

GLOSSARY OF OPTICAL TERMS

A

Abbe Value (V number). A number describing the dispersion of an optical material in the visible spectrum. It is the reciprocal of the relative dispersion.

$$V = \frac{N_D}{N_F - N_C}$$

where N_D is refractive index at 0.5893 micron, N_F is refractive index at 0.4861 micron, and N_C is refractive index at 0.6563 micron.

aberration. Any deviation from an ideal path of the image-forming rays passing through an optical system causes an imperfect image. Various types are spherical aberration, coma, curvature of field, astigmatism, longitudinal chromatic aberration, lateral chromatic aberration, and distortion.

aberration, chromatic. Image imperfection caused by light of different wavelengths following different paths through an optical system due to different degrees of dispersion of the optical materials of the system.

aberration, lateral chromatic. Variation in the size of images for light of different colors or wavelengths produced by an optical system. It is measured as the radial displacement of the image in the first color, from the image of the same point in the second color.

aberration, longitudinal chromatic. Distance between the foci for light of different colors measured along the optical axis.

aberration, spherical. Symmetrical optical defect of lenses and spherical mirrors in which light rays that come from a common axial point, but strike the lens at different distances from the optical axis, do not come to a common focus.

absorption, light. The conversion of light into other forms of energy upon traveling through a medium, thereby weakening the transmitted light beam. Energy reflectance R , transmittance T , and absorption A are related by $R + T + A = I$.

absorption, selective. Process by which a substance absorbs all the colors contained in a beam of White light, except those colors that it reflects or transmits. The color of a transparent object is the color it transmits, and the color of an opaque object is the color it reflects.

accommodations, limits of. Distances of the nearest and farthest points which can be focused clearly by the eyes of an observer. Usually varies from 4 to 5 in. to infinity.

achromatic. Having the quality of being free of chromatic aberration for two colors.

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acutance. Edge sharpness and high edge contrast in an image.

afocal. Optical system whose image point of a distant object is at infinity .

amplitude, light. Strength of the electric field of a light wave. Light intensity is proportional to the square of the amplitude.

anamorphic. Variation of magnification along mutually perpendicular radii, or an optical system that produces this condition.

anastigmat. Lens in which the astigmatism is eliminated for at least one off-axis zone in the image plane. Other aberrations are sufficiently well corrected for the intended use of this lens.

angle, critical. Angle of incidence in a denser medium, at the interface of the denser and less dense media, at which all of the light is refracted along the interface; that is, the angle of refraction is 90 deg. When the critical angle is exceeded, the light is totally reflected back into the denser medium. The critical angle varies with the indices of refraction of the two media according to the relationship, $\sin I_c = n'/n$ where I_c is the critical angle; n' , the index of refraction of the less dense medium; and n , the index of refraction of the denser medium.

angle of deviation. Angle through which a ray of light is refracted by a reflecting surface; the angle between the subtended path of an incident ray and the refracted ray.

angle of incidence. Angle between a beam striking a surface and the normal to that surface.

angle of reflection. Angle formed-between the normal to a surface and the reflected ray.

angle of refraction. Angle formed between a refracted ray and the normal to the surface.

Angstrom (A). Unit of measurement of-the wavelength of light, equal to 10^{-8} centimeters.

aperture. Opening equal to the diameter of the largest entering beam of light that can pass completely through an optical system. This may or may not be equal to the aperture of the objective.

aperture, angular. Angle between the most divergent rays that can pass through a lens to form an image.

aperture, clear. Opening in the mount of an optical system or any system component that limits the extent of the bundle of rays incident on the specific surface. It is usually circular and specified by its diameter. Also referred to as **free aperture**. or **objective aperture**.

aperture, effective. Equivalent to the diameter of the largest bundle of rays that can be imaged by an optical system.

aperture, numerical (NA). Sine of the half-angle of the widest bundle of rays capable of entering a lens, multiplied by the index of refraction of the medium containing that bundle of rays.

aperture, front operating. Limiting aperture at the front of a lens. Usually specified as the maximum diameter of the entrance cone at the front vertex for the specified field of view at infinite focus.

aperture, rear operating. Limiting opening at the rear of a lens or prism. Usually specified as the maximum diameter of the emergent cone for the specified field of view at infinite focus.

aperture, precision. Hole used as a masking device in an optical system. May be accurately produced holes in solid material, or opaque material deposited on a transparent substrate.

aperture, relative. Diameter of the entrance pupil of a lens or optical system measured in terms of the equivalent focal length of that lens or system. It is written as a fraction in which f , the equivalent focal length, is the numerator, and it is symbolized by the $f/$ followed by a numerical value. For example, $f/2$ signifies that the diameter of the entrance pupil is equal to one-half the equivalent focal length. For an object distance of infinity, the denominator of the relative aperture, and the second member N of aperture ratio, are identical, providing the image is formed in air. Relative aperture is applicable for determining exposure time only when the object is at infinity.

aperture stop. Mechanical aperture, which could be a lens, that restricts the diameter of the light bundle passing through an optical system.

aplanat. Lens that has been corrected for spherical aberration and coma. It is usually also color-corrected.

apochromat. Aplanatic lens in which the secondary spectrum has been reduced, or in which three colors have been brought to a common focus, by the use of special optical materials.

apostilb. Unit of luminance equal to $1/\pi$ candles per square meter.

aspheric. Nonspherical. Aspheric surfaces are frequently, but not necessarily, surfaces of revolution.

astigmatism. Aberration causes an off-axis point to be imaged as a pair of lines at right angles to each other. Each line is at a different distance from the image-forming element along the chief ray of the image-forming bundle of rays. The image-forming element thus has two foci, one radial and the other tangential to the optical axis. A sharp image of a point cannot be obtained. A compromise image posi-

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tion must be selected at a point between the two line images at which the image blur is smallest (circle of least confusion). Lenses, lens systems, mirrors, or mirror systems, or combinations of the two, whose curves are not symmetrical about the axis can produce axial astigmatism. Off-axis astigmatism results naturally with centered spherical surfaces. Axial astigmatism, unless deliberately introduced, is to be considered a defect of workmanship, and not an aberration: In lenses, astigmatism arises from oblique refraction; whereas in the human eye it arises from a departure of a surface from a truly spherical form.

axis, optical. Line formed by the coinciding principal axes of a series of optical elements comprising an optical system. It is the line passing through the centers of curvatures of the optical surfaces; the optical centerline.

axis, visual. Imaginary line from the object through the nodal point of the eye to the fovea, or point of sharpest retinal acuity.

B

back focus. Distance from the last surface of a lens to the image.

barrel, lens. Mechanical structure holding a complete lens.

beam. Shaft or column of light; a bundle of rays. It may consist of parallel, converging, or diverging rays.

beamsplitter. Optical device that divides a light beam into two separate beams. A simple beamsplitter is a plane-parallel plate, with one surface coated with a dielectric or metallic coating that reflects a portion and transmits a portion of the incident beam; that is, part of the light is deviated through an angle of 90° and part is unchanged in direction. The thickness of the metallic beamsplitting interface determines the proportions of the light reflected and transmitted. However, in all metallic beamsplitters, an appreciable amount of light is lost by absorption in the metal. It may be necessary to match the reflected and transmitted beam not only for brightness, but for color. In these cases it is necessary to use a material at the interface which gives the same color of light, both by transmission and reflection. Where color matching at the surface or interface cannot be accomplished, a correcting color filter may be placed in one of the beams.

beamwidth, angular. Vertex angle of a conical light beam.

bench, optical. Solid bed equipped with various sliding holders for lenses, lamps, apertures, eyepieces, etc., that permits individual longitudinal movement of the optical components. Scales are often provided for measuring interelement distances.

birefringence. Characteristic of having two indices of refraction with different values; causing the separation of a light beam into two diverging beams. Birefringence is dependent on the angle between the ray path within the medium and the optical axis (or axes) of the medium.

blackbody. Object that absorbs all the radiant energy that strikes it; a perfect radiator and a perfect absorber. It is a contraction of the term *ideal blackbody* and is often used synonymously for *ideal radiator*, *full radiator*, or *complete radiator*.

blacking, optical. Light-absorbing material applied to the surfaces of optical elements. Such material should have an index of refraction as high as that of the underlying material and must be in direct contact with it.

Brewster, law of. When the angle between a refracted and reflected ray is 90 degrees, maximum polarization occurs in both rays. The reflected ray has its maximum polarization in a direction normal to the plane of incidence, and the refracted ray has its maximum polarization in the plane of incidence.

bundle, ray. Concentrated assembly of light rays.

C

Centex. Trade name for lenses having standard (noncorrected) base curves.

centration, errors of. Lenses with spherical surfaces are usually designed to be used with the center of curvature of all the surfaces on a single straight line termed the axis of the lens. If aspheric surfaces are used, their individual axis should correspond with the axis of the lens. Failure to comply with these conditions is termed errors of centration.

chart, Foucault. Test target containing groups of alternate black and white bars spaced at various intervals, which is used to measure the resolving power of telescopes and lenses. This chart is placed at a distance from the site of observation such that the angular separations between the centers of adjacent black bars in the various groups have precalculated values. The most closely spaced group whose bars, as imaged by an optical instrument, can be resolved determines the resolving power of that instrument.

chart, resolving-power. Test target containing groups of black lines separated by white spaces, or converging wedged lines and spaces. Resolution is expressed as line pairs per millimeter resolved in the image.

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coat, hard. Usually a dielectric coating that is more durable under adverse conditions than those produced from other processes.

coating, antireflection. Single or multilayer coating applied to a surface or surfaces of a substrate for decreasing the reflectance of the surface and increasing transmission over a specified wavelength range.

coating, antistatic. Electrically conductive coating for carrying off static charges on a surface.

coating, high-reflecting. Single or multilayer coatings applied to a surface for increasing its reflectance over a specified range of wavelengths. Single films of aluminum or silver are common; but multi-layers of at least two dielectrics are used when low absorption is required.

coating, multilayer. Film comprised of several layers of materials. It is possible to produce a wide variety of properties by depositing layers of materials having alternately high and low refractive indices. They can be high-pass, low-pass, band-pass, or neutral-density filters, depending on the arrangement of the layers.

coatings, protective. Films applied to a coated or uncoated optical surface primarily for protection from mechanical abrasion or chemical corrosion, or both. An important class of protective coatings consists of evaporated thin films of titanium dioxide, silicon monoxide, or magnesium fluoride. For example, a thin layer of silicon monoxide may be added to protect an aluminized surface.

coat, soft. Coating for optical surfaces that is less durable than a hard coat. Certain evaporated coatings cannot form a hard coat and are easily removed by cleaning. Cryolite is a soft-coat material.

collector. Any optical element used to gather or converge light rays.

collimation. Process of aligning the optical axis of optical systems to the reference mechanical axes or surfaces of an instrument; or the adjustment of two or more optical axes with respect to each other. The process of making light rays parallel.

collimator. Optical device that renders diverging or converging rays parallel. It may be used to simulate a distance target, or to align the optical axes of instruments.

color. Sensation produced in an observer by light of different wave-lengths throughout the visible spectrum. Light constituting color may be defined by its luminance, dominant wavelength, and purity. White, black, and grays are called achromatic colors.

coma. Lens aberration that causes oblique pencils of light rays from an object point to be imaged as a comet-shaped blur.

concave. Term denoting a hollow curved surface.

condenser, Abbe. Two-lens, substage condenser combination originally designed by Ernest Abbe. It lacks chromatic correction, although it was designed for minimum spherical aberration, and has a very low-angle aplanatic cone. It can have a numerical aperture as high as 1.3.

condenser, variable-focus. Abbe condenser with a stabilized and movable upper lens element. The lower lens may focus the illumination between the elements so that it emerges from the fixed lens as a large-diameter parallel bundle. The condenser can be adjusted to have a numerical aperture up to 1.3.

confusion, circle of least. Circle whose perimeter defines the area, for any point in the field of view, covered by the smallest image (usually of a point source formed by the lens.)

conjugate, image. Synonym for *distance, image*.

conjugate, object. Synonym for *distance, object*.

constant, Abbe. Ratio of the refractivity of a material to its dispersion. The higher the ratio, the greater the ability to separate light into its component wavelengths. Also called *Nu* or *Vee value*.

contact, optical. Condition in which two clean and close-fitting surfaces adhere together without reflection at the interface. The optically contacted surface is practically as strong as the body of the elements.

convergence. Bending of light rays toward each other, as by a convex or plus lens.

convergence, angle of. Angle formed by the lines of sight of both eyes in focusing on an object. Also called *convergent angle*.

convex. Spherically shaped, curving outward.

cord. Large stria.

corner reflector (corner-cube prism). Usually, a prism with three mutually perpendicular surfaces and a hypotenuse face. Light entering through the hypotenuse is totally internally reflected by each of the three surfaces and emerges through the hypotenuse face parallel to the entering beam. Thus, the prism returns an entering beam to its source.

cor-recton, color. Reduction of longitudinal, lateral, and secondary chromatic aberrations. The color correction may be specified in terms of the Fraunhofer lines in the solar spectrum, indicative of the wave-length of rays for which the correction has been made; for example, C-F correction.

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curvature. Amount of departure from a flat surface, as applied to lenses. The reciprocal of the radius of curvature.

cutoff. In the case of sharp cutoff filters, the wavelength at which the transmittance has fallen to 37%.

D

definition, test-object. Printed or photographic charts consisting of 3-bar resolution test objects, sine-wave test objects for MTF measuring, or the like.

depth of field. Distance range within which a satisfactory definition of objects can be obtained by a lens focused at a point within the range.

depth of focus. Range of image distances produced by the range of object distances covered by the depth of field.

deviation, angle of. Angle through which a ray of light is bent by reflection or refraction.

deviation, constant. Property of certain optical devices, such as a penta prism, that preserves the angular relationship between the entering and emerging rays passing through the device, regardless of the orientation of the device in the plane of deviation.

dialyte. Compound lens in which the inner surfaces of the two elements have different curvatures to correct for aberrations. The dissimilar faces cannot be cemented together.

diaphragm. Fixed or adjustable aperture in an optical system. Diaphragms are used to intercept scattered light, limit field angles, or limit image-forming bundles of rays.

diaphragm, iris. Diaphragm whose circular aperture is smoothly and continuously adjustable, from its minimum to its maximum opening. Because it is composed of a number of overlapping leaves, the name is derived from this iris-like appearance.

diffraction. Modification of the propagation of radiant waves or light waves as they interact with an object or obstacle. Some of the rays are deviated from their path by diffraction at the object; other rays remain undeviated by diffraction at the object. As the object becomes small in comparison with the wavelength, the concepts of reflection and refraction becomes less meaningful, and diffraction plays the dominant role in determining the redistribution of the rays following incidence upon the object.

defraction limited. The quality of the image of an optical system is limited only by the diffraction of the light passing through the aperture of

the system. This is perfect lens performance. All aberrations have been corrected.

diffusion. Scattering of light by reflection or transmission. Diffuse reflection results when light strikes an irregular surface such as a frosted window. When light is diffused, no definite image is formed.

dig. Short scratch whose width can be measured.

diopter. Unit of refractive power of a lens or prism. In a lens or lens system, it is numerically equal to the reciprocal of the focal length measured in meters. For example, if a lens has a focal length of 25 cm, or 1/4, its power is 4 diopters.

diopter, prism. Unit of measure of the refracting power of a prism. One diopter is the power of a prism that deviates a ray of light by 1 cm at a distance of 1m from the prism.

dispersion, light. Process by which rays of light of different wavelengths are deviated angularly by different amounts as, for example, with prisms and diffraction gratings. The term dispersion is also applied to other phenomena that cause the index of refraction and other optical properties of a medium to vary with wavelength.

distance, flange-focal. Distance from the locating surface of the lens mount to the principal focus in the image space.

distance, front-vertex focal. Distance from the principal focus in the back space to the vertex of the front surface.

distance, image. Distance from last vertex of lens to the image.

distance, interpupillary. Distance between the two eye pupils when the observer is viewing distance objects.

distance, object. Distance from the object to the observer's cornea, or to the first lens vertex of the objective in an optical system.

distance, optical. Length of the path covered by a ray between two points in a medium, multiplied by the value of the index of refraction of that medium.

distance, overall. Distance from the object point to the image point.

distortion, barrel. Form of distortion in which the center of the field of view is magnified more than the edges.

distortion, pincushion. Form of distortion in which the edges of the field of view are magnified more than the center.

distortion, radial. Change in magnification from the center of the field to any other point in the field, measured in a radial direction to the center of the field.

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distortion, tangential. Image defect resulting-in the displacement of image points perpendicular to a radius from the center of the field. It is usually caused by errors of centration.

divergence. Bending of rays away from each other, as by a concave or minus lens, or by a convex mirror.

doublet. Compound lens consisting of two elements. If there is an air space between the elements it is called an *air-spaced doublet*. If the inner surfaces are cemented together, it is called a *cemented doublet*.

element, optical. Optical part constructed of a single piece of optical material; usually single lenses, prisms, or mirrors.

emergence. Trigonometric relationship between the emergent ray and the surface of the medium.

error, surface. Departure of an optical surface from its specified tolerance or figure.

eyelens. Lens of an eyepiece that is nearest to the observer's eye.

eyepiece. Optical system used to form an enlarged virtual image of the image formed by the objective, and to direct the light into the eye of the observer. The optical system of an eyepiece usually consists of two lenses, an eyelens and a collective or field lens, but may consist of only one lens or of more than two lenses. Erfle, Ramsden, Huygenian, Kellner, Pliissl, and Bertele are various types of eyepieces.

eyepiece, compensating. Eyepiece ,designed for use with apochromatic objectives, which have uncorrected lateral color.

eyepieces, parfocal. Eyepieces with common focal planes. They can be interchanged without refocusing.

eye relief. Distance from the vertex of the last optical surface of a visual optical system to the exit pupil.

F

***f*-number.** Ratio of the equivalent focal length of an objective to the diameter of its entrance pupil.

fan. Set of light rays originating at a common point and contained in one plane.

fiber optics. Transmission of light through a long flexible fiber of transparent material by a series of internal reflections. Fiber bundles can transmit an entire image wherein each fiber transmits one component

of the image. The image may be magnified by a cross-section increase toward the emergent end of the bundle, distorted by a random fiber arrangement, or curve-surfaced by forming the bundle ends into concave or convex surfaces.

field, apparent. Size of the field of view in the image space of an optical instrument, as differentiated from that in the object space.

field, curvature of. Lens aberration that causes the image of a plane to be focused into a curved surface instead of a plane.

field, linear. Actual width of the field of view at any distance.

field of view. Angle of view that can be seen through an optical system.

field, true. Size of the field of view in the object space of an optical instrument as distinguished from the size of the field of view in the image space. More specifically, it is the maximum cone or fan of rays subtended at the entrance pupil that is transmitted by the instrument to form the usable image.

filter. Device with the desired characteristics of selective transmittance and optical homogeneity, used to modify the spectral composition of radiant flux. It is usually a special glass, gelatin, or plastic optical part with plane-parallel surfaces that are placed in the light path of an optical system to selectively absorb certain wavelengths of light, reduce glare, or reduce light intensity. Colored, ultraviolet, neutral-density, and polarizing filters are in common use.

filter, wedge. Filter whose density increases from one end to the other, or angularly around a circular disc.

flare. Nonimage-forming light transmitted through the lens to the image. It is usually caused by reflections from the lens surfaces, lens barrel, or reflecting surfaces within the barrel, shutter, or lens mount. Flare may be concentrated or diffused.

flat, optical. Optical element with one or both surfaces flat to about one-tenth of a wavelength.

flux. Contraction of *radiant flux* or *luminous flux*.

focus. Synonym for *point, focal*. The term also means the process of adjusting an eyepiece or objective of a telescope, so that the image is clearly seen by the observer; or, the adjustment of the lens, plate, or film holder of a camera so that a sharp, distinct image is registered; or, with respect to a microscope specimen, to obtain the sharpest possible image.

focus, fixed. Descriptive of devices that do not have a means of focusing.

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focus, point of principal. Point to which incident parallel rays of light converge, or from which they diverge when they have been acted upon by a lens or mirror. A lens has a single point of principal focus on each side of the lens. A mirror has but one principal focus. A lens or mirror has an infinite number of image points, real or virtual, one for each position of the object.

fog. The foggy appearance of an incompletely polished surface that scatters light. The term also means the accumulation of moisture on an optical surface.

frequency. Number of wave cycles that pass a fixed point in a given unit of time. Frequency is commonly expressed with wavelengths.

frequency, spatial. Frequency of sine-wave objects; the reciprocal of the distance between maxima of the object, usually expressed in cycles per millimeter.

fringe. Interference band, such as Newton's ring.

G

geometric center. Physical center of a lens as determined by measurement.

glass. Noncrystalline inorganic mixture of various metallic oxides fused by heating with glassifiers such as silica, or boric or phosphoric oxides. Most glasses are transparent in the visible spectrum and up to about 2.5 μ m, in the infrared, but some are opaque, such as natural obsidian. Optical glass differs from common glass in its very precise formulation with pure chemicals, and in its carefully controlled refractive properties. Tempered glass has a high degree of internal strain caused by rapid cooling which gives it increased mechanical strength.

glass, crown. Type of optical glass of the alkali-lime-silica type. It usually has an index of refraction in the 1.5 to 1.6 range and an Abbe constant in the 64 to 57 range.

glass, flint. Type of optical glass to which lead, or other elements are added to produce generally a higher index of refraction (1.6 to 1.9) and a low Abbe constant (29 to 51).

H

haze. Form of fog in a polished surface caused by light scattering. The defects causing haze are larger than those causing fog, but are not large enough to be seen individually by the unaided eye.

I

image. Representation of an object produced by light rays. An image-forming optical element forms an image by collecting a bundle of light rays diverging from an object point and transforming it into a bundle of rays that converge toward, or diverge from, another point. If the rays converge to a point, a real image of the object point is formed; if the rays diverge, they appear to originate from a virtual image.

image, aspect of. Orientation of an image, such as normal, canted, inverted, or reverted.

image, brightness of. Apparent brightness of an image seen through an optical system. This brightness depends on the brightness of the object, the transmission, magnification, distortion, and diameter of the exit pupil of the instrument.

image, double. Doubling of an image caused by optical imperfections in a lens system.

image, erect. Real or virtual image that has the same spatial orientation as the object. The image obtained at the retina with the assistance of an optical system is erect when the orientation of the image is the same as obtained by the unaided eye.

image, ghost. Spurious multiple images of objects seen in optical instruments, caused by the reflections from optical surfaces. By coating the optical surfaces with low-reflection films, images are greatly reduced.

image, inverted. Inversion of a real image, as compared to the object, when formed by a single lens or mirror.

image, real (see *image*). Image formed by an optical element that can be projected on a screen or on photographic film.

image, reflection. Image formed by a reflecting surface. An unwanted reflection image is more properly termed a ghost image.

image, reverted. An image, the right side of which appears to be the left side, and vice versa.

image, virtual. Image requiring an additional optical system for its detection.

incidence, angle of. Angle between the normal to a reflecting or refracting surface and the incident ray.

index, absolute refractive. Refractive index of a medium relative to that of vacuum. Refractive index and absolute refractive index are numerically identical.

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infinity. In optics, a distance sufficiently great so that light rays emitted from a body at the distance are practically parallel. Infinity is indicated by the symbol ∞ .

infrared. Electromagnetic radiation beyond the red end of the visible spectrum, with wavelengths ranging from 768μ to the region of 30 to 40μ . Heat is radiated in the infrared region.

intensity. Strength of light or other radiated or reflected electromagnetic energy per steradian.

inverted. Turned over; upside-down. Usually refers to the effect of a prism or lens upon the image. Inversion is the effect of turning upside-down.

L

length, focal. Distance between the second principal plane of an optical system and the image of small, infinitely distant light source.

length, back focal (BFL). Distance from the vertex of the back surface of the lens to the rear focal point.

length, equivalent focal (EFL). Distance from a principal point to its corresponding principal focal point; the focal length of the equivalent thin lens. The size of the image of an object is directly proportional to the equivalent focal length of the lens forming it.

length, front focal (FFL). Distance from the principal focus located in the front space, to the first principal point.

lens. Transparent optical element with two opposite major surfaces of which at least one is convex or concave in shape and usually spherical. The major surfaces are shaped so that they change the degree of convergence or divergence of the transmitted rays.

lens, Bertrand. Small convergent lens between an objective and an eye-piece that focuses an image of the upper focal plane of the objective onto the focal plane of the eyepiece. It is used with polarized light to examine the interference figure, and also to verify centering, size, and uniform illumination of an aperture.

lens, bitoric. Lens with both surfaces shaped in a toric or cylindrical form.

lens, Cartesian. Lens, one surface of which is a cartesian oval, that produces an aplanatic condition.

lens, compound. Lens composed of two or more separate pieces of optical material which may or may not be cemented together. A common form of a compound lens is a two-element objective, one element

being a converging lens and the other a diverging lens. The combination of suitable, optical materials reduces aberrations normally present in a single lens.

lens, concentric. Usually a single-element optical component in which the centers of curvature of the surface coincide. Concentric lenses thus have a constant radial thickness in all zones.

lens, condensing. Lens or lens system of positive power used for condensing radiant energy from a source onto the pupil of a lens.

lens, conical. Lens with a surface that is conical instead of spherical that is often used as an axicon. Sometimes the surface is a portion of a side of a cone, resembling a cylinder with progressively increasing curvature from one side to the other.

lens, converging. Also known as a *convergent, positive, convex,* and *collective lens*. A lens that converges an incident bundle of rays. One surface of a converging lens may be convexly spherical and the other plane (plano-convex), both may be convex (double-convex, bi-convex) or one surface may be convex and the other concave (converging meniscus).

lens, cylindrical . Lens with a cylindrical surface. By combining cylindrical and spherical surfaces, an optical system can give a certain magnification in a given azimuth of the image and a different magnification at right angles in the same image plane. Such a system is called ***anamorphic*** .

lens, field. Positive lens that collects the chief rays (field rays) of image-forming bundles and passes them through the exit pupil of the system. A field lens is usually located at or near the focal point of the objective lens. The field lens increases the size of the field that can be viewed with any given eyepiece diameter.

lens, Fresnel. Flat lens with concentric rings cut or molded into one face. They are often used as field lenses.

lens, meridian of. Any line drawn on a lens from edge to edge that is perpendicular to the optical axis.

lens mount. Any structure that supports a lens or maintains the optical components of a system in proper relationship with each other.

lens, pancratic. Synonym for ***lens, zoom***.

lens, piano. Lens having no curved surface, or having two curved surfaces that neutralize each other so that it possesses no refracting power.

lens, plastic. Lens molded or fabricated from a transparent thermoplastic or thermosetting plastic material.

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lens, telephoto. Objective-lens system consisting of a positive and a negative component separated from each other, having such powers and separation that the front vertex length of the entire system is small in comparison with the equivalent focal length. Such lenses produce large images of distant objects without the necessity of a system with long length.

lens, thick. Lens whose axial thickness is so large that the principal points and the optical center cannot be considered as coinciding at a single point on the axis.

lens, thin. Lens whose axial thickness is sufficiently small that the principal points, the optical center, and the vertices of the two surfaces can be considered as coinciding at the same axial point.

lens, toric. Lens with a toric surface on one face. A toric optical surface has a maximum power in one meridian, and a minimum power in a perpendicular meridian.

lens, zoom. Optical system with movable components that change the focal length while maintaining a fixed image position. Thus, the image size can be varied while leaving the optical system in a fixed position. Sometimes called a *pancratic lens*.

light, polarized. *Plane polarized* light is a light beam whose electric vectors vibrate in a single plane containing the line of propagation. If each electric vector can be broken into two perpendicular components that have equal amplitudes and that differ in phase by $1/4$ wavelength, the light is said to be *circularly polarized*. Circular polarization is obtained whenever the phase differences between the two perpendicular components is any odd, integral number of quarter wavelengths. If the electric vectors are resolvable into two perpendicular components of unlike amplitudes and differing in phase by values other than $1, 1/4, 1/2, 3/4, 1, \text{etc.}$, wavelengths, the light beam is *elliptically polarized*.

light ray. Normals to light waves that indicate the direction of light travel, usually indicated as lines and arrows.

light, velocity of. Speed of monochromatic light waves, or the phase velocity. The velocity of light in vacuum is 299, 792.5 km/set, or 186,000 mi/sec.

light, white. Radiation having a spectral energy distribution that produces the same color sensation to the average human eye as average noon sunlight.

M

magnification. Lateral magnification is the ratio of the linear size of the image to that of the object. Angular magnification is the ratio of the

apparent size of the image seen through an optical system to that of the object viewed by the unaided eye. Angular magnification is often used as a synonym for *magnifying power*.

magnification, empty. Magnification that does not produce any new detail in the object; excess magnification.

magnifier. Lens or lens system that forms a magnified virtual image of an object placed near its front focal point. Magnifiers are also referred to as *loupes*, *simple microscopes*, or *magnifying glasses*. The magnifications of magnifiers range from approximately 3x to 20x .

magnifier, binocular. Pair of decentered lenses, one for each eye, that focus on a single object as a magnifier.

magnifier, biocular. Single magnifier (lens system) used with both eyes simultaneously.

magnifier, illuminated. Magnifying-lens assembly with a lamp for illuminating the viewed object.

meniscus. Lens having one convex surface and the other concave.

meniscus, converging. Converging lens with one convex surface and one concave.

micron ($m\mu$). Unit of length in the metric system equal to 0.001 mm.

millidiopters. Unit of metric measure equal to 0.001 diopters. The power of a lens in millidiopters is the reciprocal of its focal length in kilometers.

millimicron ($m\mu$). Unit of length in the metric system equal to 0.001 μ . It is also equivalent to 10 Angstroms.

mirror. Smooth plane or curved surface for reflecting light. Usually a thin coating of silver or aluminum on the substrate constitutes the actual reflecting surface. When this surface is applied to the front face of the substrate, the mirror is termed *front-surface mirror*.

mirror, aspheric. Mirror with ellipsoidal, parabolic, or other curvature for use in reflecting systems where radiation not transmitted by refractive materials is required.

mirror, Mangin. Negative meniscus lens whose second or convex surface is silvered. By carefully choosing the radii, spherical aberration can be corrected.

mirror, paraboloidal. Concave mirror that has the form of a paraboloid of revolution. The paraboloidal mirror may consist of only a portion of a paraboloidal surface through which the axis does not pass, and is known as an *off-axis paraboloidal mirror*. All axial parallel light rays are focused at the focal point of the paraboloid without spherical

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aberration, and conversely, all light rays emanating from an axial source at the focal point are reflected as a bundle of parallel rays without spherical aberration. Paraboloidal mirrors are free from chromatic aberration.

mirror, pellicle. Thin plastic membrane cemented to a rigid supporting ring. It may be lightly metallized to act as a beam-splitter, and is so thin that no image doubling is perceptible.

mirror, spherical. Concave or convex mirror with a spherical surface. They are less expensive than aspheric forms and perform equally well in nonimaging systems.

mirror, front-surface. Optical mirror on which the reflecting surface is applied to the front surface (first surface of incidence) of the mirror instead of to the back.

mirror, triple. Three mutually perpendicular reflecting surfaces arranged like the inside corner of a cube. The triple mirror may be constructed of solid transparent material in which the transmitting face is normal to the diagonal of the cube; or it may consist of the three plane mirrors supported in a precisely constructed framework. The triple reflector has a constant deviation of 180 deg. for all angles of incidence, so that a ray of light incident from any angle is reflected back parallel to itself. Such systems are also known as corner-cube reflectors, or *retrodirective reflectors*.

modulation. variation of illuminance across the image of a sine-wave object.

modulation transfer function (MTF). A merit function characterizing optical system in terms of image contrast at various frequencies. Specifically, the MTF quantifies the ability of an optical system to transfer the contrast of an object to the image formed by the system.

monochromatic. Composed of one color.

monocular. Pertaining to one eye.

mounting, eccentric. Lens mounting consisting of eccentric rings that may be rotated to shift the axis of the lens to a prescribed position.

movement, diopter. Adjustment of the eyepiece of an instrument to accommodate eyesight variations of individual observers. The axial distance through which the eyepiece must be moved to provide a convergence of the rays emerging from the eyepiece of one (1) diopter is calculated from the focal length of the eyepiece. If d is the required distance, it can be expressed: 1 diopter % d (in inches).

multifocal. Lens with two or more foci.

N

N, n. Symbol for index of refraction. It is usually used with a subscript to indicate the wavelength of light, e.g., N_D or n_D indicates the index of refraction for sodium light of an 5,893 Å wavelength.

nanometer. Measurement of wavelength equal to 10^{-9} m.

O

object. Figure viewed through or imaged by an optical system. It may consist of natural or artificial structures or targets, or may be the real or virtual image of an object formed by another optical system. In optics, an object should be thought of as an aggregation of points.

object, sine-wave. Object having a sinusoidal variation of luminance. Its image will have a sinusoidal variation of illuminance, and the only effect of degeneration by the lens system will be to decrease the modulation phase in the image relative to that in the object.

objective. Optical component that receives light from the object and forms the first or primary image in telescopes and microscopes. In cameras, the image formed by the objective is the final image. In telescopes and microscopes, the image formed by the objective is magnified by use of an eyepiece for visual study.

objective, Maksutov. Objective consisting of a spherical reflector, or reflectors, and a weak meniscus having strongly curved spherical surfaces to correct the spherical aberration of the reflector(s) without introducing significant longitudinal chromatic aberration. The corrector lens may also correct coma and reduce curvature of the field.

objective, reflecting. Image-forming mirrors, usually parabolic, that are used in place of lenses in telescopes and other instruments.

occluder. Device that controls the amount of light reaching the eye.

ocular. Lens through which any object is viewed. It is usually the lens or lens system in the end of an optical device through which the eye sees the image.

optical transfer function. Function describing modulation and spatial phase shift of the image of a sinusoidal object, with frequency as the independent variable.

optics. Branch of physical science concerned with the nature and properties of electromagnetic radiation and with the phenomena of vision.

optics, geometrical. Branch of science that treats light propagation in terms of rays that follow mathematically defined paths through optical media. It ignores diffraction.

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optics, physical. Branch of science that treats light as a wave phenomenon wherein light propagation is studied by means of wavefronts rather than rays as in geometrical optics.

P

path, optical. Sum of the optical distances along a specified ray.

peel, orange. Unevened or dimpled appearance of a lens surface that has been improperly formed; a surface showing a granular appearance under magnification.

phase shift, spatial. Displacement of the image of a sine-wave object from its ideal position. It is usually measured in degrees, with 360 deg. assigned, to a full cycle of the image.

photoelastic. Exhibiting birefringence upon the application of stress.

photometric. Pertaining to visible light measurement.

photometry. Science of measurement and analysis of visible radiant energy.

pipe, light. Transparent cylindrical or conical channel through which light is conducted by means of internal reflections.

pit. Small hole in an optical surface which can be seen as a small black particle by reflected light.

plane, image. Plane in which the image lies, or is formed. It is perpendicular to the axis of the lens. A real image formed by a converging lens would be visible upon a screen placed in this plane.

plane, object. Plane containing the object points lying within the field of view.

plate, corrector. Optical element computed to correct each zone of a reflector or refractor for spherical aberration.

plate, Schmidt. Aspheric plate placed at or near the center of curvature of a spherical reflector to correct spherical aberration.

point, focal. Point at which a bundle of rays form a sharp image of an object; alternatively, the point at which the object must be placed for a sharp image. The term is also used as a synonym for *focus*, *point of principal*.

point, first principal. Principal point relative to the object space.

point, second principal. Principal point relative to image space.

points, cardinal. In a thick lens or system of lenses, the two principal points, two nodal points, and two focal points. If the optical medium

is the same in the object and image spaces, the principal points and the modal points are coincident.

points, conjugate. Pair of points on the principal axis of a mirror or lens so located that light emitted from either point will be focused at the other. Related points in the object and image are located optically so that one is the image of the other.

points, nodal. Of all the rays passing through a lens from an off-axis object point to its corresponding image point, there is always one ray whose object-space and image-space segments are parallel. The nodal points are the intersections of the projections of these two segments with the optical axis.

points, principal. Points of intersection of the principal planes and the optical axis (see *points, cardinal*).

polarization, elliptical. See *light, polarized*.

polarizer, sheet. Sheet of plastic material containing microscopic crystals of herapathite or a similar substance that transmits light polarized in one direction, but absorbs light polarized in a perpendicular direction.

power. Measure of the ability to bend or refract light in a mirror or lens. It is usually measured in diopters. In a telescope, it is the number of times the instrument magnifies the object viewed. For example, if with a six-power instrument an object 600 yds. away is enlarged six times, it appears as it would to the naked eye if it were at a distance of only 100 yds .

power, magnifying. Synonymous with magnification; measure of the ability of an optical device to make an object appear larger than it appears to the unaided eye. For example, if an optical element or system has a magnification of 2-power ($2\times$), the object will appear twice as wide and high. The magnification of an optical instrument is equal to the diameter of the entrance pupil divided by the diameter of the exit pupil. For a telescopic system, the magnification is also equal to the focal length of the eyepiece. Another expression for the magnification of an instrument is the tangent of an angle in the apparent field divided by the tangent of the corresponding angle in the true field.

power, prism. Apparent displacement, in centimeters, of an object located 1 m distant from the prism; expressed in prism diopters.

power, resolving. Measure of the ability of a lens or optical system to form separate and distinct images of two closely spaced objects. Because of diffraction by the aperture stop, no optical system can form a perfect image of a point, but produces instead a small disk of light

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(Airy disc) surrounded by alternately dark and bright concentric rings. When two object points are at the critical separation from which the first dark ring of one diffraction pattern falls upon the central disk of the other, the points are just “resolved” or distinguished as separated, and are said to be at the limit of resolution.

power, chromatic resolving. Some optical components, such as prisms and gratings, are used, not to resolve two or more object points, but rather to separate two wavelengths of nearly equal value. The ability of the instrument to separate two such wavelengths is called chromatic resolving power and is specified as the ratio of the shorter wavelength divided by the difference between the wavelengths.

power, prism chromatic resolving. Defined for the case in which parallel rays of light are incident on the prism, which is oriented at the angle of minimum deviation at wavelength λ , and in which the entire height of the prism is utilized. The corresponding resolving power deduced on the basis of Rayleigh’s criterion, is $R = \lambda/\Delta\lambda = b \, dn/\lambda$, where n is the index of refraction of the prism for the wavelength λ , and b is the maximum thickness of prism traversed by the light rays. The quantities $dn/d\lambda$ and b are often called the dispersion and base length of the prism, respectively.

power, theoretical resolving. Maximum possible resolving power determined by diffraction. Frequently measured as a angular resolution determined from $\Theta = 1.22 \lambda/d$, where Θ is the limiting resolution in radians, λ is the wavelength of light at which the resolution is determined, and d is the diameter of the effective aperture.

Prentice’s rule. Method of determining prism power at any point on a lens. Prism power equals the product of the dioptric power and the distance, in centimeters, from the optical center.

prism. Transparent body with at least two polished plane faces inclined with respect to each other, from which light is reflected or through which light is refracted. When light is refracted by a prism whose refractive index exceeds that of the surrounding medium, it is deviated or bent toward the thicker part of the prism.

prism, Amici. Also called *roof prism* and *right-angle prism with roof*. A form of roof prism consisting of a roof edge formed upon the long reflecting face of a right-angle prism. Used as an erecting system in elbow and panoramic telescopes. It erects the image and bends the line of sight through a 90-deg. angle.

prism, apex of. Thin edge of a refracting prism. It is the line of intersection of two refracting faces of a prism.

prism, base of. Thick edge of a prism.

prism, brace. Compound prism composed of two 30-deg. prisms, one of which is partially coated with a highly reflective metal. The two prisms are cemented together with the coated prism face between the two halves.

prism, Dove (rotating prism). Prism that inverts the image in one plane without deviating or displacing the axis.

prism, Littrow. Prism with 30-60-90 deg. angles that has a reflecting coating on the side opposite the 60-deg. angle.

prism, Nicol. Prism made from a calcite crystal that is used to produce and analyze plane-polarized light.

prism, objective. Usually a right-angle prism used to bend light 90 deg before it enters the objective; a dispersing prism placed in front of an astronomical telescope objective to produce spectra of all luminous objects in the field of view.

prism, ocular. Prism used in a rangefinder to bend the lines of sight through the instruments into the eyepieces.

prism, Pechan. Prism composed of two air-spaced prism elements that can revert an image without inverting, and can be used in convergent or divergent light as well as parallel light.

prism, Pellin-Broca. Prism that produces a constant deviation of 90-deg. and disperses light.

prism, penta. Five-sided prism used to bend light through a constant angle, usually 90 deg., without inversion. A penta prism can be rotated about an axis parallel to its faces without producing a change in its deviation of 90 deg.

prism, Porro. Reflecting prism with 45-90-45 deg. angles, and with the 4 surfaces forming the 90-deg. angle reflecting the light beam through a total angle of 180 deg.

prism, rhomboidal. Reflecting prism whose unpolished side faces are rhomboidal in shape. It has two parallel transmitting faces, and two parallel reflecting faces; the latter are oblique to the former (usually but not necessarily at 45 deg.). This prism offsets the optical axis without changing the aspect of the image. By rotating the rhomboidal prism around an axis normal to the entrance surface, the offset emergent axis can be moved parallel to itself in a circular arc. Pairs of these prisms are often used to provide interpupillary adjustment of the eyepiece to binocular instruments such as stereoscopic range finders and height finders.

prism, right-angle. Type of 45-95-45 deg. prism used to turn a beam of

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light through a right angle (90 deg.), with the surfaces forming the 90-deg. angle acting as transmitting faces.

prism, rotating. See *prism, Dove*.

pupil. In a lens, the image of the aperture stop as seen in the object and image space.

pupil, entrance. Image of the limiting aperture stop formed in the object space by all optical elements preceding the limiting aperture stop; also, the aperture of the objective when there are no other limiting stops following it in the system.

pupil, exit. Image of the limiting aperture stop in an optical system formed by all lenses following this stop. In photographic objectives, this image is virtual and is usually not far from the iris diaphragm. In telescopes, the image is real and can be seen as a small, bright circular disc by looking at the eyepiece with the instrument directed toward an illuminated area or light source. In telescopes, its diameter is equal to the diameter of the entrance pupil divided by magnification of the instrument. In Galilean telescopes, the exit pupil is a virtual image between the objective and eyepiece, and acts as an out-of-focus field stop.

pyramid, error due to. Error in the position of the image introduced by pyramidal error in a prism, measured relative to a chosen line of intersection of two prism faces.

Q

quality, image. Quality of an optical image due to all the properties of a lens or optical system affecting optical performance, such as resolving power, aberrations, and surface quality. Aberrations, errors of construction, defects in materials, and scattered light, all contribute to deterioration of the image.

R

radiance. Radiant intensity per unit projected area of an extended source.

radiance; spectral. Radiance per unit wavelength interval.

radiation (or light), monochromatic. Flux at one wavelength or frequency.

ratio, aperture. In general, twice the value ρ_m in the equation $\rho_m = n \sin A_m$ where n is the index of refraction of the image space, and A_m is the maximum angular opening of the axial bundle of refracted rays.

The speed (energy per unit area of image) of an objective is proportional to the square of its aperture ratio. When the angular opening is small, $n = 1$, and the object distance is great, it is approximately true that $n \sin \alpha_m = D/2f$, or $f/D = f\text{-number} = 1/2\rho_m = 1/\text{aperture ratio}$.

ratio, telephoto. Ratio of the equivalent focal length to the front-vertex focal distance.

ray. Contraction of the term *light ray*.

ray, chief. Central ray of a bundle of rays.

ray, emergent. Ray of light emerging from a medium as contrasted to the entering or incident ray.

ray, extraordinary. Ray that has a nonisotropic velocity in a doubly refracting crystal. This ray does not necessarily obey Snell's law upon refraction at the crystal surface.

ray, ordinary. Ray that has an isotropic velocity in a doubly refracting crystal. It obeys Snell's law upon refraction at the crystal surface.

ray, paraxial. Ray in a bundle of rays that approaches the chief ray of that bundle as its limiting position. More properly, it is a ray in the sense of Gaussian or first-order optics.

ray, principal. In the object space, a ray that is directed at the first principal point. In the image space, this ray, when projected backward, intersects the axis at the second principal point.

ray, rim. Ray of an image-forming bundle that passes through the rim of the entrance pupil or aperture stop. Usually used in connection with meridian rays, an *upper* rim ray is one that passes through the bottom.

ray, skew. Ray that does not lie in a plane containing the axis of a system having rotational symmetry.

rays, marginal. Rays of light passing through an optical system near the edge of the aperture.

rectilinear. In a straight line. When applied to a lens, it indicated that images of straight lines produced by the lens are not distorted.

reflectance. Ratio of reflected flux to incident flux. This term is applied to radiant and to luminous flux. Unless qualified, reflectance applies to specular (regular) reflection.

Reflectance, diffuse. Ratio of flux reflected diffusely in all directions to the total flux at incidence, specular reflection excluded; the reflectance of a sample relative to a perfectly diffusing, and perfectly re-

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fecting, standard with 45-deg. angle of incidence and observation along the perpendicular to the surface.

reflectance, spectral. Reflectance evaluated as a function of wavelength. It is numerically the same for radiant and luminous flux.

reflection. Condition in which light rays striking a smooth, polished surface are bent back into the medium from which they came. *Specular* or **regular reflection** from a polished surface, such as a mirror, returns a major portion of the, light in a definite direction lying in the plane of the incident ray and the normal. After specular reflection, light can be made to form a sharp image of the original source. **Diffuse reflection** occurs when the surface is rough, and the reflected light is scattered from each point in the surface. These diffuse rays cannot be made to form an image of the original source, but only of the diffusely reflecting surface itself.

reflection, angle of. Angle between the normal to a reflecting surface and the reflected ray.

reflection, Fresnel. Reflection of a portion of light resulting when the light strikes the interface of two materials having different indices of refraction. It depends upon the index difference and the angle of incidence, and is zero at Brewster's angle for one polarization. A thin, transparent, antireflection coating applied to an optical element gives an additional Fresnel reflection that cancels the original one by interference .

reflection, total internal. Reflection that takes place within a substance because the angle of incidence of light striking the boundary surface is in excess of the critical angle.

reflection, mixed. Simultaneous occurrence of specular and diffuse reflection.

reflection, selective. *See absorption, selective.*

reflector, annular. Ring-shaped reflector, or a series of ring-shaped reflectors mounted about a common center.

refraction. Bending of oblique incident rays as they pass from a medium of one index of refraction into a medium of a different index of refraction.

refraction, angle of. Acute angle between the normal to a refracting surface at the point of incidence, and the refracted ray.

refraction, gobble. Separation of unpolarized light into two plane-polarized components by a doubly refracting crystal.

refraction, index of. A number applied the relation between the angle of incidence and the angle of refraction when light passes from one medium to another. The index between two media is called the *index*, and the index when the first medium is a vacuum is called the *absolute index* of the second medium. The index of refraction expressed in tables is the absolute index; that is, vacuum to substance; at a certain temperature, with light of a certain wavelength. Examples: vacuum 1.000, air, 1.000292; water, 1.333; ordinary crown glass, 1.516. Since the index of air is very close to that of vacuum, the two are often used interchangeably as being practically the same (see *Snell, law of*).

relief, eye. Synonym for *distance, eye*.

resolution, limiting angle of. Angle subtended by two points or lines which are just far enough apart to permit them to be distinguished as separate. The ability of an optical device to resolve two points or lines is called resolving power, and quantitatively is inversely proportional to the limiting angle of resolution.

resolution, photographic. Number of line pairs per inch or per millimeter that can be resolved by an optical system.

reticle (in England, graticule). Scale, indicator, or pattern placed in one of the focal planes of an optical instrument to appear to the observer to be superimposed upon the field of view. Reticles in various patterns are used to measure or locate a point in an image. A reticle may consist of fine wires or fibers mounted on a support at the ends, or lines etched on a clear plane-parallel plate. An alternate but less common spelling is reticule.

reversibility, law of. If the direction of light is reversed, it will travel in the opposite direction over the same path despite the number of times it is refracted or reflected.

reverted. Turned the opposite way so that right becomes left, and vice versa. It is the effect produced by a mirror in reflecting an image.

rings, Newton's. When two cleaned and polished surfaces are placed in contact with a thin air film between them, reflected beams of light from the two adjacent surfaces interfere to form a series of rings or bands known as Newton's rings or fringes. By counting these bands from the point of actual contact, the departure of one surface from the other is determined. The regularity of the fringes maps out the regularity of the distance between the two surfaces. This method is usually used to determine the fit of a test surface to a standard surface.

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rotation, optical. Angular displacement of the polarization plane of light passing through a medium; the azimuthal displacement of the field of view achieved through the use of a rotating prism.

run-out, total image. If a decentered lens is rotated in a chuck whose axis of rotation passes through the geometrical center of the rim of the lens, the image of an object will wobble. If the light source is at an infinite distance, the total image displacement is called the *total image run-out*, and is a measure of the decentering. Conversely, if the light source is at the focal point of the lens, the direction of the emergent parallel bundle changes through an angle that is a measure of decentering in angular terms.

S

sag. Abbreviation for *sagitta*, the height of a curve measured from the chord.

scale, diopter. Scale usually put on the focusing nut of the eyepiece of an optical instrument. It measures the change in the position of the eyepiece necessary to produce a correction to compensate the near-sightedness or farsightedness of the individual observer. Thus, if the observer knows his diopter correction, he can preset the instrument for focus.

scale, stadia. Graduations on a reticle which, in conjunction with a rod of definite length, can be used to measure distances.

scratch. Any marking or tearing of a surface appearing as though it had been done by a sharp or rough instrument. *Blocking reek* is a chain-like scratch produced in polishing. A runner-cut is a curved scratch caused by grinding. A *sleek* is a hairline scratch. A *crush* or *rub* is a surface scratch or series of small scratches generally caused by mishandling.

secondary color. Aberration that remains after primary color has been corrected. Primary color causes the back focus of a lens to vary nearly linearly with wavelength in the visible region. For example, blue light focuses closer to an uncorrected lens than green, and green closer than red. Blue and red can be made to focus at the same point, but still farther from the lens than green. The distance to the green focus is the secondary color.

sine condition. Requirement that deals with the angle, A , at which a ray strikes the optical axis in forming an on-axis image. If the entering ray has a coordinate, A , in the entrance pupil, then $\sin A = A/\text{focal length}$. If this relationship is not true, then coma is present.

slit. Usually a rectangular aperture with a large length-to-width ratio,

and a fixed or adjustable shape through which radiation passes. The opening is generally small as compared to the light source.

Snell, law of. When light passes from a given medium to a denser medium, its path is deviated toward the normal; when passing into a less dense medium, its path is deviated away from the normal. If the indices of refraction on each side of the refracting surface are N and N' , and the angles that a ray makes with the surface normal are θ and θ' , then Snell's law states that $N' \sin \theta' = N \sin \theta$.

spectral response. Variation of responsivity of a detector with the wave-length of the impinging radiation.

spectrum, line. Spectrum formed by radiation whose energy values are concentrated at discrete wavelengths, as opposed to a **spectrum**.

spectrum, secondary. Residual chromatic aberration, particularly the longitudinal chromatic aberration, of an achromatic lens. It causes the image formed in a given color to lie nearest the lens, the images in all other colors being formed behind the first at distances that increase sharply toward both ends of the useful wavelength spectrum. Another term for **color, secondary**.

spectrum, visible. Portion of the electromagnetic spectrum to which the retina is sensitive and by which the eye sees. It extends from about 400 to about 750 m, in wavelength.

speed, lens. Property of a lens that affects the illuminance of the image. Lens speed is specified in terms of aperture ratio, numerical aperture, T-stop, or f -number.

sphero-cylinder. Lens or lens surface that is a combination of a sphere and a cylinder.

spot diagram. Evaluation of image quality by numerically tracing a large number of rays through a lens from a single object point, and plotting their intersections with the focal plane.

steradian. Solid angle subtended at the center of a sphere by an area on its surface numerically equal to the square of the radius; the unit of solid angular measurement.

stop, aperture. Diaphragm that limits the size of an aperture.

stop, field. Diaphragm used to restrict the usable field, and to produce a sharply defined edge to the field.

stria. Sharply defined streak of transparent material having different index of refraction than the body of the material. a slightly.

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surface, aplauntic. A surface that images a point without spherical aberration.

surface, optical. Reflecting or refracting surface that closely approximates the desired geometrical surface.

surface, toric. Surface generated by revolving a circle about an axis that is in the plane of the circle but does not pass through its center. However, the term applied to other aspheric surfaces means a surface having different curvatures in different sections, the greatest and least powers occurring in meridians perpendicular to each other.

system, erecting. System of lenses or prisms that produces an erect image which would otherwise be inverted.

system, catadioptric optical. Optical system containing both lens (dioptric) and curved-mirror (catoptric) optical components. Occasionally, a single component may be catadioptric, serving simultaneously as a lens or mirror.

T

talbot. Meter-kilogram-second unit of luminous energy equal to one lumen-second.

temperature, brightness. Temperature at which a blackbody would have the same brightness or radiate the same flux in a given wavelength band as a particular nonblackbody source of radiation.

temperature, color. Temperature of a blackbody that emits light of the same color as the source in question. Color temperature is expressed in degrees Kelvin.

transmission. Conduction of radiant energy through a medium.

transmissivity. Internal transmittance for unit thickness of a nondiffusing substance.

transmittance. Ratio of the radiant or luminous flux transmitted by an object to the incident flux. Unless qualified, the term applies to regular (specular) transmission.

transmittance, diffuse. Transmittance measured with diffusely incident flux. Also, the ratio of the flux diffusely transmitted in all directions to the total incident flux.

transmittance, radiant. Ratio of the radiant flux transmitted by an object to the incident radiant flux.

transmittance, spectral. Transmittance evaluated at one or more wavelengths. It is numerically the same for radiant and luminous flux.

transmittancy. Ratio of the transmittance of a solution to that of an equal thickness of the solvent.

triplet. Three-lens component of an optic; system which may or may not be cemented.

T-stop. Equivalent, perfectly transmitting circular opening of diameter D such that $\pi(D/2)^2 = tA$, where A is the area of the entrance pupil of the objective, and t is the transmittance of the lens system.

U

ultraviolet. Rays of radiant energy immediately beyond the violet end of the visible spectrum and of the order of 390 to 100 $m\mu$.

V

vector, electric. Direction and amplitude of the electric field of an electromagnetic wave.

vector, magnetic. Durability and direction of the magnetic field of an electromagnetic wave.

vertex. Intersection of the optical axis with any optical surface.

view, field of. In general, the maximum cone or fan of rays passed by an aperture and measured at a given vertex. In an instrument, field of view is synonymous with *field, true*.

vignetting. Loss of light through an optical element due to only a portion of the bundle passing through.

vision, binocular. Simultaneous use of both eyes in the process of vision.

vision, distance of distinct. Near-point distance of the normal eye that is given the value of 10 in. or 25 cm. This value is used in calculating the designated magnification of a simple magnifier or eyepiece.

vision, double. Malfunction of a binocular instrument causing two images to be seen separately instead of being fused. It is caused by the optical axes of the two telescopes not being parallel. In minor cases, the eyes will adjust themselves to compensate for the error of the instrument until the images are superimposed and only one object is seen.

vision, stereoscopic. Three-dimensional vision due to the spacing of the eyes. This spacing permits the eyes to see objects, from slight different points of view.

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W

wave. vibration; a form of movement by which all radiant energy of the electro-magnetic spectrum is assumed to travel.

wavefront. Surface normal to a bundle of rays as they proceed from a source. The wavefront passes through those parts of the waves that are in the same phase. For parallel rays, the wavefront is a plane; for rays diverging from or converging toward a point, the wavefront is spherical.

wavelength. Length of a wave measured from any point on one wave to the corresponding point on the next wave; usually measured from crest to crest. Wavelength determines the nature of the various forms of radiant energy that comprise the electromagnetic spectrum.

wedge. Prism with a very small angle between the refracting surfaces. Wedges may be circular, oblong, or square in outline.

wedge, absorbing. Strip or annulus of optical material coated with a neutral-density material, and of an increasing thickness from one end to the other so that optical density increases linearly along the length.

wedge, correction. Rotatable or sliding wedge-shaped element used to divert the line of sight in order to correct errors in an optical system caused by temperature variation or any other errors in collimation.

wedge, rotating. Circular optical wedge (prism or small refracting angle) mounted to be rotated in the path of light rays to divert the line of sight to a limited degree.

window. Piece of glass with plane-parallel surfaces used to admit light into an optical instrument, and to exclude dirt and moisture.

window, correction. Optical wedges of very small angles. They admit light, seal out dirt and moisture, and are so mounted that they may be rotated to compensate for accumulated errors in the entire system.

zone plate. Usually a photograph containing a central spot surrounded by concentric annular zones, alternately transparent and opaque, with the radii and boundaries between zones being proportional to the square roots of the natural numbers (1, 2, 3, etc.). The plate represents a real image of a point on the axis formed by diffraction.