applications may require surface qualities better than that of commercially available products. Esco can supply plano-convex elements with surface quality better than laser grade, 10-5, or surface accuracies better than $\lambda/10$. Please inquire.

Tolerances:

The dimensional tolerances shown above are the standard tolerances used for off-the-shelf elements. Although Esco feels that

these tolerances are in line with the typical uses for these parts, we can manufacture custom products with different tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Coatings:

Anti-reflection coatings that allow efficient energy throughput are available. For more information, see pages 10–11 or call Esco.

ACHROMATIC LENSES

Standard

Achromatic lenses are doublet systems consisting of one crown and one flint element, cemented together along a matching curvature. They are designed to minimize spherical and chromatic aberrations for infinite conjugate, visible spectrum imaging applications.

These Achromats provide diffraction-limited performance over nearly their entire clear aperture. To achieve this performance, the individual lens elements are precision ground and polished to provide minimum wavefront distortion. Each surface is optically centered to insure optimum alignment.

The lens design is computer optimized to insure that chromatic and spherical aberrations are simultaneously minimized. This optimization, combined with careful machining, also limits many off-axis aberrations such as coma.

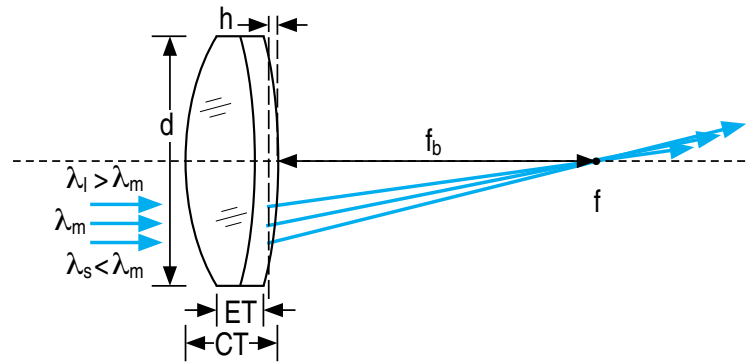
Esco Achromatic Lenses are suitable for use in most high resolution imaging systems or any application where spherical and chromatic aberrations must be minimized. Their performance is superior to that of all single element lenses, even in monochromatic applications.

Because achromats are asymmetric elements, they must be used in the proper orientation to ensure optimum performance. A good rule of thumb is that the flattest side should face toward the image.

Specifications

Focal length tolerance:	±2% at 546 nm
Clear aperture:	80%
Diameter tolerance:	+0/-0.15 mm
Thickness tolerance:	±0.25 mm
Centration:	<3'
Surface quality:	60-40, scratch-dig
Surface accuracy:	better than 1λ over clear aperture
Edges:	Fine ground and beveled
Coating:	MGF2, Single layer MgF ₂

All dimensions are in mm unless otherwise specified.



The crown and flint glasses that make up our achromats are all Grade A optical quality materials. Since more than just a few glass types are necessary to provide a complete line of optimized designs, it is not possible

to list here the specifications of all those that are used. If you require details about the specific glass types used in the achromats listed below, please contact Esco.

All standard achromatic lenses are supplied with MGF2 single layer MgF₂ anti-reflection coatings on both outside surfaces. Total energy throughput exceeds 98% average across the visible spectrum.

ACHROMATIC LENSES

P/N	f _{nom}	Diameter	f/#	CT	ET	EFL ₅₈₈	BFL ₅₈₈	h ₅₈₈
A912025	25	12.7	2.0	5.5	4.2	25.3	22.4	2.9
A912030	30	12.7	2.4	5.0	3.9	30.2	27.6	2.6
A912050	50	12.7	4.0	4.5	3.8	50.9	48.8	2.1
A925050	50	25.4	2.0	9.8	5.9	51.5	46.4	5.1
A912075	75	12.7	6.0	5.0	4.6	76.0	73.5	2.5
A925075	75	25.4	3.0	7.5	5.8	76.2	72.4	3.8
A938075	75	38.1	2.0	14.1	8.8	76.8	69.6	7.2

ACHROMATIC LENSES (cont.)

P/N	f _{nom}	Diameter	f/#	CT	ET	EFL ₅₈₈	BFL ₅₈₈	h ₅₈₈
A912100	100	12.7	8.0	3.8	3.3	99.7	98.1	1.6
A925100	100	25.4	4.0	7.2	5.8	100.0	96.5	3.5
A938100	100	38.1	2.7	12.7	8.3	100.6	94.3	6.3
A950100	100	50.8	2.0	20.5	12.5	101.4	91.1	10.3
A912150	150	12.7	12.0	5.2	5.0	150.0	147.8	2.2
A925150	150	25.4	6.0	6.2	5.3	150.0	147.1	2.9
A938150	150	38.1	4.0	10.8	7.9	150.5	145.5	5.0
A950150	150	50.8	3.0	14.3	9.1	150.8	143.7	7.1
A925175	175	25.4	7.0	6.3	5.5	175.0	172.1	2.9
A938175	175	38.1	4.7	10.4	7.9	175.5	170.8	4.7
A950175	175	50.8	3.5	12.8	8.3	175.7	169.4	6.3
A925200	200	25.4	8.0	8.1	7.2	200.1	194.7	5.4
A938200	200	38.1	5.3	9.5	7.3	200.4	196.1	4.3
A950200	200	50.8	4.0	11.9	8.0	200.6	194.8	5.8
A925250	250	25.4	10.0	5.3	4.5	249.5	247.2	2.3
A938250	250	38.1	6.7	8.8	7.1	249.9	246.1	3.8
A950250	250	50.8	5.0	10.5	7.4	250.0	245.1	4.9
A925500	500	25.4	20.0	6.5	6.1	499.6	496.6	3.0
A938500	500	38.1	13.3	10.0	9.1	500.0	495.5	4.5
A950500	500	50.8	10.0	13.0	11.9	500.4	494.7	5.7

Custom Achromatic Lenses

In addition to our standard lines of achromatic lenses, we are often called upon to design and manufacture a variety of custom elements including:

- negative achromats
- lenses designed for finite conjugate systems
- lenses whose designs have been optimized for other wavelength areas such as:
 - the ultraviolet or,
 - the near infrared.

For more information on these and other custom products or applications, please contact Esco at 1-800-922-ESCO (3726).

Sizes:

Over 152.4 mm diameter

Focal Lengths:

Any focal length greater than about f/2.0 is possible. Research quantities of some focal

lengths may be available off-the-shelf. Please contact Esco for more information.

Surface Quality:

Some applications may require surface qualities better than that of commercially available products. Esco can supply elements with surface quality better than laser grade, 10-5 or surface accuracies better than $\lambda/20$. To provide such precision, however, these systems often must be air-spaced rather than cemented. Please contact Esco for more information.

Tolerances:

The dimensional tolerances shown above are the standard tolerances used for off-the-shelf elements. Although Esco feels that these tolerances are in line with the typical uses for these parts, we can manufacture custom products with different tolerances upon request.

For certain OEM applications, looser

tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Coatings:

Anti-reflection coatings that allow efficient energy throughput are available. Yet because of the high index of the flint element, coatings more sophisticated than single-layer MgF₂ often provide only an incremental improvement. To discuss your particular needs, please contact Esco.

CYLINDRICAL LENSES

Standard

Ordinary lenses have one or more spherical surfaces. A curved surface on a cylindrical lens, however, is shaped (as the name suggests) like a cylinder. Instead of a focal point, their performance is characterized by a focal *line* that lies parallel to the cylindrical axis. The lens formulas that describe the behavior of common spherical elements also hold true for cylindrical lenses, but in

one dimension only.

Cylindrical lenses are useful in applications areas such as optical data storage and retrieval systems for imaging linear arrays, spectroscopic instrumentation for imaging slits, and other processes involving scanning techniques. In addition, they are frequently used with lasers to generate a narrow line of light that is used

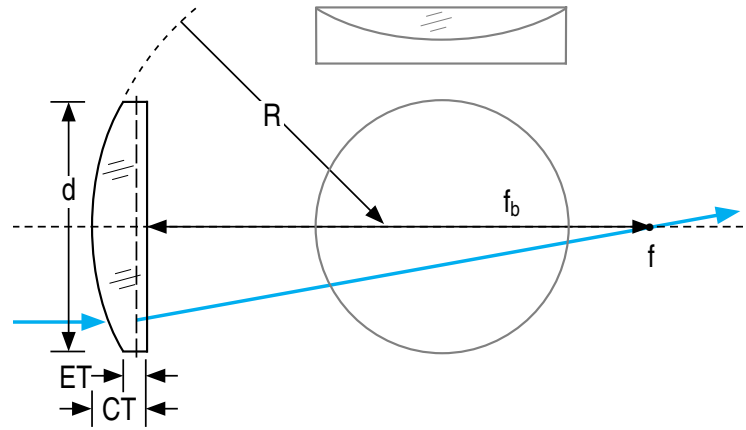
for measurement or alignment.

Esco manufactures a variety of standard plano-convex cylindrical lenses. All are pitch polished to provide good surface quality and accuracy.

Specifications

Focal length tolerance:	±3%
Thickness tolerance:	±0.5 mm
Design wavelength:	546 nm
Axis linearity:	<6'
Surface quality:	60-40, scratch-dig
Edges:	Fine ground and beveled

OPTICAL MATERIALS, pages 4-9
OPTICAL COATINGS, pages 10-14



CYLINDRICAL LENSES

S1-UV Grade Fused Silica

P/N	f_{nom}	Diameter	f/#	CT	ET	EFL ₂₅₀	BFL ₂₅₀
B110015	38.1	25.4	1.5	6.9	1.5	35.1	30.4
B110020	50.8	25.4	2.0	5.3	1.5	46.7	43.2
B115020	50.8	38.1	1.3	11.8	2.0	46.7	38.8
B110030	76.2	25.4	3.0	3.9	1.5	70.1	67.5
B115030	76.2	38.1	2.0	7.6	2.0	70.1	65.0
B120030	76.2	50.8	1.5	12.9	2.0	70.1	61.5
B110040	101.6	25.4	4.0	3.3	1.5	93.5	91.3
B115040	101.6	38.1	2.7	6.1	2.0	93.5	89.4
B120040	101.6	50.8	2.0	9.5	2.0	93.5	87.1
B110060	152.4	25.4	6.0	2.7	1.5	140.2	138.4
B115060	152.4	38.1	4.0	4.6	2.0	140.2	137.1
B120060	152.4	50.8	3.0	6.8	2.0	140.2	135.7
B110100	254.0	25.4	10.0	2.2	1.5	233.7	232.2
B115100	254.0	38.1	6.7	3.6	2.0	233.7	231.3
B120100	254.0	50.8	5.0	4.8	2.0	233.7	230.5

CYLINDRICAL LENSES

G1 Optical Grade Fused Quartz

P/N	f _{nom}	Diameter	f/#	CT	ET	EFL ₃₀₀	BFL ₃₀₀
B410015	38.1	25.4	1.5	6.9	1.5	35.9	31.2
B410020	50.8	25.4	2.0	5.3	1.5	47.9	44.4
B415020	50.8	38.1	1.3	11.8	2.0	47.9	39.9
B410030	76.2	25.4	3.0	3.9	1.5	71.8	69.2
B415030	76.2	38.1	2.0	7.6	2.0	71.8	66.7
B420030	76.2	50.8	1.5	12.9	2.0	71.8	63.2
B410040	101.6	25.4	4.0	3.3	1.5	95.8	93.6
B415040	101.6	38.1	2.7	6.1	2.0	95.8	91.7
B420040	101.6	50.8	2.0	9.5	2.0	95.8	89.4
B410060	152.4	25.4	6.0	2.7	1.5	143.7	141.9
B415060	152.4	38.1	4.0	4.6	2.0	143.7	140.5
B420060	152.4	50.8	3.0	6.8	2.0	143.7	139.1
B410100	254.0	25.4	10.0	2.2	1.5	239.4	238.0
B415100	254.0	38.1	6.7	3.6	2.0	239.4	237.0
B420100	254.0	50.8	5.0	4.8	2.0	239.4	236.2

BK7 Optical Glass

P/N	f _{nom}	Diameter	f/#	CT	ET	EFL ₅₄₆	BFL ₅₄₆
B610015	38.1	25.4	1.5	6.1	1.5	38.1	34.1
B610020	50.8	25.4	2.0	4.8	1.5	50.8	47.7
B615020	50.8	38.1	1.3	10.2	2.0	50.8	44.1
B610030	76.2	25.4	3.0	3.6	1.5	76.2	73.8
B615030	76.2	38.1	2.0	6.9	2.0	76.2	71.6
B620030	76.2	50.8	1.5	11.3	2.0	76.2	68.8
B610040	101.6	25.4	4.0	3.1	1.5	101.6	99.6
B615040	101.6	38.1	2.7	5.6	2.0	101.6	97.9
B620040	101.6	50.8	2.0	8.5	2.0	101.6	96.0
B610060	152.4	25.4	6.0	2.5	1.5	152.4	150.7
B615060	152.4	38.1	4.0	4.3	2.0	152.4	149.5
B620060	152.4	50.8	3.0	6.2	2.0	152.4	148.3
B610100	254.0	25.4	10.0	2.1	1.5	254.0	252.6
B615100	254.0	38.1	6.7	3.4	2.0	254.0	251.8
B620100	254.0	50.8	5.0	4.5	2.0	254.0	251.0

CYLINDRICAL LENSES

All dimensions are in mm unless otherwise specified.

Custom Cylindrical Lenses

In addition to our standard lines of cylindrical lenses, we also manufacture a variety of custom elements including negative cylindrical lenses and lenses made of other optical materials. For more information on these and other custom products or applications, please contact Esco at 1-800-922-ESCO (3726).

Sizes:

Rectangular or round, maximum and minimum sizes vary depending on other dimensions. Please inquire.

Materials:

Fused Quartz/Fused Silica (all grades)
Pyrex®

BK7 Optical Glass
Other materials upon request

Focal Lengths:

Nearly any focal length is possible. Research quantities of some focal lengths may be available off-the-shelf. Please contact Esco for more information.

Surface Quality:

Some applications may require surface qualities better than that of commercially available products. Esco can supply cylindrical elements with improved surface accuracy and quality. Please inquire.

Tolerances:

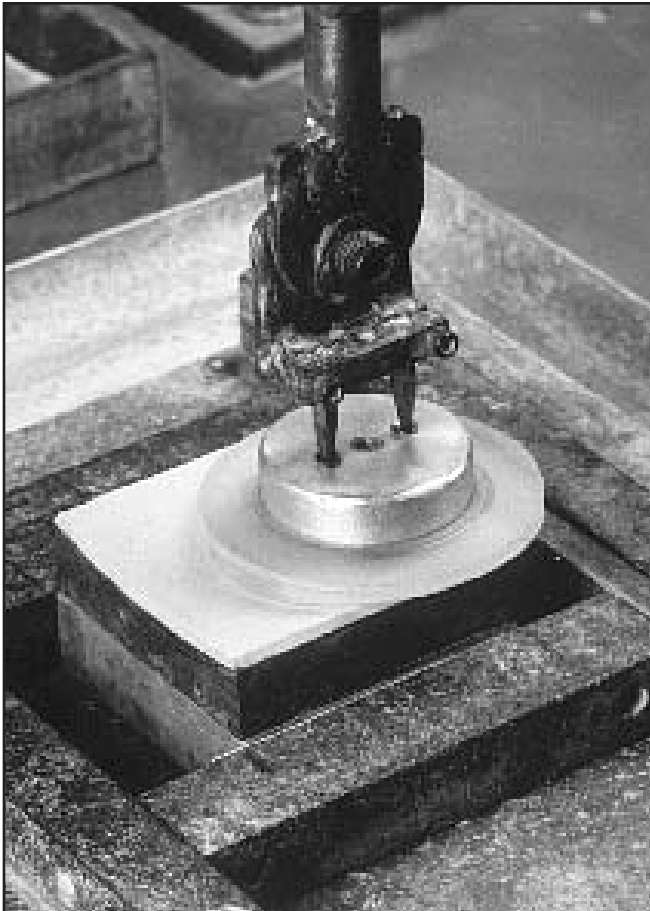
The dimensional tolerances shown above are the standard tolerances used for off-the-shelf elements. Although Esco feels that these tolerances are in line with the typical uses for these parts, we can manufacture

custom products with different tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Coatings:

Anti-reflection coatings that allow efficient energy throughput are available. For more information, see pages 10–11 or call Esco.



Standard

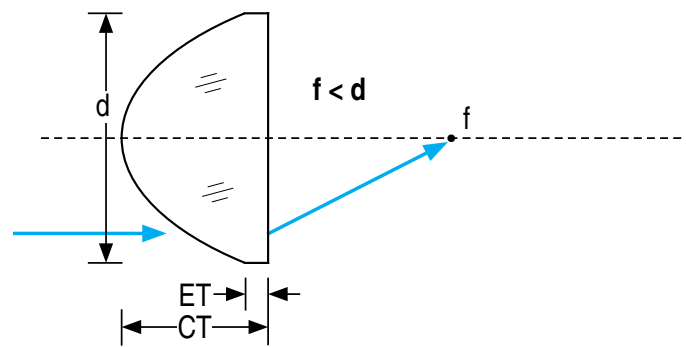
An aspheric lens is a single element optical component with one aspheric convex surface and one plano or spherical convex surface. Characterized by f-numbers less than 1.0, aspheres provide maximum energy throughput over a limited path length. Although not designed for imaging applications, they are ideal for use in illumination systems where it is often necessary to collect and/or focus as much light as possible.

Esco manufactures aspheric lenses from high quality optical crown glass. They are precision molded and felt polished to provide excellent performance in critical condenser applications.

Specifications

Material:	Schott K5 Crown glass or equivalent $n_d = 1.522$, $\nu_d = 59.5$
Focal length tolerance:	$\pm 7\%$
Diameter tolerance:	± 0.5 mm
Center thickness tolerance:	± 0.5 mm
Surface quality:	80-50, scratch-dig
Maximum operating temperature:	175°C

All dimensions are in mm unless otherwise specified.



ASPHERIC LENSES

P/N	f_{nom}	Diameter	f/#	CT
C118150	15.0	18.0	0.83	7.4
C124180	18.0	24.0	0.75	10.6
C134240	24.0	34.0	0.63	14.0
C150355	35.5	50.0	0.71	21.1
C160390	39.0	60.0	0.65	27.0

Coatings:

Anti-reflection coatings that allow efficient energy throughput are available. Because of the steepness of the aspheric surface, however, multilayer coatings may not perform properly. Single layer MgF_2 is recommended for most applications. For more information, see pages 10–11 or call Esco.

BESTFORM (LASER) LENSES

To insure that only minimum spherical aberration is introduced by an optical element, it is necessary to consider its shape. For each condition there is a preferred lens shape that minimizes spherical aberration. In 1:1 imaging applications, for example, the best shape is a symmetric biconvex lens.

In the infinite conjugate case of focusing a laser beam to a minimum spot, the shape of a single element lens that most effectively re-

duces spherical aberration is called *bestform*. The front and back radii of these lenses are chosen to be of a specific ratio. This ratio is determined by the proper shape factor, which is governed by the lens material.

with superior homogeneity specifications should be used in laser applications. Pitch polishing provides excellent surface quality, a necessary characteristic for limiting scatter.

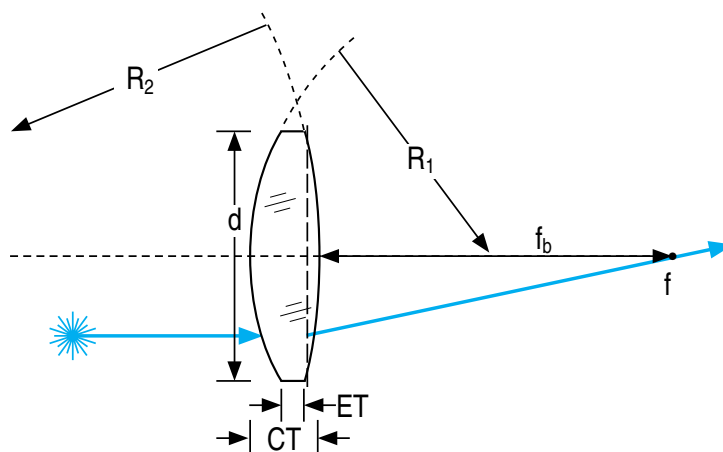
Standard

Esco manufactures bestform lenses from only the highest quality optical grade materials listed in this handbook. Only materials

Specifications

Focal length tolerance:	±3%
Diameter tolerance:	±0.15 mm
Thickness tolerance:	±0.2 mm
Centration:	<3'
Surface quality:	20-10, scratch-dig
Surface accuracy:	$\lambda/10$ or better
	over 80% of clear aperture
Edges:	Fine ground and beveled
Coating:	AR-V Multilayer AR coating at the design wavelength available upon request
	OPTICAL MATERIALS, pages 4-9
	OPTICAL COATINGS, pages 10-14

All dimensions are in mm unless otherwise specified.



BESTFORM LENSES

S1-UVA Fused Silica

P/N	f_{nom}	Diameter	λ_{des}	CT	ET	EFL _{des}	BFL _{des}	Beam Diameter	Spot Diameter
A610510	10	5.0	325 nm	2.6	1.5	11.1	9.6	1.0	4.6 μ m
A611220	20	12.7	325 nm	5.6	1.5	19.4	16.1	2.0	4.0 μ m
A612510	100	25.4	325 nm	4.4	1.5	100.4	97.9	8.0	5.2 μ m
A612525	250	25.4	325 nm	2.6	1.5	248.5	247.0	15.0	6.8 μ m
A615011	1100	50.8	325 nm	3.1	2.0	1087.8	1086.0	45.0	9.9 μ m
A650510	10	5.0	1064 nm	2.6	1.5	11.6	10.1	1.0	15.7 μ m
A651220	20	12.7	1064 nm	5.6	1.5	20.1	16.8	2.0	13.5 μ m
A652510	100	25.4	1064 nm	4.5	1.5	102.4	99.8	8.0	18.6 μ m
A652525	250	25.4	1064 nm	2.7	1.5	248.9	247.4	15.0	23.4 μ m
A655011	1100	50.8	1064 nm	3.0	2.0	1109.5	1107.8	45.0	33.4 μ m

BESTFORM (LASER) LENSES

BK7 Optical Glass

P/N	f _{nom}	Diameter	λ _{des}	CT	ET	EFL _{des}	BFL _{des}	Beam Diameter	Spot Diameter
A630510	10	5.0	633 nm	2.6	1.5	10.5	9.0	1.0	8.6 μm
A631220	20	12.7	633 nm	5.2	1.5	20.4	17.4	2.0	8.2 μm
A632510	100	25.4	633 nm	4.2	1.5	101.2	98.8	8.0	10.2 μm
A632525	250	25.4	633 nm	2.6	1.5	244.0	242.5	15.0	13.1 μm
A635011	1100	50.0	633 nm	2.9	2.0	1133.5	1131.9	45.0	20.3 μm

Custom Bestform Lenses

In addition to our standard lines of bestform lenses, we also manufacture a variety of custom designs. For more information on these and other custom products or applications, please contact Esco at 1-800-922-ESCO (3726).

Sizes:

Over 50 mm diameter

Materials:

S1-UV Fused Silica (both grades)
I2-IR Fused Quartz
A1 Optical Grade Fused Quartz
BK7 Optical Glass
Other materials upon request

Focal Lengths:

Although f/#s greater than about f/1.33 are physically possible, not a lot is gained by using 'fast' bestform lenses. Since the intention of this design is to minimize aberrations, focal lengths should be chosen as long as possible to maximize the lens' performance. For more information, please contact Esco. Research quantities of some focal lengths may be available off-the-shelf.

Surface Quality:

Some applications may require surface qualities better than that of commercially available products. Esco can supply bestform lenses with surface quality better than laser grade 10-5 or surface accuracies better than λ/20. Please inquire.

Tolerances:

The dimensional tolerances shown above are the standard tolerances used for off-the-shelf elements. Although Esco feels that these tolerances are in line with the typical uses for these parts, we can manufacture custom products with different tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Coatings:

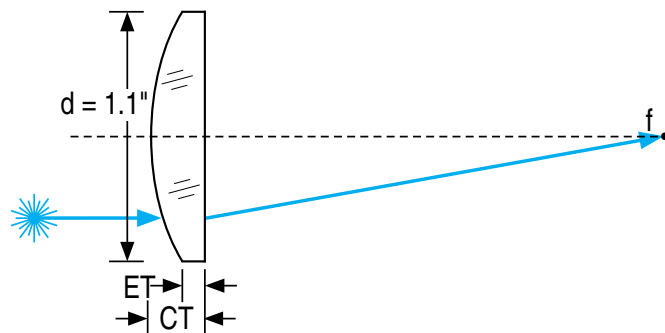
Anti-reflection coatings that allow efficient energy throughput are available. For more information, see pages 10-11 or call Esco.



INDUSTRIAL LASER LENSES

Standard

Esco manufactures special plano-convex lenses as replacement elements for industrial Nd:YAG lasers that operate at 1.06 μm . These lenses are guaranteed to meet or exceed the performance requirements of the original laser equipment. They are manufactured from Schlieren-free fused silica and multilayer AR coated to resist thermal damage.



Specifications

Material:	S1-UV Grade Fused Silica
Design wavelength:	1.06 μm
Focal length tolerance:	$\pm 2\%$
Diameter:	1.1" (27.94 mm) ± 0.125 mm
Clear aperture:	1" (25.4 mm)
Edge thickness:	1.5 mm ± 0.5 mm
Surface quality:	20-10, scratch-dig
Coating:	AR-V Multilayer AR coating for <0.25% R per surface at 1.06 μm
	OPTICAL MATERIALS, pages 4–9
	OPTICAL COATINGS, pages 10–14

All dimensions are in mm unless otherwise specified.

INDUSTRIAL LASER LENSES

P/N	f_{nom}	f/#	CT
A711020	50.8 (2")	1.8	6.3
A711040	101.6 (4")	3.6	3.7
A711060	152.4 (6")	5.5	2.9
A711080	203.2 (8")	7.3	2.6
A711100	254.0 (10")	9.1	2.4
A711120	304.8 (12")	10.9	2.2

Custom Industrial Laser Lenses

Besides our standard line of industrial laser lenses, we also manufacture custom elements, designed specifically for individual applications. To discuss your custom specifications or applications, please contact Esco at 1-800-922-ESCO (3726).

Materials:

Fused Quartz/Fused Silica (all grades)
BK7 Optical Glass
Other precision quality materials upon request

Focal Lengths:

Nearly any focal length is possible. Research quantities of some non-standard focal lengths may be available off-the-shelf. Please contact Esco for more information.

Surface Quality:

Because of the high power nature of most industrial lasers, Esco strongly recommends using lenses whose surface characteristics are conducive to scatter-free operation.

Tolerances:

The dimensional tolerances shown above are the standard tolerances used for off-the-shelf elements. Although Esco feels that these tolerances are in line with the typical uses for these parts, we can manufacture custom products with different tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while

many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Coatings:

Because of the high power nature of most industrial lasers, Esco strongly recommends using lenses with AR-V coatings to minimize the potential for system damage due to back reflections.

OPTICAL FLATS

Optical flats are most commonly used as test plates to evaluate the accuracy of flat optical surfaces. Holding the precision face of an optical flat against a test surface under monochromatic light creates a fringe pattern that is visible through the back surface of the flat. This fringe pattern describes the contour of the test surface.

Esco manufactures optical flats out of G1 grade fused quartz. The low thermal expansion, abrasion resistance and general stability of this material allow continuous use with minimum degradation over time.

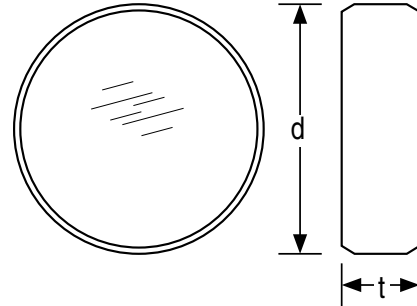
Optical flats are available with either one or two precision surfaces. The fringe pattern that is visible through an optical flat is not affected by the accuracy of the rear surface. Some users, however, require the versatility and extended lifetime that two precision surfaces offer.



Specifications

Material:	G1 Optical Grade Fused Quartz
Diameter tolerance:	±1.0 mm
Thickness tolerance:	±1.0 mm
Parallelism:	<15'
Surface Quality:	60-40, scratch-dig
Clear aperture:	90%

All dimensions are in mm unless otherwise specified.



OPTICAL FLATS

Diameter	Thickness	Flatness, One Precision Surface			Flatness, Two Precision Surfaces		
		$\lambda/20$ (0.000001")	$\lambda/10$ (0.000002")	$\lambda/4$ (0.000005")	$\lambda/20$ (0.000001")	$\lambda/10$ (0.000002")	$\lambda/4$ (0.000005")
25.4 (1")	12.7 (1/2")	F101001	F101002	F101005	F201001	F201002	F201005
50.8 (2")	12.7 (1/2")	F102001	F102002	F102005	F202001	F202002	F202005
76.2 (3")	15.9 (5/8")	F103001	F103002	F103005	F203001	F203002	F203005

Larger optical flats are also available upon request



WINDOWS

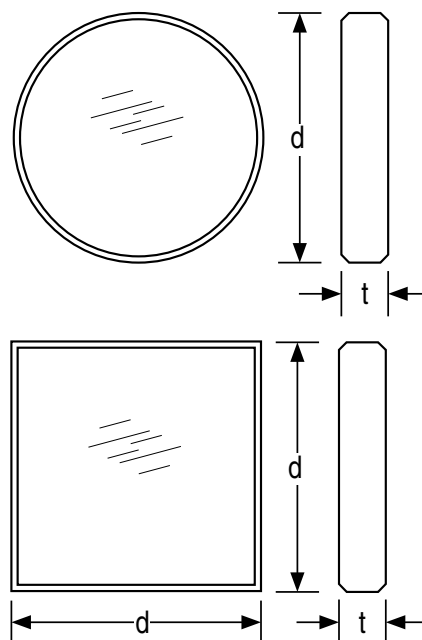
Esco offers flat windows made from a wide variety of optical materials. A range of quality and styles is available to suit nearly every application.

Commercial Quality Flat Windows

Esco Products is one of the largest American suppliers of commercial quality flat windows. Our standard product line is perhaps the most complete listing available. These elements are commonly used for a variety of applications including sight glasses, instrument windows, beamsplitter substrates, vacuum windows, etc. All products listed are available in research or large OEM quantities. For more information, please contact Esco.

Specifications

Diameter tolerance:	±0.125 mm
Length/Width tolerance:	±0.125 mm
Thickness tolerance:	±0.125 mm
Surface Accuracy:	~5λ per inch
Surface quality:	60-40, scratch-dig or better
Parallelism:	<15'
Edges:	Fine ground and beveled



MATERIAL:

Esco manufactures commercial quality windows out of every material listed in this handbook. To order, apply the prefixes shown below to the part numbers in the table.

PREFIXES

Circular Windows

S1-UVP1	BK7P9
I2-IRP2	G1P6
A1P3	Pyrex®P7

Square Windows

S1-UVQ1	BK7Q9
I2-IRQ2	G1Q6
A1Q3	Pyrex®Q7

EXAMPLE

S1-UV window, 2" diameter, 1/4" thk:
Pyrex® window, 4" × 4", 1/8" thk:

P1 + 20250 = P/N: P120250
Q7 + 40125 = P/N: Q740125

All dimensions are in mm unless otherwise specified.

COMMERCIAL QUALITY FLAT WINDOWS

Circular Windows

Diameter	Thickness, mm (inches)						
	1.0 (0.04")	1.59 (1/16")	3.18 (1/8")	4.76 (3/16")	6.35 (1/4")	9.53 (3/8")	12.7 (1/2")
12.7 (1/2")	+05040	+05063	+05125	+05188	+05250	+05375	+05500
19.05 (3/4")	+07040	+07063	+07125	+07188	+07250	+07375	+07500
25.4 (1")	+10040	+10063	+10125	+10188	+10250	+10375	+10500
31.75 (1 1/4")	+12040	+12063	+12125	+12188	+12250	+12375	+12500
38.1 (1 1/2")	+15040	+15063	+15125	+15188	+15250	+15375	+15500
44.45 (1 3/4")	+17040	+17063	+17125	+17188	+17250	+17375	+17500
50.8 (2")	+20040	+20063	+20125	+20188	+20250	+20375	+20500
63.5 (2 1/2")	+25040	+25063	+25125	+25188	+25250	+25375	+25500
76.2 (3")	+30040	+30063	+30125	+30188	+30250	+30375	+30500
88.9 (3 1/2")	+35040	+35063	+35125	+35188	+35250	+35375	+35500
101.6 (4")	+40040	+40063	+40125	+40188	+40250	+40375	+40500
127.0 (5")	+50040	+50063	+50125	+50188	+50250	+50375	+50500
152.4 (6")	+60040	+60063	+60125	+60188	+60250	+60375	+60500

NOTE: To specify a Window's material when ordering, add the appropriate Material Prefix in front of these Part Numbers. See page 32 for details.

Square Windows

Square	Thickness, mm (inches)						
	1.0 (0.04")	1.59 (1/16")	3.18 (1/8")	4.76 (3/16")	6.35 (1/4")	9.53 (3/8")	12.7 (1/2")
25.4 (1")	+10040	+10063	+10125	+10188	+10250	+10375	+10500
31.75 (1 1/4")	+12040	+12063	+12125	+12188	+12250	+12375	+12500
38.1 (1 1/2")	+15040	+15063	+15125	+15188	+15250	+15375	+15500
44.45 (1 3/4")	+17040	+17063	+17125	+17188	+17250	+17375	+17500
50.8 (2")	+20040	+20063	+20125	+20188	+20250	+20375	+20500
63.5 (2 1/2")	+25040	+25063	+25125	+25188	+25250	+25375	+25500
76.2 (3")	+30040	+30063	+30125	+30188	+30250	+30375	+30500
88.9 (3 1/2")	+35040	+35063	+35125	+35188	+35250	+35375	+35500
101.6 (4")	+40040	+40063	+40125	+40188	+40250	+40375	+40500
127.0 (5")	+50040	+50063	+50125	+50188	+50250	+50375	+50500
152.4 (6")	+60040	+60063	+60125	+60188	+60250	+60375	+60500

WINDOWS

Precision Flat and Wedge Windows

Precision Flat Windows

These elements are ideal for applications such as :

- Interferometer flats
- Laser windows
- Beamsplitter substrates
- Parallel plates, etc.

FLAT WINDOWS

Diameter	Thickness	Parallelism	Flatness	BK7 P/N	S1-UV P/N
25.4	6.35	10'	$\lambda/4$	E610250	E210250
25.4	6.35	5"	$\lambda/10$	E810250	E410250
38.1	6.35	10'	$\lambda/4$	E615250	E215250
38.1	6.35	5"	$\lambda/10$	E815250	E415250
50.8	9.53	10'	$\lambda/4$	E620375	E220375
50.8	9.53	5"	$\lambda/10$	E820375	E420375

Wedge Windows

These elements are similar to the precision flat windows described above, but have a deliberate wedge of $30' \pm 5'$. They are ideal for applications where direct back reflections would usually be a problem.

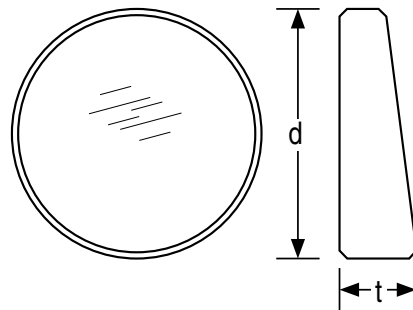
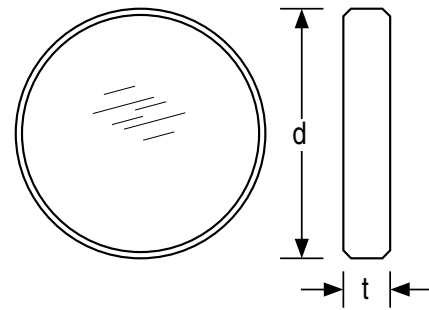
WEDGE WINDOWS

Diameter	Thickness	Wedge	Flatness	BK7 P/N	S1-UV P/N
25.4	6.35	30'	$\lambda/4$	V210250	V510250
25.4	6.35	30'	$\lambda/10$	V310250	V610250
38.1	9.53	30'	$\lambda/4$	V215375	V515375
38.1	9.53	30'	$\lambda/10$	V315375	V615375
50.8	9.53	30'	$\lambda/4$	V220375	V520375
50.8	9.53	30'	$\lambda/10$	V320375	V620375

Specifications

Material:	BK7 Optical Glass or S1-UV Fused Silica
Diameter tolerance:	± 0.125 mm
Thickness tolerance:	± 0.125 mm
Surface quality:	20-10, scratch-dig
Clear aperture:	90%
Edges:	Fine ground and beveled

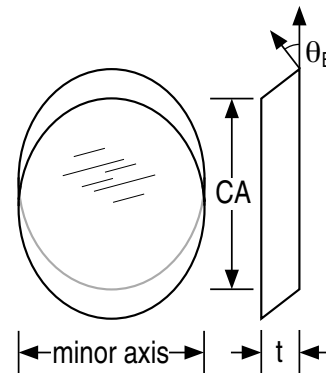
All dimensions are in mm unless otherwise specified.



Brewster Angle Laser Window

These elements are designed for use inside laser cavities. To perform satisfactorily, each laser window must be made from the highest purity fused silica and finished to superior quality standards.

The physical angle is within 0.5% of the actual Brewster angle for any wavelength in the visible and near infrared spectrum.



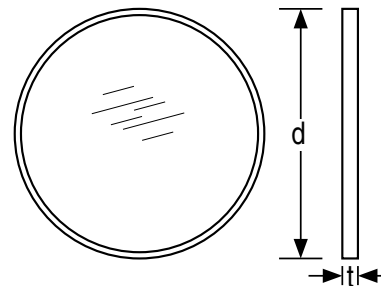
Specifications

Material:	S1-UVA <i>Schlieren-free</i> UV Grade Fused Silica
Diameter tolerance:	±0.125 mm
Thickness tolerance:	±0.125 mm
Surface Accuracy:	$\lambda/20$ over clear aperture
Surface quality:	10-5, scratch-dig
Parallelism:	1"
Brewster Angle:	55° 30'
Clear aperture:	Central 50% of minor diameter
Edges:	Fine ground and beveled

All dimensions are in mm unless otherwise specified.

BREWSTER LASER WINDOWS

Minor Axis	Thickness	P/N
12.0	2.0	H112005
25.0	3.0	H125005



Sapphire Windows

Because of its wide spectral transmissivity, extreme hardness and excellent durability, sapphire makes an ideal window material for many applications. Due to reduced scatter losses and high polarization uniformity, it has easily twice the life span of other crystals used in high power laser applications.

Specifications

Material:	Optical Grade Sapphire
Diameter tolerance:	±0.05 mm
Thickness tolerance:	±0.05 mm
Surface quality:	1 micro-inch RMS
Surface accuracy:	~15 λ per inch
Clear aperture:	90%
Edges:	Fine ground and beveled

All dimensions are in mm unless otherwise specified.

SAPPHIRE WINDOWS

Diameter	Thickness, mm (inches)			
	0.5 (0.020")	1.0 (0.040")	2.0 (0.080")	3.0 (0.125")
6.35 (0.25")	G102020	G102040	G102080	G102125
9.53 (0.375")	G103020	G103040	G103080	G103125
12.7 (0.5")	G105020	G105040	G105080	G105125
15.88 (0.625")	G106020	G106040	G106080	G106125
19.05 (0.75")	G107020	G107040	G107080	G107125
22.23 (0.875")	G108020	G108040	G108080	G108125
25.4 (1")	G110020	G110040	G110080	G110125
28.58 (1.125")	G111020	G111040	G111080	G111125

WINDOWS

Custom Windows-All Types

In addition to our standard lines of windows, we also manufacture a variety of custom elements. For more information on these and other custom products or applications, please contact Esco at 1-800-922-ESCO (3726).

Sizes:

Over 24" diameter or diagonal measure.
Sapphire up to 4" diameter.

Aspect Ratio:

If wavefront distortion is required, it is often necessary to use a window whose aspect ratio (diameter:thickness) is as high as possible. Although all materials act differently, a good rule of thumb for $\lambda/10$ surface accuracy is about a 6:1 aspect ratio.

Parallelism:

The specification of parallelism is not trivial. The tighter the requirement, the more costly

the window is to manufacture. If you are unsure about your needs, please contact Esco for assistance.

Surface Quality:

Some applications may require surface qualities better than that of commercially available products. Esco can supply windows with surface quality better than laser grade, 10-5 or surface accuracies better than $\lambda/20$. Please inquire.

Materials:

Esco manufactures standard and custom windows out of every material listed in this handbook. Additional materials are available upon request. Please contact Esco for more information.

Tolerances:

The dimensional tolerances shown above are the standard tolerances used for off-the-

shelf elements. Although Esco feels that these tolerances are in line with the typical uses for these parts, we can manufacture custom products with different tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Coatings:

Esco will apply AR or beamsplitter coatings to any window. For more information concerning coatings, please see pages 10-14 or contact Esco.



Esco offers a special line of flat optical elements for use with various laboratory techniques such as preparing samples for viewing under a microscope. These parts provide optical characteristics not found in ordinary glass slides and cover slips. Their above average material and surface quality can dramatically enhance image quality.

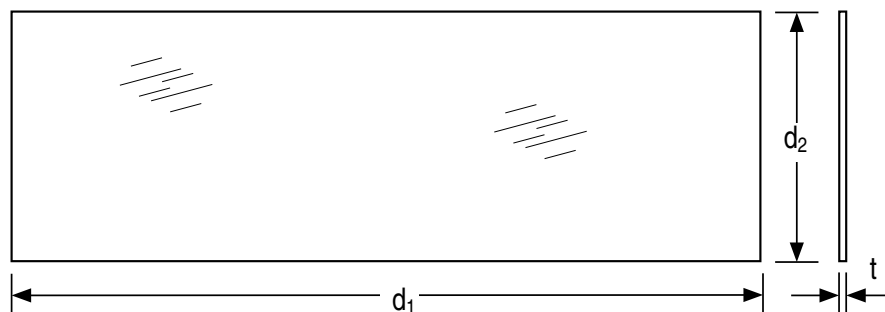
Microscope Slides

Esco provides microscope slides made from a variety of optical materials and in several different convenient sizes. This assortment, like that of our standard optical windows, is the most comprehensive on the market. Although they possess excellent surface quality, the aspect ratio of these elements is very high and good surface accuracy is not achievable.

Specifications

Dimensional tolerance: ± 0.125 mm
Thickness tolerance: ± 0.125 mm
Surface quality: 60-40, scratch-dig
Clear aperture: 90%
Edges: Fine ground and beveled

All dimensions are in mm unless otherwise specified.



MICROSCOPE SLIDES

Size	Thickness	S1-UV	A1	Pyrex®
25.4 × 25.4	1.0	Q110040	Q310040	Q710040
50.8 × 25.4	1.0	R320110	R120110	R220110
76.2 × 25.4	1.0	R330110	R130110	R230110
101.6 × 25.4	1.5	R340115	R140115	R240115
152.4 × 25.4	2.0	R360120	R160120	R260120

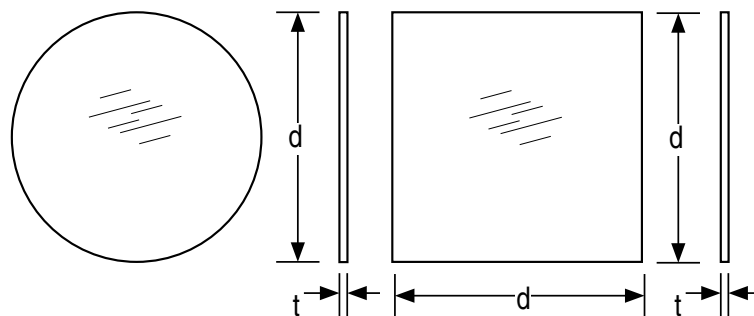
Cover Slips

These ultra-thin elements are made from high quality materials and provide above average optical characteristics to enhance image quality.

Specifications

Thickness: 0.16 ± 0.01 mm
Dimensional tolerance: ± 0.125 mm
Surface quality: 60-40, scratch-dig
Clear aperture: 90%

All dimensions are in mm unless otherwise specified.



COVER SLIPS

Diameter	S1-UV	A1	Pyrex®
12.0	R412000	R512000	R612000
25.0	R425000	R525000	R625000

Size	S1-UV	A1	Pyrex®
12.0 × 12.0	R412012	R512012	R612012
25.0 × 25.0	R425025	R525025	R625025

Please refer to these part numbers when ordering.

MIRRORS

Standard

Esco provides a variety of flat mirror substrates. Standard items are supplied front surface-coated with aluminum (Al) over-coated with either silicon monoxide (SiO) or magnesium fluoride (MgF₂).

Al-SiO is an excellent all-purpose coating that provides greater than 85% average reflectance from 350-800 nm. For broadband ultraviolet-visible applications, Al-MgF₂ provides greater than 85% average reflectance from 200–800 nm. For detailed information concerning the characteristics of optical coatings, see pages 10–14.

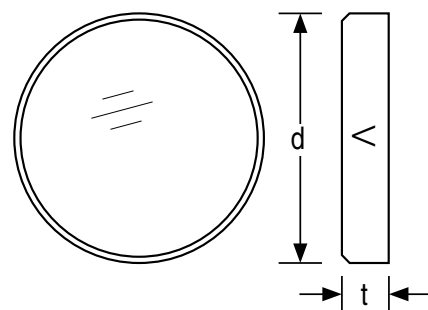
For higher reflectivity or in cases where high laser energy requires the use of non-metallic coatings, Esco provides select off-the-shelf Laser Quality Mirrors coated with all-dielectric (MAX R) coatings for 488/514.5, 532 and 633 nm. Uncoated substrates can also be customized with a variety of MAX R coatings. Order as UNCOATED and add the desired coating specifications from page 12.

Precision (Laser) Quality Flat Mirrors

Specifications

Materials:	Pyrex®
Surface Quality:	40-20, scratch-dig
Dimensions:	±0.15 mm
Rear Surface:	Fine ground
Edges:	Fine ground and beveled

All dimensions are in mm unless otherwise specified.



LASER QUALITY MIRRORS

Pyrex®

Diameter	Thickness	Surface Accuracy	Uncoated	Al-SiO	Al-MgF ₂	MAX R 488/514.5 nm	MAX R 532 nm	MAX R 633 nm
12.7	3.2	λ/10	D405000	D405100	D405200	D405488-0	D405532-0	D405633-0
12.7	3.2	λ/10				D405488-45	D405532-45	D405633-45
25.4	6.4	λ/4	D310000	D310100	D310200			
25.4	6.4	λ/10	D410000	D410100	D410200	D410488-0	D410532-0	D410633-0
25.4	6.4	λ/10				D410488-45	D410532-45	D410633-45
50.8	12.7	λ/4	D320000	D320100	D320200			
50.8	12.7	λ/10	D420000	D420100	D420200			
76.2	19.1	λ/10	D430000	D430100	D430200			
101.6	25.4	λ/10	D440000	D440100	D440200			
152.4	38.1	λ/10	D460000	D460100	D460200			

NOTE: The spectral performance of an all-dielectric coated mirror depends on the angle at which it is used. For your convenience, Esco provides off-the-shelf MAX R coated

mirrors at three common wavelength areas, designed for use at either 0° (normal) or 45° incidence, as indicated above by the section of the part number following the dash.

Specifications

Materials:	Zerodur®
Surface Quality:	20-10, scratch-dig
Dimensions:	±0.15 mm
Rear Surface:	Fine ground
Edges:	Fine ground and beveled

All dimensions are in mm unless otherwise specified.

ULTRA-STABLE LASER QUALITY MIRRORS

Zerodur®

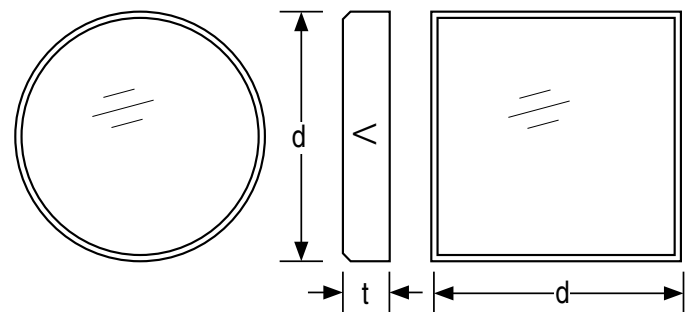
Diameter	Thickness	Surface Accuracy	Uncoated	Al-SiO	Al-MgF ₂
12.7	3.2	$\lambda/20$	D205000	D205100	D205200
25.4	6.4	$\lambda/20$	D210000	D210100	D210200
50.8	12.7	$\lambda/20$	D220000	D220100	D220200
76.2	19.1	$\lambda/20$	D230000	D230100	D230200
101.6	25.4	$\lambda/20$	D240000	D240100	D240200
152.4	38.1	$\lambda/20$	D260000	D260100	D260200

Commercial Quality Flat Mirrors

Specifications

Material:	Soda-lime Float Glass
Coating:	Al-SiO
Surface Quality:	80-50, scratch-dig
Dimensions:	±0.5 mm
Rear Surface:	Commercial Polish
Edges:	Fine ground and beveled

All dimensions are in mm unless otherwise specified.



Square/Rectangular

P/N	Length (L)	Width (W)	Thickness
D610010	25.4	25.4	6.0
D610020	25.4	50.8	6.0
D620030	50.8	76.2	6.0
D620060	50.8	152.4	9.5
D630050	76.2	127	9.5

Round

P/N	Diameter	Thickness
D502500	25.0	6.0
D505000	50.0	6.0
D507500	75.0	6.0
D510000	100.0	6.0

MIRRORS

Custom Mirrors-All Types

In addition to our standard lines of mirrors, we also manufacture a variety of custom elements. For more information on these and other custom products or applications, please contact Esco at 1-800-922-ESCO (3726).

Shapes:

Concave and convex spherical, ellipsoidal, flat. Square, round or custom.

Sizes:

Concave, over 12" diameter. Flat, nearly any size is possible. Please contact Esco to discuss your particular application.

Aspect Ratio:

If good surface accuracy is required, it is often necessary to use a mirror whose aspect ratio (diameter:thickness) is as high as possible. Although all materials act differently, a good rule of thumb for $\lambda/10$ surface accuracy is about a 6:1 aspect ratio.

Surface Quality:

Some applications may require surface qualities better than that of commercially available products. Esco can supply mirrors with surface quality better than laser grade, 10-5 or surface accuracies better than $\lambda/10$. Please inquire.

Tolerances:

The dimensional tolerances shown above are the standard tolerances used for off-the-

shelf elements. Although Esco feels that these tolerances are in line with the typical uses for these parts, we can manufacture custom products with different tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Materials:

Fused Quartz/Fused Silica (all grades)
Pyrex®
Any optical glass
Other materials upon request

Thermal Expansion:

For thermal environments that may affect the surface accuracy of a mirror, we suggest using a substrate material with good thermal expansion properties. Contact Esco to discuss which material is best for your application.

Rear Surface:

For metallized front surface mirrors, such as our standard lines, an unpolished rear surface presents a cost savings and does not interfere with the performance of the mirror. For dielectrically coated mirrors, however, a fine ground rear surface is a source of scatter of the superfluous transmitted radiation and may degrade the mirror or the system's per-

formance. Back reflections from this surface cannot only interfere with the desired wavefront, but can (in the case of high power lasers) heat the substrate, causing deformation of the reflecting surface. In these cases, Esco recommends a polished rear surface with an anti-reflection coating.

Coatings:

Al-SiO₂, -MgF₂
Silver, Gold
All dielectric Max-R
Other coatings upon request



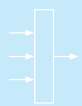
Color Filter Glass

Esco is pleased to offer Schott color filter glasses in a standard square 2" size. Although we stock the most common thickness for each type, other thicknesses and sizes are available upon request. For more information concerning the transmission characteristics, properties or applications of color filter glasses, request *ESCO TechMemo #Two*, "Filters." To discuss custom sizes, please contact Esco Products at 1-800-922-ESCO (3726).

Specifications

Size:	50.8 mm × 50.8 mm
Dimensional tolerance:	±0.25 mm
Surface accuracy:	<5λ per 25 mm
Surface quality:	60-40, scratch-dig
Parallelism:	<10'
Edges:	Fine ground and beveled

All dimensions are in mm unless otherwise specified.



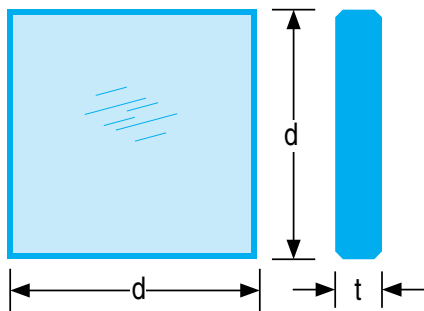
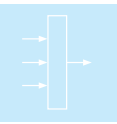
SCHOTT COLOR FILTER GLASS

Schott Designation	Thickness	P/N
UG 1	1.0	S284001
UG 3	1.0	S284003
UG 5	1.0	S284005
UG 11	1.0	S284011
BG 1	1.0	S224001
BG 3	1.0	S224003
BG 4	1.0	S224004
BG 7	1.0	S224007
BG 12	1.0	S224012
BG 13	1.0	S224013
BG 18	1.0	S224018
BG 20	1.0	S224020
BG 23	1.0	S224023
BG 24A	1.0	S224024A
BG 25	1.0	S224025
BG 26	1.0	S224026
BG 28	1.0	S224028
BG 34	1.0	S224034
BG 36	1.0	S224036
BG 37	1.0	S224037
BG 38	1.0	S224038
BG 39	1.0	S224039
BG 40	1.0	S224040
BG 42	1.0	S224042
WG 225	1.0	S294225
WG 280	1.0	S294280
WG 295	1.0	S294295

Schott Designation	Thickness	P/N
WG 305	1.0	S294305
WG 320	1.0	S294320
WG 345	1.0	S294345
KG 1	2.0	S254001
KG 2	2.0	S254002
KG 3	2.0	S254003
KG 4	2.0	S254004
KG 5	2.0	S254005
FG 3	1.0	S234003
FG 6	1.0	S234006
FG 13	2.0	S234013
GG 385	1.0	S244385
GG 395	1.0	S244395
GG 400	2.0	S244400
GG 435	2.0	S244435
GG 455	2.0	S244455
GG 475	2.0	S244475
GG 495	2.0	S244495
GG 10	1.0	S244010
OG 515	3.0	S264515
OG 530	3.0	S264530
OG 550	3.0	S264550

Schott Designation	Thickness	P/N
OG 570	3.0	S264570
OG 590	3.0	S264590
RG 610	3.0	S274610
RG 630	3.0	S274630
RG 645	3.0	S274645
RG 665	3.0	S274665
RG 695	3.0	S274695
RG 715	3.0	S274715
RG 780	3.0	S274780
RG 830	3.0	S274830
RG 850	3.0	S274850
RG 1000	3.0	S274100
RG 9	3.0	S274009
NG 1	1.0	S261001
NG 3	1.0	S261003
NG 4	1.0	S261004
NG 5	1.0	S261005
NG 9	1.0	S261009
NG 10	1.0	S261010
NG 11	1.0	S261011
NG 12	1.0	S261012
VG 4	1.0	S281004
VG 5	1.0	S281005
VG 6	1.0	S281006
VG 9	1.0	S281009
VG 10	1.0	S281010
VG 14	1.0	S281014

FILTERS



Custom Machined Color Glass

In addition to our standard line of Schott color filter glass, we also carry a range of glasses from other manufacturers. For more information on these as well as custom machining of color filter glass, please contact Esco at 1-800-922-ESCO (3726).

Sizes:

Color glass is only available in sheets up to 165 mm. Maximum thickness varies with glass-type. Please contact Esco for more information.

Surface Quality:

Some applications may require surface qualities better than that of commercially available products. Esco can supply color filter glass with surface quality better than laser grade, 10-5 or surface accuracies better than $\lambda/20$. In these cases, glass types with excellent homogeneity should be used. For more information, please contact Esco.

Tolerances:

The dimensional tolerances shown above are the standard tolerances used for off-the-shelf elements. Although Esco feels that these tolerances are in line with the typical uses for these parts, we can manufacture custom products with different tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.



Neutral Density Filters

Neutral density (ND) filters are used to attenuate incident radiation without altering its spectral distribution. The neutral density value of an ND filter is related to the transmittance by:

$$T=10^{-D} \quad \text{or} \quad D=\log(1/T)$$

If two or more filters are placed in sequence, the resultant density value is calculated from either the sum of the individual density values or the product of the transmittances. This holds true if no multiple reflections occur between elements.

ND filters are available in two types. The first uses neutral density color filter glass such as the NG types made by Schott.

- These filters can be AR coated to prevent back reflections.
- They can handle higher input energy, especially if actively cooled.
- Very accurate ND values are possible by controlling the thickness of the color glass.

The other type of ND filter is a glass or quartz substrate with a precision metallic coating (Inconel) that provides uniform attenuation across a wide spectral range. Some advantages of metallic coated ND filters include:

- Coating on quartz allows controlled attenuation in the UV.
- Coating provides attenuation with greater linearity over a wide spectral range.

- Can handle higher intensity light sources because part of the beam is reflected rather than absorbed.

The film is comprised of a very hard alloy material that is resistant to aging under normal conditions. Use at high temperatures can cause oxidation however, and is not recommended. Any commercial cleaning solution can be used to clean these filters.

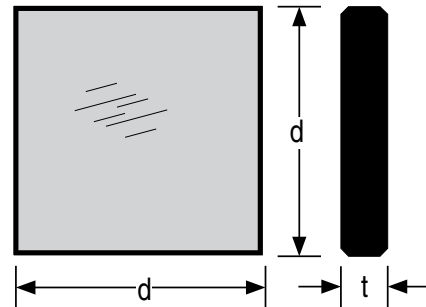
NOTE: Use of any of these neutral density filters with high power lasers or other extreme light sources can cause catastrophic failure and is not recommended.

Neutral Density Color Glass Filters

Specifications

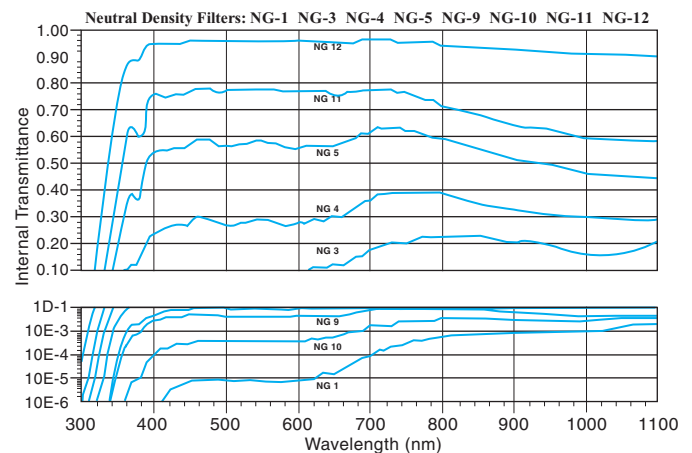
Size:	50.8 mm × 50.8 mm
Dimensional tolerance:	±0.25 mm
Density tolerance:	± 4% at 550 nm
Surface accuracy:	<5λ per 25 mm
Surface quality:	60-40, scratch-dig
Parallelism:	<10'
Edges:	Fine ground and beveled

All dimensions are in mm unless otherwise specified

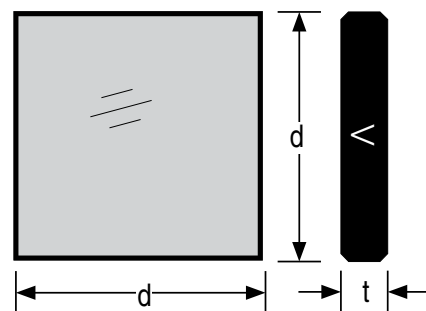


Neutral Density Color Glass Filters

Nominal Density	Transmission	Glass Type	Part Number
0.1	79.4%	NG12	S301000
0.2	63.1%	NG11	S302000
0.3	50.1%	NG11	S303000
0.4	39.8%	NG11	S304000
0.5	31.6%	NG11	S305000
0.6	25.1%	NG5	S306000
1.0	10.0%	NG5	S310000
2.0	1.0%	NG4	S320000
3.0	0.1%	NG3	S330000
4.0	0.01%	NG3	S340000
Set of all 10			S300000



Transmission (internal) measured at 550 nm. For a small charge, Esco will provide curves showing the actual transmission characteristics of any standard or custom neutral density filter.



Metallic Coated Neutral Density Filters

Specifications

Substrate materials:	K5 Crown Glass and S1-UV Ultraviolet Grade Fused Silica
Size:	50.8 mm × 50.8 mm
Thickness:	1.0 mm
Density tolerance:	±10% of density for values <0.5 and ±5% for values >0.5
Dimensional tolerance:	±0.25 mm
Surface accuracy:	<5λ per 25 mm
Surface quality:	60-40, scratch-dig
Parallelism:	<10'
Edges:	Fine ground and beveled

All dimensions are in mm unless otherwise specified

FILTERS

Metallic Coated Neutral Density Filters

Nominal Density	Transmission	BK7	Fused Quartz
0.1	79.4%	S701000	S501000
0.2	63.1%	S702000	S502000
0.3	50.1%	S703000	S503000
0.4	39.8%	S704000	S504000
0.5	31.6%	S705000	S505000
0.6	25.1%	S706000	S506000
1.0	10.0%	S710000	S510000
2.0	1.0%	S720000	S520000
3.0	0.1%	S730000	S530000
4.0	0.01%	S740000	S540000
Set of all 10		S700000	S500000



Transmission measured at 550 nm. For a small charge, Esco will provide curves showing the actual transmission characteristics of any standard or custom neutral density filter.

Custom Neutral Density Filters

In addition to our standard lines of neutral density filters, we also manufacture a variety of custom elements. For more information on these and other custom products or applications, please contact Esco at 1-800-922-ESCO (3726).

Sizes:

Up to 165 mm for color filter glass, larger for metallic coated.

NOTE: Coating thickness variations can occur on larger substrates. This can lead to non-linear attenuation across the face of the filter. Please contact Esco if you are considering neutral density filters larger than 50 mm.

Materials:

Fused Quartz/Fused Silica (all grades)
Pyrex®
BK7 Optical Glass
Other materials upon request

Surface Quality:

Some applications may require surface qualities better than that of commercially available products. Esco can supply neutral density filters with surface quality better than laser grade, 10-5 or surface accuracies better than $\lambda/20$. In these cases, materials with excellent homogeneity should be used. For more information, please contact Esco.

Tolerances:

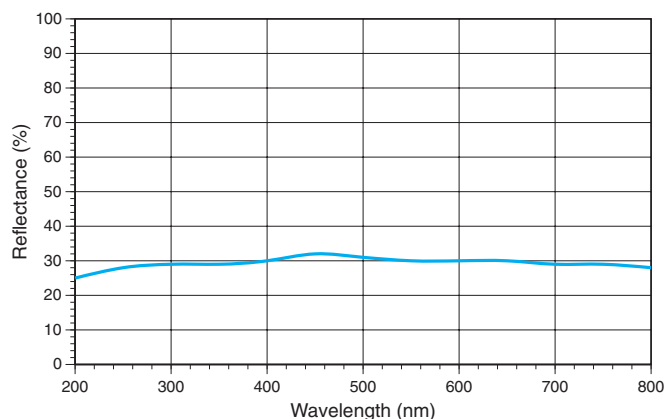
The dimensional tolerances shown above are the standard tolerances used for off-the-shelf elements. Although Esco feels that these tolerances are in line with the typical uses for these parts, we can manufacture

custom products with different tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Coatings:

Although AR coatings cannot be used on metallic coated ND filters, they are available for color filter glass models. Please see pages 10–11 for more information or contact Esco.



Typical spectral characteristics of Inconel, the metal used for both Metal Coated Neutral Density Filters and Metallic Beamsplitter Coatings

Bandpass Filters

Thin film bandpass filters are optical elements that are designed to transmit a specific spectral band with high efficiency, while rejecting, by both absorption and reflection, all unwanted energy outside that region. The characteristics of the passband are controlled by multilayer dielectric coatings. Blocking is usually achieved with a combination of color filter glass and specially designed metallic films. The bandpass and blocking elements are laminated (epoxied) together to form a single unit and then edge sealed to prevent degradation due to moisture.

Bandpass filters are used in any application area requiring the isolation of a narrow spectral bandwidth and a high signal-to-noise ratio. Esco supplies bandpass filters that provide transmission bands from the ultraviolet to the near infrared.

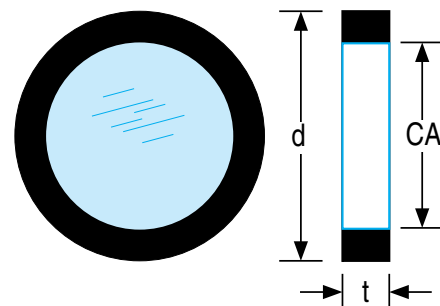
Standard

Esco provides standard bandpass filters that are designed for use at several common wavelengths. All models provide out of band blocking of better than 10^{-4} . Two sizes are available: 0.5" and 1.0" diameter. Each filter is provided sealed in metal (aluminum) rings. These rings provide additional protection against degradation due to water absorption, as well as a more accurate edge that can often help in some mounting situations.

For a small charge, Esco will provide individual curves showing the actual transmission characteristics of any filter.

Specifications

Sizes (Clear aperture):	12.7 mm (8.1 mm) diameter 25.4 mm (20.3 mm) diameter
Dimensional tolerance:	+0/-0.13 mm
Thickness:	<6.4 mm
Center wavelength tolerance:	254-313 nm: ± 3 nm, 340-1064 nm: ± 2 nm
Bandwidth tolerance:	254-313 nm: ± 2.5 nm, 340-1064 nm: ± 2 nm
Surface accuracy:	Not applicable
Surface quality:	80-50, scratch-dig
Blocking:	Better than 10^{-4} from X-ray to far infrared
Temperature limits:	-50° C to +80° C



RING MOUNTED

NOTE: Bandpass Filters will be shipped as RING-MOUNTED unless unmounted filters are requested at the time of the order.

FILTERS

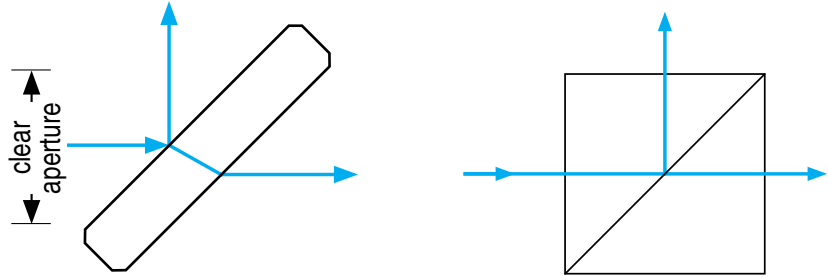
BANDPASS FILTERS

Wavelength (nm)	Bandwidth	Minimum Transmission	12.7 mm Dia.	25.4 mm Dia.
254.0	10	17	S912540	S902540
265.0	10	17	S912650	S902650
280.0	10	17	S912800	S902800
289.0	10	17	S912890	S902890
297.0	10	17	S912970	S902970
308.0	10	17	S913080	S903080
313.0	10	17	S913130	S903130
334.0	10	20	S913340	S903340
337.1	10	20	S913371	S903371
340.0	10	35	S913400	S903400
350.0	10	35	S913500	S903500
360.0	10	35	S913600	S903600
370.0	10	35	S913700	S903700
378.0	10	35	S913780	S903780
380.0	10	35	S913800	S903800
390.0	10	35	S913900	S903900
394.0	10	35	S913940	S903940
400.0	10	40	S914000	S904000
405.0	10	40	S914050	S904050
410.0	10	40	S914100	S904100
420.0	10	40	S914200	S904200
430.0	10	40	S914300	S904300
435.8	10	45	S914358	S904358
440.0	10	45	S914400	S904400
441.6	10	45	S914416	S904416
450.0	10	50	S914500	S904500
457.9	10	50	S914579	S904579
460.0	10	50	S914600	S904600
470.0	10	50	S914700	S904700
480.0	10	50	S914800	S904800
488.0	10	50	S914880	S904880
490.0	10	50	S914900	S904900
500.0	10	50	S915000	S905000
510.0	10	50	S915100	S905100
514.5	10	50	S915145	S905145
520.0	10	50	S915200	S905200
530.0	10	50	S915300	S905300
532.0	10	50	S915320	S905320
540.0	10	50	S915400	S905400
546.1	10	50	S915461	S905461
550.0	10	50	S915500	S905500
560.0	10	50	S915600	S905600
570.0	10	50	S915700	S905700
577.7	10	50	S915777	S905777
580.0	10	50	S915800	S905800
589.6	10	50	S915896	S905896
590.0	10	50	S915900	S905900
600.0	10	50	S916000	S906000
610.0	10	50	S916100	S906100
620.0	10	50	S916200	S906200
630.0	10	50	S916300	S906300

Wavelength (nm)	Bandwidth	Minimum Transmission	12.7 mm Dia.	25.4 mm Dia.
632.8	10	50	S916328	S906328
640.0	10	50	S916400	S906400
650.0	10	50	S916500	S906500
656.3	10	50	S916560	S906560
660.0	10	50	S916600	S906600
670.0	10	50	S916700	S906700
671.0	10	50	S916710	S906710
680.0	10	50	S916800	S906800
690.0	10	50	S916900	S906900
694.3	10	50	S916943	S906943
700.0	10	50	S917000	S907000
710.0	10	45	S917100	S907100
720.0	10	45	S917200	S907200
730.0	10	45	S917300	S907300
740.0	10	45	S917400	S907400
750.0	10	45	S917500	S907500
760.0	10	45	S917600	S907600
765.0	10	45	S917650	S907650
770.0	10	45	S917700	S907700
780.0	10	45	S917800	S907800
790.0	10	45	S917900	S907900
800.0	10	45	S918000	S908000
810.0	10	45	S918100	S908100
820.0	10	45	S918200	S908200
830.0	10	45	S918300	S908300
840.0	10	45	S918400	S908400
850.0	10	45	S918500	S908500
852.0	10	45	S918520	S908520
860.0	10	45	S918600	S908600
870.0	10	45	S918700	S908700
880.0	10	45	S918800	S908800
890.0	10	45	S918900	S908900
900.0	10	45	S919000	S909000
905.0	10	45	S919050	S909050
910.0	10	45	S919100	S909100
920.0	10	45	S919200	S909200
930.0	10	45	S919300	S909300
940.0	10	45	S919400	S909400
950.0	10	45	S919500	S909500
960.0	10	45	S919600	S909600
970.0	10	45	S919700	S909700
980.0	10	45	S919800	S909800
990.0	10	45	S919900	S909900
1000.0	10	45	S911000	S901000
1010.0	10	45	S911010	S901010
1020.0	10	45	S911020	S901020
1030.0	10	45	S911030	S901030
1040.0	10	45	S911040	S901040
1050.0	10	45	S911050	S901050
1060.0	10	45	S911060	S901060
1064.0	10	45	S911064	S901064

BEAMSPLITTERS

A beamsplitter is any optical component that is used to split light into, or recombine from, two separate beam paths. Esco provides two different types of beamsplitters: plates and cubes. Each has certain advantages and disadvantages depending on the intended application. Please call Esco to discuss the form that is best suited to your application.



Beamsplitter Plates

Standard

Esco manufactures general purpose beamsplitter plates for use in the visible and UV spectra. If you require elements with different spectral or physical characteristics, please contact Esco.

Features:

- Compact, lighter than cubes with similar apertures
- No epoxy is used, so use with higher power lasers is possible
- Transmitted and reflected wavefronts easier to control
- Beams travel different optical paths
- R/T ratio is dependent on the state of polarization
- Internal reflection from second surface produces ghost image in reflected path
- Can be built with custom wedge to divert back reflections from beam path
- Beam can be shifted angularly by controlling the wedge or, laterally by controlling the thickness

Specifications

General

Edge dimension tolerance:	±0.125 mm
Thickness tolerance:	±0.125 mm
Parallelism:	10'
Surface quality:	60-40, scratch-dig
Edges:	Fine ground and beveled

for Visible

Substrate material:	BK7 Optical Glass
Coatings	
First surface:	BEAMSPLITTER (All-dielectric)
Angle of incidence:	45°
Polarization:	Unpolarized
Wavelength range:	400-700 nm
R/T ratio:	50/50 ±5%
Back surface:	ANTI-REFLECTION
Single layer MgF ₂ :	<1.5% R average from 400-700 nm

All dimensions are in mm unless otherwise specified.

for UV

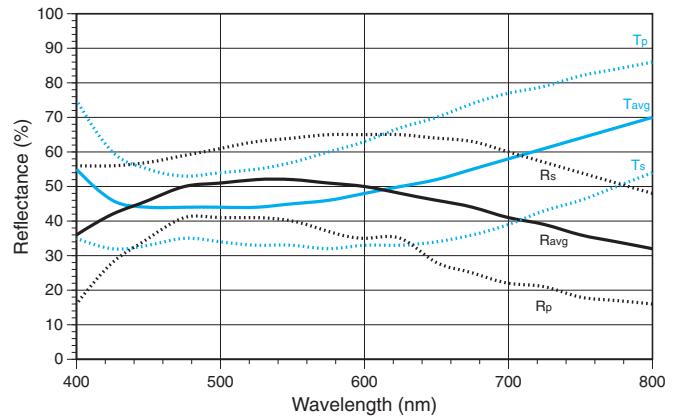
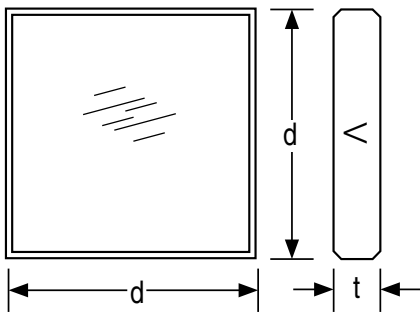
Substrate material:	S1-UV Grade Fused Silica
Coatings	
First surface:	BEAMSPLITTER (Metallic)
Angle of incidence:	45°
Polarization:	Unpolarized
Wavelength range:	200-700 nm
R/T ratio:	30/30 ±5% (200-400 nm)
Back surface:	ANTI-REFLECTION
Single layer MgF ₂ :	<1.5% R average from 200-400 nm

BEAMSPLITTERS

BEAMSPLITTER PLATES

Size (square)	Thickness	Surface Accuracy	for Visible	for UV
25.4 × 25.4	1.0	3λ/25 mm	0101010	0201010
50.8 × 50.8	1.0	3λ/25 mm	0102020	0202020
25.4 × 25.4	5.0	λ/10	0111010	0211010
50.8 × 50.8	10.0	λ/10	0112020	0212020

Round				
25.4	1.0	3λ/25 mm	0101000	0201000
50.8	1.0	3λ/25 mm	0102000	0202000
25.4	5.0	λ/10	0111000	0211000
50.8	10.0	λ/10	0112000	0212000



Typical spectral characteristics of an All-Dielectric Beamsplitter Coating

Beamsplitter Cubes

Standard

Beamsplitter cubes are constructed by cementing two right angle prisms together at their hypotenuses. They are supplied with one of the beamsplitter coatings described below applied to the hypotenuse of one of the prisms. The leg faces are uncoated, but can be AR coated upon request. Esco manufactures general purpose beamsplitter cubes for use in the visible and UV spectra. If you require elements with different spectral or physical characteristics, please contact Esco.

Features:

- Transmitted beam is neither displaced or deflected
- Reflected and transmitted beams travel identical optical path lengths
- No ghost images
- Less susceptible to mechanical stress than plates
- R/T ratio dependent on the state of polarization
- Designed for use with collimated beams
- Contains cemented interface that may be susceptible to high power
- Cemented interface may introduce undesired wavefront distortion in larger cubes

BEAMSPLITTERS

Specifications

General

Dimensional tolerance: ± 0.5 mm
 Surface quality: 60-40, scratch-dig
 Edges: Fine ground and beveled

for Visible

Prism material: BK7 optical glass
 Coatings

Beamsplitter (Hybrid metal-dielectric)

Polarization: Unpolarized
 Wavelength range: 400–700 nm
 R/T ratio: 45/45 $\pm 5\%$
 Absorption: $\sim 10\%$

for UV

Prism material: S1-UV grade fused silica
 Coatings

Beamsplitter (metallic)

Polarization: Unpolarized
 Wavelength range: 200–700 nm
 R/T ratio: 30/30 $\pm 5\%$ (200-400 nm)

for Laser

Substrate material: S1-UV Grade Fused Silica
 Coatings

Beamsplitter (All-dielectric)

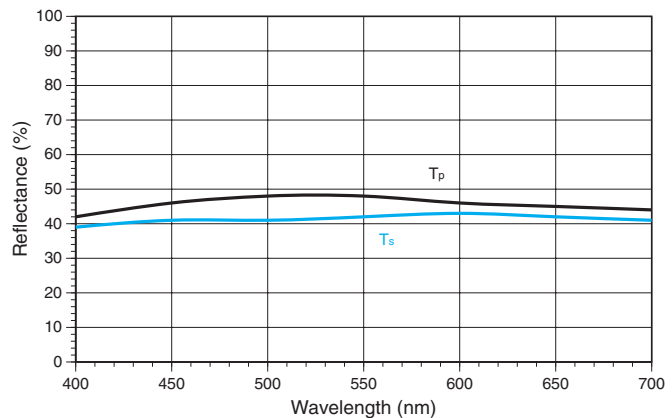
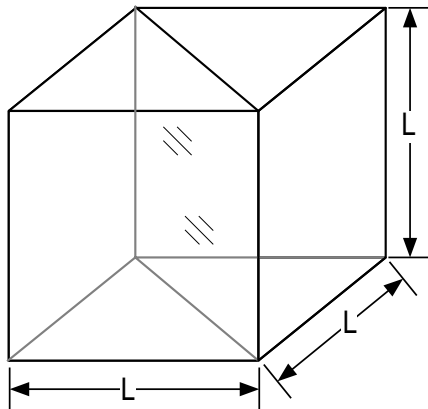
Angle of incidence: 45°
 Polarization: Unpolarized
 Wavelength range: SPECIFY
 R/T ratio: 45/45 $\pm 5\%$

All dimensions are in mm unless otherwise specified.

BEAMSPLITTER CUBES

Size (mm)	Flatness	for Visible	for UV	for Laser*
15	1 λ	0315015	0415015	0515015
20	1 λ	0320020	0420020	0520020
15	$\lambda/10$	0315115	0415115	0515115
20	$\lambda/10$	0320120	0420120	0520120
25	1 λ	0325025	0425025	0525025
38	1 λ	0338038	0438038	0538038
50	1 λ	0350050	0450050	0550050

*IMPORTANT: Specify laser wavelength when ordering. Call Esco for more information.



Typical spectral characteristics of a Hybrid Metal-Dielectric Beamsplitter Coating

BEAMSPLITTERS

Custom Beamsplitters

In addition to our standard beamsplitters, we also manufacture a variety of custom elements including custom plates and cubes. For more information concerning beamsplitter variations or applications, please contact Esco at 1-800-922-ESCO (3726).

Sizes:

Flat: nearly any size is possible. Size may limit the choice of coating, however. Please contact Esco to discuss your particular application. Cubes: up to 100.0 mm

Materials:

Fused Quartz/Fused Silica (all grades)
Any optical glass
Other materials upon request

Surface Quality:

Some applications may require surface qualities better than that of commercially available products. Esco can supply beamsplitters with surface quality better than laser grade, 10-5 or surface accuracies better than $\lambda/20$. Please inquire.

Wavefront Distortion:

If good wavefront distortion is required, it is necessary to use a beamsplitter plate whose aspect ratio (diameter:thickness) is as high as possible. Although all materials act differently, a good rule of thumb for $\lambda/10$ surface accuracy is about a 6:1 aspect ratio.

It is often difficult to achieve good wavefront distortion with large beamsplitter cubes, despite the surface accuracy of the constituent prisms. Many optical epoxies cause stress that can adversely affect wavefront performance in cubes larger than about 30 mm. Please contact Esco for more information.

Tolerances:

The dimensional tolerances shown above are the standard tolerances used for off-the-shelf elements. Although Esco feels that these tolerances are in line with the typical uses for these parts, we can manufacture custom products with different tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Coatings:

Whenever specifying a custom beamsplitter, it is important to know:

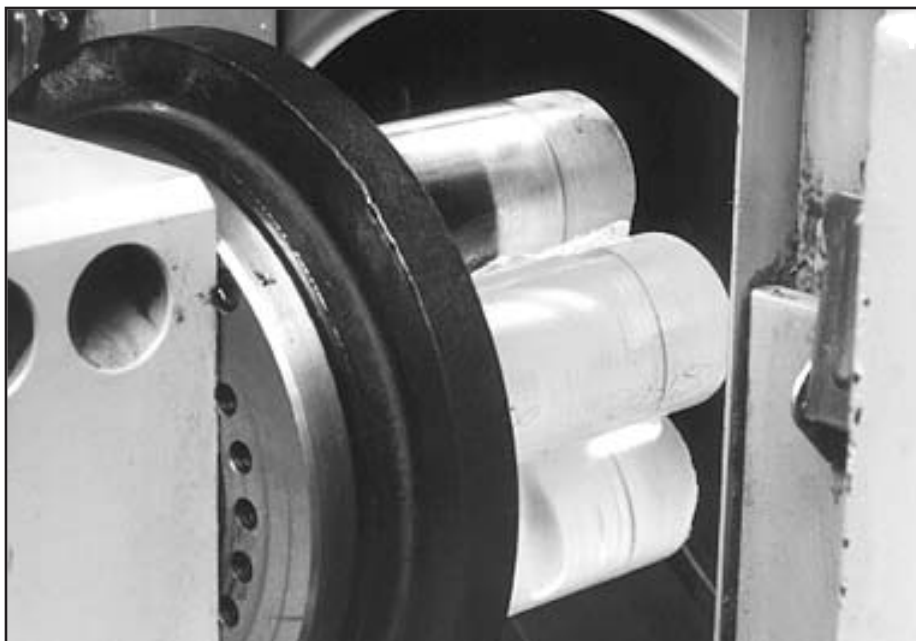
- Wavelength, or wavelength range
- Angle of incidence
- State of polarization

Esco can provide custom beamsplitter coatings for almost any combination of these conditions. Three basic types of coatings can be used:

- (1) **All dielectric** beamsplitter coatings provide good R/T characteristics with negligible absorption. They are extremely sensitive to polarization and angle of incidence however, and are designed for use over a narrow spectral region.
- (2) **Metal** (Inconel) beamsplitter coatings are not sensitive to polarization or angle of incidence. They provide steady R/T characteristics over a wide spectral range but can absorb as much as 35% of the incident energy.
- (3) **Hybrid** beamsplitter coatings are a combination of metal and dielectric films and therefore share many of their properties. They tend to be less absorptive than metal coatings and have a wider spectral response than an all dielectric coating. For more information, please contact Esco.

Polarizing beamsplitter coatings are narrowband coatings that separate the S and P states of the incident light. These coatings are extremely angle sensitive, but highly effective with collimated beams.

AR coatings for the side faces of cubes or the rear surface of plates are always available and encouraged. For information concerning availability, please see pages 10–11 or contact Esco.



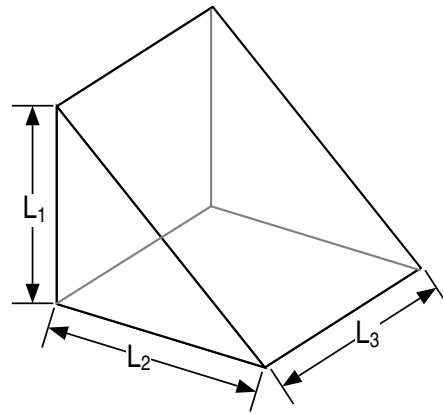
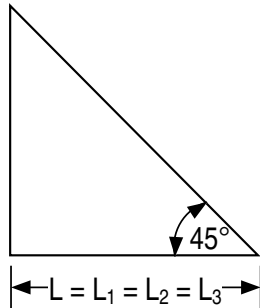
Standard

A prism is an optical element whose purpose is to deflect or deviate a beam of light. Literally dozens of basic prism types exist. Esco's standard product line consists of three elementary shapes:

- *Right angle prisms:* Typically used to deflect beams either 90° or 180°.
- *Equilateral prisms:* Used to spectrally disperse polychromatic light.
- *Laser prisms:* Used to select a discrete wavelength from multi-wavelength lasers.

Right Angle Prisms

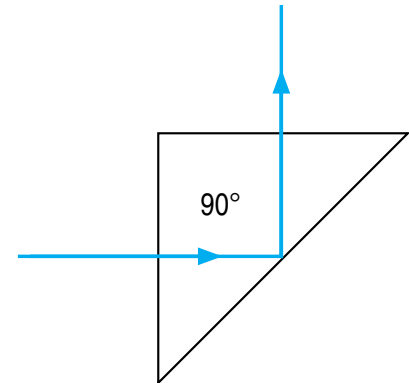
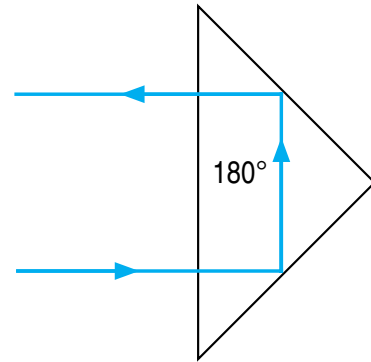
In many situations involving collimated light, prisms are superior to mirrors for deflecting light. Prisms, because of their shape accuracy, require less positioning than mirrors. Light is always reflected within the plane parallel to the ground face of the prism. Also, because light is reflected by total internal reflection, prisms can be used to reflect high power laser beams that might otherwise damage sensitive coatings.



Specifications

	Commercial	Laser Quality
Dimensional tolerance:	± 0.25 mm	± 0.125 mm
Angle tolerance:	$\pm 10'$	$\pm 30''$
Surface accuracy:	$\lambda/2$ per inch	$\lambda/10$
Surface quality:	60-40, scratch-dig	20-10, scratch-dig
Edges:	Fine ground and beveled	Fine ground and beveled

All dimensions are in mm unless otherwise specified.



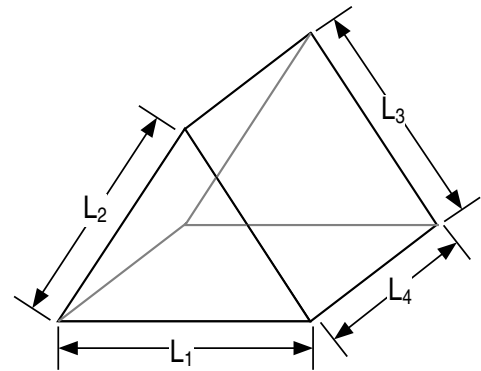
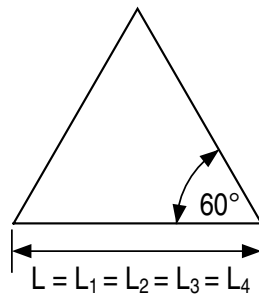
RIGHT ANGLE PRISMS

Size (L)	Commercial		Laser Quality	
	BK7	S1-UV	BK7	S1-UV
5.0	I405050	I105050	I405151	I105051
10.0	I410100	I110100	---	---
15.0	I415150	I115150	I415151	I115151
20.0	I420200	I120200	I420201	I120201
25.0	I425250	I125250	I425251	I125251
38.1	I438380	I138380	I438381	I138381
50.0	I450500	I150500	I450501	I150501

PRISMS

Equilateral Prisms

These elements, also called dispersion prisms, are commonly used to separate multiple wavelengths of a polychromatic source. The direction of the exit beam is dependent on the wavelength, the angle of incidence and the shape of the prism. The equilateral shape of these prisms takes full advantage of the dispersive properties of the optical materials to provide maximum separation between wavelengths.



Specifications

	Commercial	Laser Quality
Dimensional tolerance:	±0.25 mm	±0.125 mm
Angle tolerance:	±10'	±10'
Surface accuracy:	1λ per inch	λ/10
Surface quality:	60-40, scratch-dig	20-10, scratch-dig
Edges:	Fine ground and beveled	Fine ground and beveled

All dimensions are in mm unless otherwise specified.

For visible light incident at a 60° angle of incidence to one face of an equilateral prism, the following angular separations between the h (404.7 nm) and r (706.5 nm) lines can be realized for the materials listed below.

S1-UV	1° 5'
BK7	1° 22'
SF10	7° 9'

EQUILATERAL PRISMS

Size (L × L)	Commercial			Laser Quality		
	BK7	SF10	S1-UV	BK7	SF10	S1-UV
20 × 20	L420200	L520200	L120200	L420201	L520201	L120201
25 × 25	L425250	L525250	L125250	L425251	L525251	L125251
30 × 30	L430300	L530300	L130300	L430301	L530301	L130301
40 × 40	L440400	L540400	L140400	L440401	L540401	L140401
45 × 45	L445450	L545450	L145450	L445451	L545451	L145451
50 × 50	L450500	L550500	L150500	L450501	L550501	L150501

Laser Prisms

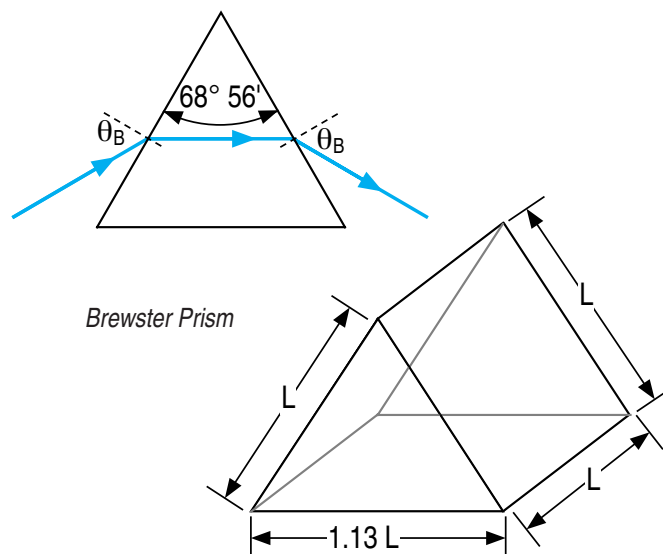
Brewster & Littrow Prisms

These prisms are used to select a particular wavelength from a multi-wavelength laser. The apex angle of a Brewster laser prism is designed to deviate a ray of a particular wavelength by Brewster's angle, thus minimizing reflection losses when used with

linearly polarized light. Only light that travels within the prism parallel to the base will be perfectly transmitted. Since other wavelengths will experience high losses, the Brewster prism can be used intracavity to suppress their gain.

A Littrow laser prism is the result of cutting a Brewster prism in half. The plane of the cut divides the apex angle and is perpendicular to the base of the prism. By adding a reflective coating to the new leg face, the Littrow is used like the Brewster prism, but the output exits back toward the source.

Each of these elements can be used to tune a variety of laser systems efficiently. Tuning is performed by tilting the prism in the path of the beam. The apex angle has been carefully chosen to allow maximum performance at any desired wavelength within the visible spectrum. For assistance with these or other similar custom products, please contact Esco at 1-800-922-ESCO (3726).



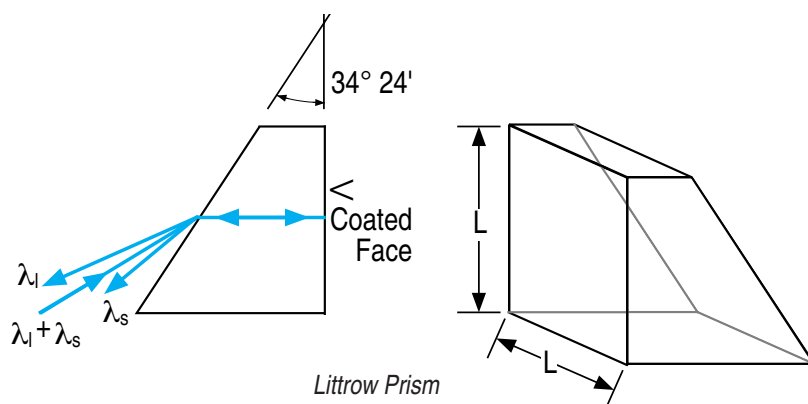
Specifications

Material:	S1-UVA, UV Grade Fused Silica
Surface accuracy:	$\lambda/20$ over clear aperture
Surface quality:	10-5, scratch-dig
Clear aperture:	Central 80% diameter
Dimensional tolerance:	± 0.5 mm
Apex angle tolerance:	$\pm 5'$
Edges:	Fine ground and beveled
Width of bevel:	<0.5 mm
Coatings:	Uncoated, specify optional coating on Littrow prisms

All dimensions are in mm unless otherwise specified.

LASER PRISMS

Type	Size (L)	Apex Angle	Part Number
Brewster	15	68° 56'	I515015
Brewster	25	68° 56'	I525025
Littrow	15	34° 28'	I615015
Littrow	25	34° 28'	I625025



Custom Prisms

In addition to our standard lines of prisms, we are often called upon to design and manufacture a variety of custom elements. For more information on custom products or applications, please contact Esco.

Sizes:

There is almost no size limitation for prisms that we can build. There is, however, usually a trade off between size and angular accuracy. Please call Esco to discuss your particular application.

Materials:

Fused Quartz/Fused Silica (all grades)
Rutile (TiO₂)
BK7 Optical Glass
Other materials upon request

Surface Quality:

Some applications may require surface qualities better than that of commercially available products. Esco can supply elements with surface quality better than laser grade, 10-5 or surface accuracies better than $\lambda/20$. Please contact Esco for more information.

Tolerances:

The dimensional tolerances shown above are the standard tolerances used for off-the-

shelf elements. Although Esco feels these tolerances are in line with the typical uses for these parts, we can manufacture custom products with other tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Coatings:

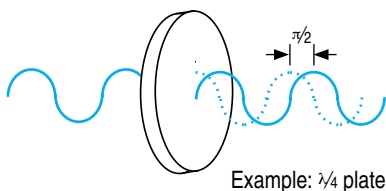
Unless otherwise specified, all standard Esco prisms are supplied uncoated. Coatings can, however, greatly enhance a prism's performance. To discuss your specific coating needs, please contact Esco.

A retardation plate, or *waveplate* is an optical

RETARDATION PLATES

element that changes the polarization state of an incident beam by causing one P-state to lag behind the other. The phase difference, or *retardation value*, is not only dependent on the thickness of the plate but on the wavelength as well. Although transparent to the entire spectrum allowed by the material, a waveplate will only perform correctly at the design wavelength(s).

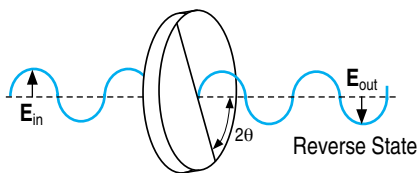
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Example: $\lambda/4$ plate

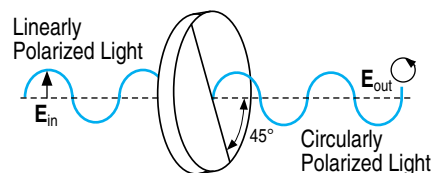
1/2 Waveplates

A 1/2 wave retardation plate is used to reverse the handedness of circularly polarized light or to produce a 180° flip of linear or elliptical light.



1/4 Waveplates

A 1/4 waveplate will produce circularly polarized light when the axis is placed at 45° to the axis of the incident linear light. Reversing the direction of propagation will transform circular light into linearly polarized light.



Mica Waveplates

Mica retarders are made from thin sheets of mica and sealed with optical epoxy between two thin plates of glass. The extraordinary properties of mica make it an ideal general purpose waveplate. Because of its inherently high absorption however, the transmittance of these plates is roughly 70-80% and should be used for low power applications only.

Crystal Quartz Waveplates

These retardation plates are made from Schlieren-free, natural crystal quartz. Because of the high material quality and the fact that quartz surfaces are necessarily polished, these plates can withstand much higher power levels than mica plates. To improve their efficiency further, quartz waveplates can be anti-reflection coated.

Crystal quartz retardation plates are available as either multiple order or zero order plates. Each has its own set of advantages.

Multiple order waveplates are made from a single piece of crystal quartz that is about 1 mm thick. The phase difference of the two orthogonal P-states passing through them is a multiple of full wave retardations plus the designed fractional retardation. Single element multiple order plates permit higher input powers than cemented or even optically contacted components.

Zero order waveplates are comprised of two optically contacted quartz plates whose optic axes are mutually perpendicular. As light passes from the first plate to the second, the roles of the o- and e-waves are reversed. The result is a phase difference that is dependent not on the total thickness of the two plates, but on the net difference. Because temperature fluctuations and non-normal incidence will affect both plates simultaneously, their effects are also subtractive. Zero order plates offer the highest degree of retardation accuracy.

Esco's Retardation Plates are mounted in black anodized aluminum cells. The optic axis is clearly marked on the face of the cell.



Specifications

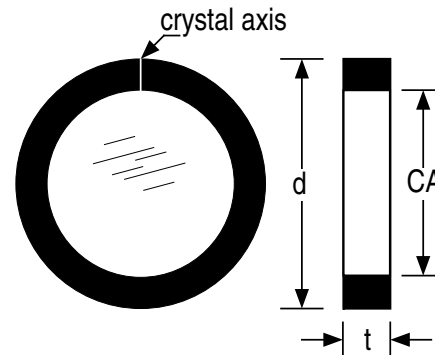
Mica Retardation Plates

Cell dimensions: 25.4 mm dia. × 10 mm thick.
Clear aperture: 15 mm
Retardation tolerance: $<\lambda/5$
Wavefront distortion: $<\lambda/4$
Parallelism: $<3'$

Quartz Retardation Plates

Cell dimensions: 25.4 mm dia. × 10 mm thick.
Clear aperture: 15 mm
Retardation tolerance: $<\lambda/300$
Wavefront distortion: $<\lambda/10$
Parallelism: $<1''$

All dimensions are in mm unless otherwise specified.



WAVEPLATES

Wavelength (nm)	Retardation	Mica Multiple Order	Quartz Multiple Order	Quartz Zero Order
488.0	1/2 wave	H314880	H414880	H514880
488.0	1/4 wave	H324880	H424880	H524880
514.5	1/2 wave	H315145	H415145	H515145
514.5	1/4 wave	H325145	H425145	H525145
632.8	1/2 wave	H316328	H416328	H516328
632.8	1/4 wave	H326328	H426328	H526328
830.0	1/2 wave	-	H418300	H518300
830.0	1/4 wave	-	H428300	H528300
1060.0	1/2 wave	-	H411060	H511060
1060.0	1/4 wave	-	H421060	H521060

Custom Retardation Plates

In addition to our standard lines of retardation plates, we also manufacture a variety of custom elements. For more information on these and other custom products or applications, please contact Esco at 1-800-922-ESCO (3726).

Sizes:
10 mm to 75 mm diameter

Wavelengths:
Since the design wavelength of a retarder is strictly a function of its thickness, one can easily be designed for any wavelength within the transmission range of the material.

In fact, all plates can be used correctly at more than one wavelength. To check the availability of a waveplate for use at a non-standard wavelength, or to discuss your particular application, please contact Esco.

Tolerances:
The dimensional tolerances shown above are the standard tolerances used for off-the-shelf elements. Although Esco feels that these tolerances are in line with the typical uses for these parts, we can manufacture custom products with different tolerances upon request.

For certain OEM applications, looser tolerances may lead to a cost savings, while many critical applications may require much tighter tolerances. To discuss your particular needs, please contact Esco.

Coatings:
AR coatings are available for all retardation plates. See pages 10–11 for more information or contact Esco.

CONDITIONS OF SALE



Delivery

Shipping dates are approximate and are based upon prompt receipt of all necessary information.

The Company shall not be liable for delays in delivery or failure to manufacture or deliver (1) due to causes beyond its reasonable control, or (2) due to acts of God, acts of the Purchaser, acts of civil or military authorities, priorities, fires, strikes, floods, epidemics, war, riot, delays in transportation or car shortages, or (3) inability due to causes beyond its reasonable control to obtain necessary labor, materials, components or manufacturing facilities. In the event of any such delay, the date of delivery shall be extended for a period equal to the time lost by reason of the delay.

In all cases, risk of loss or damage to goods in transit shall fall upon the Purchaser, whose responsibility it shall be to file claims with the carrier.

Payments

Each shipment shall be considered a separate and independent transaction, and payment therefore shall be made accordingly. If shipments are delayed by the Purchaser, payments shall become due on the date when the Company is prepared to make shipment. If the work to be performed hereunder is delayed by the Purchaser, payments shall be made based on the purchase price and the percentage of completion. Products held for the Purchaser shall be at the risk and expense of the Purchaser.

If the financial condition of the Purchaser at any time does not, in the judgement of the Company, justify continuance of the work to be performed by the Company hereunder on the terms of the payment as agreed upon, the Company may require full or partial payment in advance or shall be entitled to cancel any order then outstanding and shall receive reimbursement for its reasonable and proper cancellation charges, and in the event of bankruptcy or insolvency of the purchaser or in the event any proceeding is brought against the Purchaser, voluntary or involuntary under the bankruptcy or any insolvency laws, the Company shall be entitled to cancel any order then outstanding at any time during the period allowed for filing claims against the estate and shall receive reimbursement for its reasonable and proper cancellation charges.

Sales and Similar Taxes

Unless otherwise stated herein, the Company's prices do not include sales, use, excise or similar taxes. Consequently, in addition to the price specified herein, the amount of any present or future sales, use, excise or other similar tax applicable to the sale or use of the equipment

hereunder shall be paid by the Purchaser, or in lieu thereof the Purchaser shall provide the Company with a tax-exemption certificate acceptable to the taxing authorities.

Cancellations and Returns

The Purchaser may cancel his order only upon written notice and upon payment to the company of the reasonable and proper cancellation charges. No returns will be accepted after 30 days from the date of receipt of goods.

Limitation of Liability

The Company's liability on any claim of any kind, including negligence, for any loss or damage arising out of, connected with, or resulting from this contract, or from the performance or breach thereof, or from the manufacture, sale, delivery, resale, repair or use of any product covered by or furnished under this contract shall in no case exceed the price allocable to the product covered by or furnished under this contract nor exceed the price allocable to the product or part thereof which gives rise to the claim. In no event shall the Company be liable for special or consequential damages.

Security Title

Title and right of possession of the products sold hereunder shall remain with the Company and such products shall remain personal property until all payments hereunder (including deferred payments whether evidenced by notes or otherwise) shall have been made in full in each, and the Purchaser agrees to do all acts necessary to perfect and maintain such right and title in the Company.

Variations

Unless otherwise specified in writing, any variation in quantities shipped not exceeding 10% of the quantities ordered shall constitute compliance with the order and the unit price will continue to apply.

General

The Company will comply with all applicable Federal, State and local laws, and specifically represents that any goods to be delivered hereunder will be produced in compliance with the requirements of the Fair Labor Standards Act of 1938, as amended.

An extra charge will be made for special containers, but refund will be made if returned in good condition to the factory or other point designated by the Company within 90 days from date of original shipment, charges prepaid.

Any assignment of this order, or any rights hereunder, by the Purchaser without written consent of the Company shall be void.

The provisions of any contract resulting from this quotation are for the benefit of the parties thereto and not for any other person.

No waiver, alteration, or modification of any of the provisions hereof shall be binding unless in writing and signed by a duly authorized representative of the Company.

The product sold hereunder was not designed or manufactured for use in or with any atomic installation or activity. If so used, the Company disclaims all responsibility of every kind, including negligence, and in addition the Purchaser shall indemnify and hold the Company harmless for any liability or damage whatsoever arising out of the use of the product in such a manner.

Prices

The prices in this handbook agree with corrected list prices at the time of press, but are subject to a change without notice. All orders will be furnished at prices in effect at the time of shipment. A minimum charge of \$50.00 per order will be made.

Delivery Terms

All prices are F.O.B. Factory, Esco Products, Inc., Oak Ridge, New Jersey. Shipping carrier chosen at Esco Products' discretion unless specified on order.

Terms of Payment — USA

All invoices are due and payable not later than 30 days from date of invoice. Orders may be prepaid by either MASTERCARD or VISA credit cards.

Terms of Payment — Foreign

Orders must be pre-paid, F.O.B. Oak Ridge, New Jersey, either by wire transfer, check, MASTERCARD or VISA, U.S. funds only. Acceptable alternative would be Irrevocable Letter of Credit, drawn on U.S. bank. For banking information, please contact Esco. A maximum of \$50.00 processing charge will be added to each order. All other Conditions of Sale remain the same.

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- Low Expansion Materials
- Sapphire
- Color Filter Glass
- Commercial Plate Glass
- Other Materials upon request

ESCO Products, Inc.

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