Section 6

OPTICS

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CONTENTS

6a. Fundamental Definitions, Standards, and Photometric Units

6a-1. Fundamental Definitions

Absorptance. The ratio of the radiant flux lost by absorption to the incident radiant flux. If I_0 represents the incident flux, I_r the reflected flux, I_t the transmitted flux, the absorptance is given by the expression

$$\frac{I_0 - (I_t + I_r)}{I_0}$$

Absorption, Bouger's Law. If I_0 is the incident flux, I the flux passing through a thickness x of a material whose *absorption coefficient* is α,

$$I = I_0 e^{-\alpha x}$$

where it is implied that I and I_0 are measured within the material.

The *extinction coefficient* k is given by the relation $k = \alpha\lambda/4\pi$, where λ is the wavelength *in vacuo* and α is the absorption coefficient. The mass absorption is given by k/d, where d is the density. The transmittance is given by I/I_0.

Absorption Spectrum. The spectrum obtained by the examination of light from a source that gives a continuous spectrum, after this light has passed through an absorbing medium. The absorption spectrum will be marked by dark lines or bands; in the case of gases these will be the reverse of many of the features of the emission spectrum. When the absorbing medium is in the solid or liquid state, the spectrum of the transmitted light shows broad, dark regions which are not resolvable into lines and usually have no sharp or distinct edges.

Achromatic. A term applied to a lens, signifying that its focal length is the same for two quite different wavelengths.

Angular Aperture. The arc sine of the ratio of radius to focal length of a lens.

Apochromat. A term applied to a photographic or microscopic objective indicating that its focal length is the same for three quite different wavelengths.

Astigmatism. An error characteristic of the formation of images oblique to the axis of axially symmetric optical systems. When astigmatism is present, the sharpest image of a radial line will be formed at a distance from the lens different from the sharpest image of a tangential line.

Balmer Series of Spectral Lines. The wavelengths of a series of lines in the spectrum of hydrogen given in nanometers by the equation

$$\lambda = 364.6 \frac{N^2}{N^2 - 4}$$

where N is an integer having values greater than 2.

Beer's Law (1852). If two solutions of the same salt are made in the same solvent, one of which is, say, twice the concentration of the other, the absorptance of a given thickness of the first solution should be equal to that of twice the thickness of the second.

Blackbody. An almost completely enclosed cavity in a material of constant temperature. A small hole in the cavity completely absorbs all wavelengths of incident radiant energy.

Brewster's Law (1811). The tangent of the polarizing angle for a nonabsorbing substance is equal to the index of refraction. The polarizing angle is that angle of incidence for which the completely polarized reflected ray is at right angles to the refracted ray. If n is the index of refraction, and θ the polarizing angle, $n = \tan \theta$.

Candela. Symbol cd. International unit of luminous intensity. It is $\frac{1}{60}$ of the intensity of one square centimeter of a blackbody at the temperature of solidification of platinum (2045 K).

Chemiluminescence. Emission of light during a chemical reaction.

Christiansen Effect. When a clean, finely powdered, homogeneous substance such as glass or quartz is immersed in a liquid of the same index of refraction, nearly complete transparency can be obtained, but only for substantially monochromatic light. If white light is incident, the transmitted color corresponds to the particular wavelength band for which the two substances, solid and liquid, have very nearly equal indices of refraction. Because of differences of dispersion, the indices of refraction will sufficiently match for only a narrow band of the spectrum.

Chromatic Aberration. Because of the differences in the indices of refraction for different wavelengths, light of various wavelengths from the same source cannot be sharply focused at the same distance by any lens. The differences of focus are called chromatic aberration.

Coma. An aberration characteristic of the formation of images oblique to the axis of axially symmetric optical systems. The image of a point consists of a family of eccentric circles all tangent to two intersecting, nearly straight lines in the focal plane.

Conjugate Foci. Rays close to the axis, divergent from a point source on the axis of an axially symmetric optical system, converge on another point on the axis. The point of convergence and the position of the source are interchangeable and are called conjugate foci.

Diffraction. Deviation of light from the paths and foci prescribed by rectilinear propagation (geometrical optics) consequent on the wave nature of light. Thus, even with a very small, distant source, some light, in the form of bright and dark bands, is found within a geometrical shadow because of the diffraction of the light at the edge of the object forming the shadow.

Diffraction Grating. An array of fine, parallel, equally spaced reflecting or transmitting lines which mutually enhance the effects of diffraction at the edges of each so as to concentrate the diffracted light very close to a few directions characteristic of the spacing of the lines and the wavelength of the diffracted light. If i is the angle of incidence, d the angle of diffraction, s the center-to-center distance between successive rulings, n the order of the spectrum, the wavelength is

$$\lambda = \frac{s}{n} (\sin i + \sin d)$$

Dispersion. In any spectrum-forming device, the difference of position along the spectrum per unit of wavelength difference, e.g., 1 millimeter per nanometer.

Dispersion Equations. It is convenient and sometimes necessary to obtain equations relating refractive index to wavelength so that one can interpolate or perhaps even extrapolate with considerable accuracy and also obtain the most accurate values for $dn/d\lambda$. The equation due to Hartmann is $n = n_0 + (C/\lambda - \lambda_0)$. That due to Cauchy is $n = A + (B/\lambda^2) + (C/\lambda^4)$, and a more complicated one derived by

Sellmeier is $n^2 = 1 + (A_0\lambda^2/\lambda^2 - \lambda_0^2)$. An extension of the Sellmeier equation that is useful for covering more than one absorption region is $n^2 = 1 + \sum_{i=0}^{m} \frac{A_i\lambda^2}{\lambda^2 - \lambda_i^2}$. Finally, the Helmholtz expression, which includes an additional term $B_i/(\lambda^2 - \lambda_i^2)$ is useful within absorption regions as well. Usually, some of the terms of the summation are replaced by a constant. In practice, one of the above expressions is often used, and then a more accurate fit is found by an appropriate curve-fitting technique such as the method of least squares. A formula developed by Herzberger, which in some respects resembles Helmholtz's, is employed in Sec. 6d-2 to generalize the data in a condensed glass table.

Dispersive Power. If n_1 and n_2 are the indices of refraction of a substance for wavelengths λ_1 and λ_2, and n is the mean index, or that for sodium light, the dispersive power of that substance for the specified wavelengths is

$$\omega = \frac{n_2 - n_1}{n - 1}$$

This is also called *Mean Dispersion.* See also *Reciprocal Dispersion.*

Doppler Effect (Light). Change of wavelength of the light observed which arises from any change of relative velocity of the observer with respect to the source of light.

Emissive Power. See *Radiation Formula, Planck's.*

Emissivity. Ratio of flux radiated by a hot substance to the flux radiated by a blackbody at the same temperature. Emissivity is usually a function of wavelength.

Extinction Coefficient. See *Absorption.*

Faraday Effect. Rotation of the plane of polarization produced when linearly polarized light is passed through certain substances in a magnetic field, the light traveling in a direction parallel to the magnetic field. For a given substance, the rotation is proportional to the thickness traversed by the light and to the magnetic field strength.

Fermat's Principle of Least Time. The path followed by a ray between two points is that along which light can be propagated in less time than for any neighboring path.

Fraunhofer's Lines. When sunlight is examined through a spectroscope, an enormous number of dark lines parallel to the length of the slit are seen against a bright continuous spectrum. The dark lines are Fraunhofer's lines. They are caused by resonance absorption by all the elements in the layers of vapors by which the sun is surrounded. The continuous spectrum from which those resonant frequencies are absorbed is produced by the extremely hot, highly compressed substances in the body of the sun proper. Many of the reversed or dark lines have the same wavelengths as bright lines found in the emission spectrum of the absorbing elements.

Huygens' Theory of Light. Light is a continuous, cyclical disturbance propagated through space with constant velocity, frequency, and wavelength in any homogeneous transparent substance. Every point (subjected to that disturbance) acts as the center of a new disturbance having the same frequency, velocity, and wavelength radiating from it equally in all directions. The secondary disturbances from the neighboring points which were simultaneously disturbed by the initial wave coalesce to produce a net effect only along a surface which is the envelope of all the simultaneous neighboring secondary disturbances. This surface forms a new wavefront, which is further propagated in the same manner.

Illuminance. Luminous flux incident per unit area. Metric units are the lux, one lumen per square meter, and the phot, one lumen per square centimeter. In the United States the lumen per square foot is commonly used. Unit illuminance is produced by a unit source at unit distance; hence the older names meter-candle for the metric unit the lux and the foot-candle, which is the same as the lumen per square foot.

Index of Refraction. For any substance this is the ratio of the velocity of propagation of waves of light in a vacuum to its velocity of propagation in the substance. It is also the ratio of the sine of the angle of incidence to the sine of the angle of refraction. The index of refraction for any substance varies with the wavelength of the refracted light.

Irradiance. Radiant power incident per unit area of a surface. The preferred symbol for this quantity is E; it is expressed in watts/m^2.

Kirchhoff's Laws of Radiation. For each wavelength and temperature the emittance of any substance is equal to its absorptance.

Lambert's Law of Absorption. Each layer of equal thickness of any homogeneous substance absorbs an equal fraction of the light which is incident upon that layer.

Lambert's Law of Illumination. The illuminance of a surface on which light falls normally from a source small compared with its distance is inversely proportional to the square of the distance of the surface from the source. If the normal to the surface is inclined at an angle with the direction of the rays, the illuminance is proportional to the cosine of that angle.

Lens Combination. If f_1 and f_2 are the focal lengths of two thin lenses separated by a distance d, the focal length of the system is

$$F = \frac{f_1 f_2}{f_1 + f_2 - d}$$

Lens Formulas. The focal length F and distances p and q of pairs of conjugate foci (positive if convex) for a single thin lens which has index of refraction n and whose surfaces have radii of curvature r_1 and r_2 are connected by

$$\frac{1}{F} = \frac{1}{p} + \frac{1}{q} = (n - 1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

If that lens has thickness t,

$$F = \frac{n r_1 r_2}{(n - 1)[n(r_1 + r_2) - t(n - 1)]}$$

Lumen. See *Luminous Flux.*

Luminance. The luminous flux per unit solid angle emitted per unit area as projected on a plane normal to the line of sight. The unit of luminance is that of a perfectly diffusing surface giving out one lumen per square centimeter and is called the *lambert.* The millilambert (0.001 lambert) is a more convenient unit. The candela per square centimeter is the luminance of a surface which has, in the direction considered, a luminous intensity of one candela per square centimeter of projected area.

Luminosity. Ratio of the luminous flux in lumens to the total radiant flux in watts.

Luminosity Maximum. 673 lumens per watt for 555 nm.

Luminous Flux. The total amount of light emitted by a source per unit time is called the luminous flux from the the source. The unit of luminous flux, the *lumen* (symbol lm), is the flux emitted in a unit solid angle by a point source that has one candela luminous intensity. A one-candela point source that radiates uniformly in all directions thus emits 4π lumens into all space.

Luminous Intensity. Luminous flux emitted per unit solid angle. The unit of luminous intensity is the candela. The symbol for luminous intensity is I.

The mean horizontal intensity is the average intensity measured in a horizontal plane passing through the source. The mean spherical intensity is the average intensity measured in all directions; it is equal to the total luminous flux in lumens divided by 4π.

Magnifying Power. In an optical instrument this is the ratio of the visual angle subtended by the image of the object seen through the instrument to the visual angle subtended by the object when observed by the unaided eye. In the case of the microscope or simple magnifier the object when viewed by the unaided eye is supposed to be at a distance of 25 cm.

Minimum Deviation. The deviation, or change of direction, of light passing through a prism is a minimum when the angle of incidence is equal to the angle of emergence. If D is the angle of minimum deviation and A the angle of the prism, the index of refraction of the prism for the wavelength used is

$$n = \frac{\sin \frac{1}{2}(A + D)}{\sin \frac{1}{2}A}$$

Molecular Refraction. The molecular refraction of a substance can be computed by the following relation:

$$N = \frac{M(n^2 - 1)}{d(n^2 + 2)}$$

where N is the molecular refraction for a specified wavelength and temperature, M the molecular weight, d the density, and n the refractive index for the specified conditions.

Nodal Points. Two points on the axis of a lens such that a ray entering the lens in the direction of one leaves as if from the other and parallel to the original direction.

Optical Density. The common logarithm of the reciprocal of transmittance

$$D = \log \frac{1}{t}$$

Polarized Light. Light which exhibits different properties in different directions at right angles to the line of propagation is said to be polarized. Specific rotation is the power of materials to rotate the plane of polarization. It is stated in terms of the rotation in degrees per decimeter per unit density or concentration.

Principal Focus. For a lens or spherical mirror, this is the point of convergence of light coming from a source at an infinite distance.

Radiance. The radiant power (flux) emitted in a specified direction, per unit projected area of surface, per unit solid angle. The preferred symbol for this quantity is L; it is expressed in watts per steradian per square meter.

Radiant Energy. When a substance is excited—e.g., because it has a temperature above 0 K—it radiates energy, called radiant energy. This may be the amount of energy emitted during the entire radiating lifetime of the body, it may be the amount of energy for a given time period, or it may be the amount in a given volume of space. The preferred symbol for this quantity is Q; it is expressed in joules.

Radiant Density. The radiant energy per unit volume of space is sometimes a useful quantity; it is called radiant density. The preferred symbol for this quantity is w, and it is expressed in joules/m^3.

Radiant Exitance. Radiant power emitted into a full sphere (4π steradians) by a unit area of source. The preferred symbol for this quantity is M; it is expressed in watts/m^2.

Radiant Flux. The rate at which energy is radiated is called radiant power or flux. Radiant energy is the time integral of radiant flux. The preferred symbol for this quantity is Φ; it is expressed in watts = joules/sec.

Radiant Intensity. Radiant flux per unit solid angle, expressed in watts per steradian. The preferred symbol for radiant intensity is I.

Radiation Formula, Planck's. The spectral exitance of a blackbody at wavelength λ and in a spectral range $\Delta\lambda$ can be written

$$M_\lambda = \frac{c_1\lambda^{-5}\Delta\lambda}{e^{c_2/\lambda T} - 1}$$

where M_λ is watts/m^2; c_1 and c_2 are constants with numerical values 3.7415×10^{-16} watt $\cdot$ m^2 and 0.014388 m $\cdot$ K, respectively; λ is the wavelength in meters; and T is Kelvin temperature.

Radius of Curvature from Spherometer Readings. If l is the mean length of the sides of the nearly equilateral triangle formed by the points of the three legs, and d is the normal distance from the mid-point of the triangle to the spherical surface on which the points rest, then the radius of curvature of the surface is

$$R = \frac{l^2}{6d} + \frac{d}{2}$$

Reciprocal Dispersion. $\nu = (n_D - 1)/(n_F - n_C)$, where n_C, n_D, and n_F are indices of refraction for the Fraunhofer lines C, D, F. The index n_d for the Fraunhofer d lines is sometimes used instead of n_D. The ν value is sometimes called the *Abbe Number*.

Reflectance. The ratio of the reflected flux to the flux incident on a surface is called the reflectance; it may refer to diffuse or to specular reflection. In general, it varies with the angle of incidence and with the wavelength of the light. Symbol ρ.

Reflection of Light at a Smooth Boundary between an Absorbing Medium and a Transparent Medium. At normal incidence, if n_0 is the index of the transparent medium, and n_1 and k_1 are the index and extinction coefficients of the absorbing medium, the reflectance is

$$\rho = \frac{(n_0 - n_1)^2 + k_1^2}{(n_0 + n_1)^2 + k_1^2}$$

Reflection of Light by a Smooth Surface between Two Transparent Media (Fresnel's Formulas). If i is the angle of incidence, r the angle of refraction, n_1 the index of refraction of the medium from which the light is incident, n_2 the index of refraction of the other, then for unpolarized incident light the reflectance is

$$R = \frac{1}{2}\left[\frac{\sin^2 (i - r)}{\sin^2 (i + r)} + \frac{\tan^2 (i - r)}{\tan^2 (i + r)}\right] \qquad \text{where } \frac{\sin r}{\sin i} = \frac{n_1}{n_2}$$

If $i = 0$ (normal incidence),

$$R = \left(\frac{n_2 - n_1}{n_2 + n_1}\right)^2$$

Refraction at a Spherical Surface. If u is the distance of a point object from a spherical surface separating two media, v is the distance of the point image or the intersection of a nearby refracted ray with the line defined by the object and the center of curvature, n_1 and n_2 are the indices of refraction of the first and second media, and r is the radius of curvature of the separating surface, then

$$\frac{n_2}{v} + \frac{n_1}{u} = \frac{n_2 - n_1}{r}$$

Refractivity. This is given by $n - 1$, where n is the index of refraction; the *specific refractivity* is given by $(n - 1)/d$, where d is the density; *molecular refractivity* is the product of the specific refractivity and the molecular weight.

Relationships between Radiometric Units. In a nonabsorbing medium, for the geometrical arrangement in which the source and receiver areas are both perpendicular to the line joining their centers, the radiation quantities above are related as follows:

$$\Phi = \frac{\partial Q}{\partial t}, \qquad M = \frac{\Phi}{A_s}, \qquad L = \frac{M}{\omega_r}, \qquad E = L\omega_s, \qquad I = Er^2, \qquad \Phi = I\omega_r$$

where A_s is source area, ω_s is the solid angle subtended by the source area at the receiver, ω_r is the solid angle subtended by the receiver area at the source, and r is the distance between the centers of the source and receiver areas. The corresponding relations connect the corresponding photometric quantities, which are distinguished by the root "lumi-" in place of "radi-." The same symbols are preferred for the photometric quantities as for the corresponding radiometric quantities. When symbols are needed for both photometric and radiometric quantities in the same context, the symbols for photometric quantities should be followed by the subscript v. The symbols of radiometric quantities should, in such cases, be followed by the subscript e.

Resolving Power. For a telescope or microscope this is the minimum separation of two objects for which they appear distinct and separate when viewed through the instrument. Resolving power is often specified by the reciprocal, e.g., lines per millimeter.

Rotatory Power, Molecular or Atomic. This is the product of the specific rotatory power by the molecular or atomic weight. Magnetic rotatory power is given by

$$\frac{\theta}{t} G \cos \alpha$$

where G is the magnetic field strength, t is the thickness traversed, θ is the rotation of the plane of polarization by the Faraday effect, and α is the angle between the field and the direction of the light.

Snell's Law of Refraction. If i is the angle of incidence, r the angle of refraction, v the velocity of light waves in the first medium, and v' the velocity in the second medium, the relative index of refraction n is

$$n = \frac{\sin i}{\sin r} = \frac{v}{v'}$$

Specific Rotation. If there is n g of active substance in v cm^3 of solution, and the light passes through 1 cm, r being the observed rotation of the plane of polarization in degrees, the specific rotation (for 1 cm) is

$$[\alpha] = \frac{rv}{n1}$$

Spectral Irradiance. Irradiance per unit wavelength interval. The preferred symbol for this quantity is E_λ; it is measured in units of watts per square meter per micrometer.

Spectral Radiance. Radiance per unit wavelength interval. The preferred symbol for this quantity is L_λ; it is measured in units of watts per steradian per square meter per micrometer.

Spectral Series. Spectral lines or groups of lines which occur in an orderly sequence in the spectrum of an element.

Spherical Aberration. When large surfaces of spherical mirrors or lenses are used, the light divergent from a point source is not focused exactly at a point. The phenomenon is known as spherical aberration. For oblique pencils it produces coma.

Spherical Mirrors. If R is the radius of curvature, F is the principal focus, and f_1 and f_2 are any two conjugate focal distances,

$$\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{F} = \frac{2}{R}$$

If the transverse dimensions of the object and the image are O and I, respectively, and u and v their distances from the mirror,

$$\frac{O}{I} = \frac{u}{v}$$

Total Reflection. When light passes from a denser medium to one in which the velocity is greater, refraction ceases and total reflection begins, at a certain critical angle of incidence such that

$$\sin\theta = \frac{1}{n}$$

where n is the index of the denser medium relative to that of the less dense.

Transmissivity. The internal transmittance for unit thickness of a nondiffusing substance.

Transmittance. If Φ_0 and Φ are the incident and transmitted luminous flux, respectively, the transmittance is given by Φ/Φ_0.

Transmittance, External. The external transmittance is the ratio of the flux that is transmitted through a sample to that which is incident on it. This is the quantity that is usually measured. The greater the losses by reflections at the surfaces, the smaller is the external transmittance; the greater the absorption, the smaller is the external transmittance.

Transmittance, Internal. The ratio of the flux incident internally on the second internal surface of a sample to that leaving the first surface is the internal transmittance. This is not a measurable quantity but is obtained from measurements of external transmittance corrected for reflection losses. Internal transmittance is related to sample thickness and absorption coefficient by Bouguer's law:

$$\text{Internal transmittance} = \exp(-\alpha x)$$

Transmittance, Luminous. External transmittance, when flux is measured in photometric units (lumens).

Transmittance, Radiant. External transmittance, when flux is measured in radiometric (powers) units.

Transmittancy. The transmittancy is the ratio of the transmittance of a solution to that of a solvent.

Wein's Displacement Law. When the temperature of a radiating blackbody increases, the wavelength corresponding to maximum radiance decreases in such a way that the product of the absolute temperature and wavelength is constant.

$$\lambda_{max} T = 0.0028978 \text{ m}\cdot\text{K}$$

Zeeman Effect. The splitting of a spectrum line into several symmetrically disposed polarized components, which occurs when the source of light is placed in a strong magnetic field. The directions of polarization and the appearance of the effect depend on the direction from which the source is viewed relative to the lines of force.

6a-2. Fundamental Standards

Candela. The international standard unit of luminous intensity. It is $\frac{1}{60}$ of the intensity of one square centimeter of a blackbody radiator at the temperature of solidification of platinum (2045 K).

Primary Standard of Wavelength. The krypton^{86} line whose vacuum wavelength is $6.057802106 \times 10^{-7}$ m. This is the unperturbed $2P_{10}$-$5d_5$ transition of ^{86}Kr. The actual definition was given by defining the standard meter as 1,650,763.73 vacuum wavelengths of the krypton line.

Velocity of Light. An acceptable present value is $2.9979250 \pm 10 \times 10^8$ meters per second (in SI units). This figure is taken from a paper by Taylor, Parker, and Langenberg, *Rev. Mod. Phys.*, **41,** 375 (1969). It should be considered an interim value pending completion of the work of the Task Group on Fundamental Constants, of the Committee on Data for Science and Technology, International Council of Scientific Unions. It is expected that the Task Group's recommended figure will be available in 1973.

6a-3. Photometric Quantities, Units, and Standards

Apostilb. Unit of luminance. $1/\pi$ cd/m^2. Symbol, asb.

Blondel. Alternate name for apostilb.

Candela. Unit of luminous intensity. It is $\frac{1}{60}$ of the intensity of one square centimeter of a blackbody radiator at the temperature of solidification of platinum (2045 K). Symbol, cd.

Efficiency of a Source of Light. The efficiency of a source is the ratio of the total luminous flux to the total power consumed. It is expressed in lumens per watt.

Foot-Lambert. Unit of luminance equal to $1/\pi$ candela per square foot. Symbol, fL.

Lambert. Unit of luminance equal to $1/\pi$ candela per square centimeter. Symbol, L. $1/\pi$ sb.

Least Mechanical Equivalent of Light. One lumen at the wavelength of maximum luminosity (555 nm) equals 0.00147 watt; 1 watt at the same wavelength equals 680 lumens.

Lumen. The lumen is the unit of luminous flux. Symbol, lm. It is equal to the flux through a unit solid angle (steradian) from a one-candela point source or to the flux on a unit surface all points of which are at unit distance from a one-candela uniform point source. Luminous power of 1 talbot per second.

Lux. Unit of illuminance. 1 lm/m^2. Symbol, lx.

Nit. Unit of luminance. 1 cd/m^2. Symbol, nt.

Phot. Unit of illuminance. 1 lm/cm^2. Symbol, ph.

Relative Luminosity. The relative luminosity for a particular wavelength is the ratio of the luminosity for that wavelength to the maximum luminosity. Values of the relative luminosity are given in Sec. 6j, Colorimetry.

Spherical Candlepower. The spherical candlepower of a lamp is the average intensity (candela) of the lamp in all directions. It is equal to the total luminous flux from the lamp, in lumens, divided by 4π.

Stilb. Unit of luminance. 1 cd/cm^2. Symbol, sb.

Talbot. Unit of luminous energy, the product of lumens times seconds, 1 lm·sec.

Troland. Unit of retinal illuminance. Illuminance produced on the retina of the human eye when a surface having luminance of 1 cd/m^2 is viewed through a pupil whose area is 1 mm^2. 0.4 times the illuminance produced on the retina when a surface having 1 millilambert luminance is viewed through a pupil having 1 millimeter diameter. Symbol, td.

6a-4. Photometric Equivalents

Candela per Square Centimeter (Luminance). 1 stilb, 10,000 nit, π apostilbs, 3.1416 lamberts, 3,141.6 millilamberts.

Candela per Square Inch (Luminance). 0.48695 lambert; 486.95 millilamberts.

Foot-Candle (Illuminance). 1 lumen incident per square foot, 1.0764 milliphots, 10.764 lumens per square meter, 10.764 lux.

Foot-Lambert (Luminance). 1.0764 millilambert.

Lambert (Luminance). 0.3183 candela per square centimeter; 2.054 candela per square inch. One lumen is emitted per square centimeter of a perfectly diffusing surface having a luminance of 1 lambert.

Lumen (Luminous Flux). Emitted by 0.07958 candela spherical intensity. A source of one candela spherical intensity emits $4\pi = 12.566$ lumens.

Lumen per Square Centimeter per Steradian (Luminance). 3.1416 lamberts.

Lumen per Square Foot (Illuminance). One foot-candle, 10.764 lumens per square meter; 10.764 lux.

Lumen per Square Foot per Steradian (Luminance). 3.3816 millilamberts.

Lumen per Square Meter (Illuminance). 1×10^{-4} phot, 0.092902 foot-candle or lumen per square foot; 1.0 lux.

Lux. 1×10^{-4} phot, 0.1 milliphot, 0.092902 foot-candle.

Meter-Candle (Illuminance). 1 lux, or 0.0929 lumen emitted per square foot (perfect diffusion).

Millilambert (Luminance). 0.929 foot-lambert.

Milliphot (Illuminance). 0.001 phot, 0.929 foot-candle; 10 lux.

Phot. 1,000 milliphots, 1.000×10^4 lm/m^2, 10^{-4} lx; 929 candles.

Stilb. 10,000 nit, 3.1416 lamberts, 31,416 apostilbs.