

The Vocabulary Explanation of Optical Components

Abbe Number: The constant of an optical medium that describes the ratio of its refractivity to its dispersion.

(Specifically, $V_d = (n_d - 1)/(n_F - n_C)$, where n is the index of refraction at the Fraunhofer d, F, and C lines, respectively.

Aberration: An optical defect resulting from design or fabrication error that prevents the lens from achieving precise focus. The primary aberrations are spherical, coma, astigmatism, field curvature, distortion, and chromatic aberration.

Achromatic Lens: Lens in which chromatic aberration has been corrected at a minimum of two wavelengths.

Airy Disc: A pattern of illumination caused by diffraction at the edge of a circular aperture, consisting of a central core of light surrounded by concentric rings of gradually decreasing intensity.

Anamorphic: Distorted, as in an optical system with different magnification levels or with focal lengths perpendicular to the optical axis.

Angle of Incidence: The angle formed by a ray of light striking a surface and the normal to that surface.

Antireflection (AR) Coating: A thin layer of material that, when applied to a lens or window, increases its transmittance by reduction of its reflectance. AR coatings may be multilayer or single layer coatings.

Aperture: An opening through which light may pass. The clear aperture is that area in an optical system limiting the bundle of light able to pass through the system.

Aspheric: Not spherical. To reduce spherical aberration, a lens may be altered slightly so that one or more surfaces are Aspheric.

Astigmatism: An aberration in a lens in which the tangential and sagittal (horizontal and vertical) lines are focused at two different points along the optical axis.

Back Focal Length (BFL): The distance between the last surface of a lens to its image focal plane.

Bandpass: The range of wavelengths that passes through a filter or other optical component.

Bandwidth: Range of wavelengths that specified transmission or reflection occurs.

Beam Deviation: See Deviation.

Beamsplitter: An optical device that divides an incident beam into at least two distinct beams.

Bi-Concave: Having two outer surfaces that curve inward.

Bi-Convex: Having two outer surfaces that curve outward.

Birefringence: The change in refractive index with the polarization of light. A birefringent crystal, such as calcite or quartz, will divide an unpolarized beam into two beams (ordinary and extraordinary) having opposite polarization.

Blocking: Refers to filter transmittance outside the bandpass region. It is the rejection of out-of-band wavelengths by a filter.

Blur Circle: The image of a point-source object formed by an optical system on its focal surface. The precision level of the lens and its state of focus determine the size of the blur.

Borosilicate Glass: An optical glass containing boric oxide, along with silica and other ingredients. BK 7 and Pyrex® are examples of borosilicate glasses.

Brewster's Angle: For light incident on a plano boundary between two materials having different index of refraction; that angle of incidence at which the reflectance is zero for light that has its electrical field vector in the plane defined by the direction of propagation and the normal to the surface. For propagation from material 1 to material 2, Brewster's angle is given as $\tan^{-1}(n_2/n_1)$.

Broadband Coating: A multilayer coating with specified reflection or transmission over a broad spectral band. Newport's AR.14 is a broadband AR coating, while Newport BD.1 is broadband mirror coating.

Cavity: A periodic structure of thin films comprised of two quarter-wave stack reflectors separated by a dielectric spacer. Cavities are the building blocks of bandpass filters.

Center Wavelength: The center of the wavelength band of a coating.

Centration: The deviation between the optical axis and the mechanical axis of a lens. Centration is specified in terms of the deflection of a beam directed along the mechanical axis of the lens.

Chromatic Aberration: An optical defect in a lens resulting in different wavelengths of light focusing at different distances from the lens. Corrected by achromatic lenses.

Circle of Least Confusion: The smallest cross-section of a focused beam of light; the point of best focus for the image.

Clear Aperture: The area of an optical component that controls the amount of light incident on a given surface. In Newport lenses and mirrors, the clear aperture gives the diameter over which specifications are guaranteed.

Coefficient of Thermal Expansion: A material property defined as the fractional change in length per original length (or fractional change in volume) with a change in temperature.

Collimated Beam: A beam of light in which all of the rays are parallel to each other.

Coma: An aberration that occurs in a lens when rays emanating from points not on the optical axis do not converge, causing the image of a point to appear comet-shaped.

Cone Angle: The central angle of a cone of rays converging to or diverging from a point. See Numerical Aperture.

Conjugate Ratio: The ratio of the object distance to the image distance.

Continuous Wave Irradiation: Emission of radiant energy (light) in a continuous wave, rather than pulsed.

Contrast: The difference in light intensity in an object or image; defined as $(I_{\max} - I_{\min}) / (I_{\max} + I_{\min})$, where I_{\max} and I_{\min} are the maximum and minimum intensities.

Converging: The bending of light rays toward one another, achieved with a positive (convex) lens.

Critical Angle: Basically, the smallest angle of incidence at which total internal reflectance takes place. Maximum angle of incidence formed by a ray of light as it passes from a denser to a less dense medium. When the critical angle is exceeded, total internal reflection occurs, and all the incident light reflects back in to the more dense media.

Crown Glass: A silicate glass containing oxides of sodium and potassium, used in lenses and windows. Harder than flint glass, it has low index and low dispersion, such as BK 7.

Crystal Quartz: Crystalline form of silicon dioxide; used in wave plates.

Cut-Off Wavelength: For a filter, the wavelength where the transmission falls below 50%.

Cut-On Wavelength: For a filter, the wavelength where the transmission increases above 50%.

Cylindrical Lens: A lens with at least one surface shaped like a portion of a cylinder. A typical application is reducing the astigmatism of laser diodes.

Damage Threshold: The maximum energy density to which an optical surface may be subjected without failure.

Decentration: The failure of one or more lens surfaces to align their centers of curvature with the geometric axis of a lens system.

Density, Optical: A measure of the transmittance (T) through an optical medium; expressed as $D = -\log(T)$ or $T = 10^{-D}$.

Depth of Field: The distance along the optical axis through which an object can be located and clearly defined when the lens is in focus.

Depth of Focus: The distance along the optical axis through which an image can be clearly focused.

Deviation: The angle between the paths of a ray of light before and after passing through one or more optics.

Dielectric Coatings: High-reflectance or antireflective coatings made up of alternating layers of material with higher and lower indices of refraction than the substrate.

Diffraction: The sidewise or sideways spread of light as it passes the edge of an object or emerges from a small aperture; causes halos or blurring of the image.

Diffraction Limited: Describes an optical system in which the quality of the image is determined only by the effects of diffraction and not by lens aberrations.

Dispersion: The separation of a beam into its various wavelength components due to wavelength dependent speed of propagation in the material.

Distortion: Variations in magnification from the center to the edge of an image, making straight lines look curved. Barrel, or negative, distortion causes a square grid to appear barrel-shaped; pincushion, or positive, distortion increases in proportion to the distance from the center of the image.

Diverging: The bending of light rays away from each other, achieved with a negative (concave) lens.

Edging: Grinding, or finishing, the edge of an optical element or lens.

Effective (or Equivalent) Focal Length (EFL): The focal length of an infinitely thin lens having the same paraxial imaging properties as a thick lens or multiple-element lens system.

Entrance Pupil: The image of the aperture stop as viewed through the object side of the lens.

Erect Image: An image whose spatial orientation is the same as that of the object.

Extinction Ratio: The ratio of the intensities along the polarization axes of a plane-polarized beam that is (transmitted through a polarizer; expressed as T_p/T_s).

F-Number: A measure of the ability of a lens to gather light. Represented by $F/\#$ and also called its "speed". The ratio of the focal length of the lens to its effective aperture. Related to numerical aperture by $F/\#=1/(2NA)$.

Field Curvature: An aberration in which the edges of a field seem to be out of focus when the center is focused clearly.

Field of View: The maximum visible space seen through a lens or optical instrument.

Figure: See Surface Figure.

Flatness: See Surface Flatness.

Flint Glass: An optical glass with higher dispersion and higher refractive index than crown glass; a heavy, brilliant glass, softer than crown glass. For example, SF Series glasses are used in Newport achromatic lenses.

Focal Length (FL): See Effective Focal Length.

Front Focal Length (FFL): The distance from the objective plane of a lens to its first surface.

Fused Silica: Crystal quartz melted at a high temperature to make an amorphous, non-birefringent glass of low refractive index. Used in high-energy components and optical components designed for UV. It can be used down to 195 nm.

FWHM: Full Width Half Maximum. The bandwidth of an optical instrument as measured at the half-power points.

Gaussian Optics: Optical characteristics limited to infinitesimally small pencils of light; also called paraxial or first-order optics.

Geometric Optics: That branch of optics dealing with the tracing of ray paths through optical systems. Geometric optics ignores the nature of the electromagnetic modes of light.

High-Efficiency Coating: Specialized coating applied to optics to improve transmission or reflection.

Homogeneity: The state in which all volume components of a substance are identical in optical properties and composition.

Hybrid: Anything formed out of heterogenous elements.

Image Circle: The circular image field over which image quality is acceptable; can be defined in terms of its angular subtense. Alternately known as circle of coverage.

Image Inversion: Change in the orientation of an image in one meridian.

Image Plane: The plane perpendicular to the optical axis at the image point.

Image Transposition: The flipping of an image's orientation, such as inversion of an image's orientation in one axis or the reversion of an image's orientation in two axes.

Index of Refraction: The ratio of the speed of light in air to its velocity in another medium; determines how much light bends as it passes through a lens, e.g., high-index flint glass bends light more than low-index crown glass does.

Infrared: The long wavelength portion of the spectrum whose wavelengths are invisible to the human eye (the range is approximately 780 nm and longer wavelengths).

Interference Filter: A filter that controls the spectral composition of transmitted energy by interference. Such filters, typically constructed of thin alternating layers of metals and dielectrics, are also known as narrowband or broadband bandpass filters.

Interferometer: An instrument that uses the interference of light waves to measure small displacements or deformation.

Iris Diaphragm: A mechanical device for varying the effective diameter of an optical system.

Irregularity: Refers to figure deviations that are not spherical in nature. Using a test plate, irregularity is measured by counting the difference in the number of fringes in two orthogonal axes.

Knoop Hardness: A measure of hardness determined by the depth of penetration of a diamond stylus under a specified load. Similar to the Rockwell hardness test.

Lateral Color: A chromatic aberration resulting in image size variation as a function of wavelength. Also known as chromatic difference of magnification.

Limit of Resolution: The limit to the performance of a lens imposed by the diffraction pattern resulting from the finite aperture of the optical system.

Long Pass: Filter that efficiently passes radiation whose wavelengths are longer than a specific wavelength, but not shorter.

Longitudinal Color: The longitudinal variation of focus (or image position) with wavelength; often referred to as axial chromatic aberration.

Magnesium Fluoride: Material used as antireflection coating for lenses because of its low refractive index. Also used as an optical substrate material for UV and infrared applications.

Magnification: The enlargement of an object by an optical instrument; ratio of the size of the image to the actual size of the object.

Meniscus: Describes a lens having one convex and one concave surface.

Meridional Plane: The plane in an optical system containing its optical axis and the chief ray.

Metallic Coating: A thin layer of metal applied to a substrate by evaporation to create a mirrored surface.

Micro Optics: A term referring to small (less than 5 mm in size) lenses, beamsplitters, prisms, cylinders or other optical components commonly found in endoscopes or microscopes. Micro optics are also used to focus light in semiconductor laser and fiber optic applications.

Microscope Eyepiece: An eyepiece located at the near end of the microscope tube. Often a simple Huygen's eyepiece, though other varieties (negative eyepieces, flat field projection eyepieces) are common, depending on application.

Microscope Objective: The lens located at the object end of a microscope tube. Many types of objectives are used in microscopy; simple achromats and color-corrected apochromats are popular choices.

MIL-C-675: Specifies that a coating will not show degradation to the naked eye after 20 strokes with a rubber pumice eraser. Coatings meeting MIL-C-675 can be cleaned repeatedly and survive moderate to severe handling.

MIL-C-14806: Specifies durability of surfaces under environmental stress. Coatings are tested at high humidity, or in brine solutions to determine resistance to chemical attack. These coatings can survive in humid or vapor filled areas.

MIL-M-13508: Sets the durability standards for metallic coatings. Coatings will not peel away from the substrate when pulled with cellophane tape. Further, no damage visible to the naked eye will appear after 50 strokes with a dry cheesecloth pad. Gentle, nonabrasive cleaning is advised.

Modulation Transfer Function (MTF): A measure of the ability of an optical lens or system to transfer detail of the object to the image. Given as degree of contrast (or modulation depth) in the image as a function of spatial frequency.

Multi-Element System: An assembly of single and/or compound lenses optimized to provide certain optical characteristics.

Multilayer Coating: Coating composed of several layers of dielectric material with alternating high-low refractive indices; different designs produce a variety of coating components, such as mirrors, AR coatings and beamsplitters.

Narrowband Coating: A coating designed to provide transmittance (or reflectance) over a very restricted band of wavelengths.

Neutral Density: A coating or absorbing glass, which has a flat or nearly-flat absorption curve throughout a specified spectrum. Neutral density filters decrease the intensity of light without changing the relative spectral distribution of energy.

Newton's Rings: Used to measure the fit of a lens surface against the surface of a test glass. The rings result when two adjacent polished surfaces are placed together with an air space between them and the light beams they reflect interfere.

Nodal Points: The two points at which the nodal planes appear to intersect with the optical axis. When a ray is directed at the first nodal point in an optical system, it appears to emerge from a second nodal point on the optical axis with no deviation in its angle.

Numerical Aperture: Defines the maximum cone angle of light accepted or emitted by an optical system. Given by sine of the half-angle of the maximum cone. Related to f-number by $NA = 1/(2f/\#)$.

Object-to-Image Distance: Also known as the total conjugate distance or track length. Can be finite or infinite depending on the application.

Objective: The optical element that receives light from the object and forms the first or primary image in telescopes, microscopes, and other optical systems.

Oblique Ray: A ray of light that is neither perpendicular nor parallel, but inclined.

Optical Axis: A line passing through the centers of curvature of a lens or other optical components.

Optical Density: See Density, Optical.

Optical Flat: A piece of glass with one or both surfaces polished flat. Also known as a test plate, test glass or reference flat.

Optical Interference: The additive process, whereby the amplitudes of two or more overlapping light waves are systematically attenuated and reinforced.

Optical Path Difference: For a perfect optical system, the optical path or distance from an object point to a corresponding image point will be equal for all rays. In near-perfect systems, slight differences will exist between rays resulting in an optical path difference, usually expressed in fractions of the wavelength being analyzed.

Orthogonal: Mutually perpendicular. Out-of-Band Blocking; See Blocking.

Paraxial Image Plane: Image plane located by using first-order geometric optics. See Gaussian Optics.

Pinhole Aperture: A small, sharp-edged hole that functions as an aperture, for example, in a spatial filter.

Plane of Incidence: The plane that is defined by the incident and reflected rays.

Plano-Concave: A lens with one flat (plano) surface and one inward-curved (concave) surface.

Plano-Convex: A lens with one flat (plano) surface and the other outward-curved (convex) surface.

Plano Elements: Lenses or mirrors with flat surfaces.

Polarized, Circularly: Light whose electric field vector describes a circle as a function of time.

Polarized, Linearly: See Polarized, Plane.

Polarized, Plane: Light whose electric field vector vibrates in only one plane.

Polychromatic Aberrations: The separation of an image into planes of distinct color, caused by the variation of the index of refraction of glass, and the focal length of a lens, with the wavelength of light; in a given plane, all colors but one are unfocused.

Power: 1) Lens, See Magnification (magnification power). 2) Refers to figure deviations that are spherical in nature. Using a test plate, power is measured by counting the number of fringes in two orthogonal axes. Power comprises the majority of figure deviations in a lens. Sometimes called Spherical Error.

Primary Reflections: The principal, intended reflections at optical surfaces, as differentiated from secondary, usually unintended or unwanted reflections occurring in an optical system.

Principal Planes: In a thick lens or multiple-lens system, the plane at which the entering rays and exiting rays appear to intersect the position of the equivalent thick lens.

Pulse Modulation: The process of periodically or intermittently varying the amplitude of a pulse of light.

Q: The Q of a resonator is defined as: $(2\pi \times \text{average energy stored in the resonator})/(\text{energy dissipated per cycle})$

Q-Switched: In an optical resonator, the higher the reflectivity of its surfaces, the higher the Q. A Q-switch rapidly changes the Q in the optical resonator of a laser to prevent lasing until a high level of optical gain and energy storage has been reached in the lasing medium; a giant pulse is generated when the Q is rapidly decreased.

Quarter Wave Optical Thickness: Common thin-film term. The QWOT (Quarter Wave Optical Thickness) is the wavelength at which the optical thickness; defined as the index of refraction, n , multiplied by the physical thickness, d , of a coating evaporant layer; is one quarter wavelength, or $n \times d = \lambda/4$.

Radius of Curvature: One-half the diameter of a circle defining the convex or concave shape of a lens.

Real Image: Light rays reproduce an object, called an image, by gathering a beam of light diverging from an object point and transforming it into a beam converging toward another point. If the beam is converging, it produces a real image.

Reference Flat: An optical flat used as a test glass.

Refraction: The change in direction of a ray of light as it passes from one optical medium to another with a different optical density. See Snell's Law.

Refractive Index: The ratio between the speed of light through vacuum to the speed of light through the particular medium. The index determines how much a ray of light will bend as it passes from one given medium to another. See Snell's law.

Resolution: The ability of a lens to image the points, lines, and surfaces of an object so they are perceived as discrete entities.

Reticle: An optical element containing a pattern placed at the image plane of a system. The reticle facilitates system alignment or the measurement of target characteristics.

Reverted Image: An image in which left and right seem to be reversed.

Rockwell Hardness: Resistance of a substance to penetration by a pyramidal stylus pressed in under a specific load; also see Knoop hardness.

Sag: An abbreviation for "sagitta," the Latin word for "arrow," referring to the height of a curve measured from the chord,

Sagittal Focus: The focus of rays lying in the sagittal plane, which is the plane perpendicular to the meridional plane.

Scratch-Dig: A measure of the visibility of surface defects as defined by U.S. military standard MIL-O-13830. The ratings consist of two numbers, the first denoting the visibility of scratches, the second, of digs (small pits). A 0-0 scratch-dig number indicates a surface free of visible defects. Numbers increase as the visibility of blemishes increases. Scratch numbers are linear with a #10 scratch appearing identical to a 1.0 μm wide standard scratch on glass. Similarly, a #1 dig appears identical to a 0.01 mm diameter standard pit. No absolute measurement of defect size is made or implied by the scratch-dig standard.

Short Pass: Filter that efficiently passes radiation whose wavelengths are shorter than a specific wavelength, but not longer.

Slit: An aperture, typically rectangular in shape, whose length is large compared to its width.

Snell's Law of Refraction: Gives the ratio of bend angles as light passes from one medium to another; expressed as $n_1 \sin \theta_1 = n_2 \sin \theta_2$, where n is the index of refraction.

Spatial Filtering: Enhancing an image by increasing or decreasing its spatial frequencies.

Spectrophotometry: Measuring the reflection or transmission of light for each component wavelength in the spectrum of a specimen.

Spherical Error: See Power.

Spot Size: Minimum image size to which a lens may focus a collimated beam.

Striae: An imperfection in optical glass characterized by streaks of transparent material of a different refractive index than the body.

Substrate: The underlying material to which an optical coating is applied.

Surface Contour: The outline or profile of a surface.

Surface Figure: A measure of how closely the surface of an optical element matches a reference surface. Since geometrical errors will cause distortion of a transmitted or reflected wave, deviations from the ideal are measured in terms of wavelengths of light.

Surface Flatness: The amount by which an optical surface differs from a perfect plane. It is typically measured by an interferometric technique.

Surface Roughness: A measure of the texture of a surface on a microscopic scale. It is usually denoted as a root mean square (rms) value and measured in units of length, such as angstroms.

Surface Quality: See Scratch-Dig.

Total Internal Reflection (TIR): When the angle of incidence of light striking the boundary surface of a substance exceeds the critical angle, the result is total internal reflection.

Transmission: Amount of light that is passed through an optical component or system. Given as fraction or percentage of input light.

Truncation Ratio: The dimensionless ratio of the Gaussian beam diameter at the $1/e^2$ intensity point to the limiting aperture of the lens.

Ultraviolet: The short wavelength of the electromagnetic spectrum invisible to the human eye. The range is approximately 400 nm and shorter wavelengths.

V-Coating: A narrowband coating for specific laser wavelengths. This term is usually applied in reference to AR coatings.

Vignetting: The gradual reduction of image illuminance with an increasing off-axis angle, resulting from limitations of the clear apertures of elements within an optical system.

Virtual Image: Light rays that diverge from an object point can be captured by an optical system to form an image. Depending on the optical system, the light beam can either converge to another point or diverge from another point. In the case that the light converges, it will form a real image. In the case that the light diverges it will form a virtual image.

V-Value: See Abbe Number.

Wavefront Distortion: Departure of a wavefront from ideal (usually spherical or planar) caused by surface errors or design limitations.

Wavelength: The distance light travels in one cycle of its electromagnetic wave.

Wedge: An optical element with its faces inclined toward each other at very small angles, diverting light toward the thicker parts of the element.

Young's Modulus: Modulus of elasticity; the amount of stress required to produce a unit change in length (strain); expressed in pounds per square inch (PSI) or dynes per square cm.