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Vision Glossary

1. ***Scope***—The function of uniform terminology is to promote understandable and exact communication in the area of vision. A great deal of effort has been expended to make these definitions suit this purpose. It is recognized that this terminology, like other dictionaries, must be revised periodically to reflect current usage and changing needs. The Driver Vision Subcommittee of the Human Factors Engineering Committee, therefore, solicits suggestions for improvements and additions to be considered in future revisions.

2. ***References***

2.1 Related Publications—The following publications are provided for information purposes only and are not a required part of this document.

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3. ***Definitions***

3.1 Field of View

3.1.1 AMBINOCULAR FIELD OF VIEW—The total field of view that can be seen by either eye. It is the combination of all of the right and all of the left monocular fields of view.

NOTE—The ambinocular field of view is larger than the binocular field of view.

3.1.2 BINOCULAR FIELD OF VIEW—The field of view that can be seen simultaneously by both eyes (i.e., only the overlapping areas of the right and left monocular fields of view).

3.1.3 CENTRAL FIELD OF VIEW—(See Foveal Field of View.)

3.1.4 DIRECT FIELD OF VIEW—The field of view which can be viewed directly, without any mirrors or other imaging devices (e.g., periscopes or video monitors).

3.1.5 FIELD OF VIEW (VISUAL FIELD)—The extent of visual space over which vision is possible with the eyes in a fixed position (i.e., while looking straight ahead, it is the entire region of space visible). The size of the visual field is influenced by such individual factors as age, alcohol, anxiety, attentiveness, drugs, fatigue, gender, and general health.

3.1.6 FOVEAL FIELD OF VIEW (CENTRAL FIELD OF VIEW)—The small, 1 to 2 degree region in the center of the visual field where visual acuity is greatest.

3.1.7 INDIRECT FIELD OF VIEW—The field of view provided by imaging devices (e.g., mirrors, periscopes, or video monitors).

3.1.8 MONOCULAR FIELD OF VIEW—The field of view that can be seen by one eye.

3.1.9 PERIPHERAL FIELD OF VIEW—The outer, non-foveal field of view. For practical purposes, anything beyond the small (1 to 2 degree) central area of vision can be considered part of the peripheral field of view. This area is characterized by (a) poor acuity, (b) poor color discrimination, and (c) optimal sensitivity to low levels of light.

3.1.10 PRIMARY LINE OF SIGHT—The line connecting the point of observation and the fixation point. (The point of observation is the midpoint of a line connecting the centers of rotation of the two eyes.)

3.1.11 VISUAL FIELD—(See Field of View.)

3.2 Psychophysics

3.2.1 ABSOLUTE THRESHOLD—The minimum value required for the presence of a stimulus or stimulus attribute to be detected. For example, the minimum intensity required for a light to be detected, or the minimum amount of contrast required for a pattern to be detected. The more perceptible a stimulus is—or the more sensitive the observer—the lower the absolute threshold will be. See threshold.

3.2.2 DIFFERENCE THRESHOLD—The least amount by which two stimuli must differ along a given dimension (e.g., intensity, color, length, weight, etc.) to be perceived as different. The more perceptible a difference is—or the more sensitive the observer—the lower the difference threshold will be. See threshold.

3.2.3 JUST-NOTICEABLE DIFFERENCE (JND)—(See difference threshold.)

3.2.4 PSYCHOPHYSICS—The study of the quantitative relationship between physical aspects of a stimulus and the perception of that stimulus.

3.2.5 SENSITIVITY—As a psychophysical expression, it is the reciprocal of the measured threshold. For example, contrast sensitivity is the reciprocal of contrast threshold; a spectral sensitivity curve plots the reciprocals of the thresholds obtained for each of the wavelengths.

3.2.6 STEVEN'S POWER LAW (POWER FUNCTION)—The mathematical relationship between physical magnitude and perceived magnitude. S. S. Steven found that the perceived magnitude was a function of the stimulus magnitude raised to a power ($S = kI^b$, where S = the perceived magnitude, k is a constant, and I is the actual physical magnitude). The exponent's value, b, is specific to modality (vision, audition, taste, etc.) and stimulus attribute of interest (brightness of a light versus redness of a light, for example).

3.2.7 THRESHOLD—The smallest value of a stimulus which results in a change in perceptual states (e.g., 'seeing' versus 'not seeing'). Thresholds are mathematically defined, usually as the point at which performance is 50%. (For example, the intensity of light which can just be seen 50% of the time.) See also absolute threshold and difference threshold.

3.2.8 WEBER'S LAW—A psychophysical law which states that the relationship between the initial stimulus intensity and the change in intensity required to perceive a difference (difference threshold) is a constant. Weber's law is usually expressed as the equation $\Delta I / I = k$, where I is the initial intensity, ΔI is the smallest detectable change in intensity, and k is the constant.

3.3 Retina

3.3.1 BLIND SPOT (OPTIC DISC)—The area of the retina where the fibers of the optic nerve leave the eye. This area contains no photoreceptors and is therefore insensitive to light.

3.3.2 CONES—The type of photoreceptor responsible for color vision and resolution of fine detail (acuity). Cones only function at high light levels (referred to as photopic vision). Most people have three types of cones, each containing a different photopigment. Abnormalities in one or more of the cone types will result in a deficiency of color vision. The type of vision provided by cones is analogous to a picture taken with slow, high resolution, color film. Cones are the only type of photoreceptor found in the fovea. Although there are some cones in the peripheral areas, their number falls off rapidly as you move away from the center of the retina.

3.3.3 FOVEA—The small, central area of the retina (1 to 2 degrees visual angle), with the highest density of photoreceptors. When a viewer focuses on an object, it is imaged on the fovea. Foveal vision is chromatic and has the greatest visual acuity.

3.3.4 OPTIC NERVE—The nerve bundle which transmits retinal sensations from the eye to the brain.

3.3.5 PHOTOPIGMENT—A light sensitive molecule contained within the photoreceptors of the eye. There are four different types of photopigments (one found in rods, and three different types for cones). Each photopigment absorbs light of various wavelengths to a different degree.

3.3.6 PHOTORECEPTORS—Specialized nerve cells (rods and cones) found in the retina of the eye that contain light-sensitive materials (called photopigments).

3.3.7 RETINA—An outgrowth of the brain forming a thin lining at the back of the eyeball and containing the light-sensitive rods and cones which are the peripheral end organs of the optic nerve.

3.3.8 RODS—The most light-sensitive type of photoreceptor. Rods form an achromatic (color blind) part of the visual system, which is functional even at low light levels (scotopic vision). However, acuity is very poor. The type of vision created by rods is analogous to a picture taken with fast but coarsely grained photographic film. Rods are located throughout the retina, except in the fovea and the blind spot, and are primarily responsible for peripheral vision.

3.4 Sensitivity to Light

3.4.1 GLARE—The light or reflection from a relatively bright light source (compared to the luminance levels in the rest of the visual field.) Depending on the relative intensity of the glare source and the physical condition of the observer:

a. Glare can result in annoyance, discomfort, visual fatigue, reduced visual ability, and even temporary "blindness;"
b. The effect of glare can be magnified by the scattering of light inside the observer's eyes (this problem becomes more prevalent with increasing age).

3.4.1.1 Discomfort Glare—Glare of sufficient magnitude so as to cause annoyance or discomfort.

3.4.1.2 Disability Glare—Glare of sufficient magnitude so as to cause a reduction in visual ability.

3.4.2 LATERAL INHIBITION—Lateral inhibition refers to antagonistic interactions between neighboring neural regions. In terms of vision, stimulating one area of the retina with light may cause adjacent areas to be less responsive. Essentially, excitation in one cell causes an inhibitory message to be sent to other neighboring cells. Lateral inhibition occurs throughout the visual pathway, and is believed to play a key role in such diverse phenomena as contrast effects, Mach bands, and color perception.

3.4.3 MESOPIC—Refers to the low and intermediate levels of light (0.001 to 100 candelas/meter^2), that fall between photopic and scotopic levels, or the type of vision available under these lighting conditions. Both rods and cones contribute to mesopic vision.

3.4.4 PHOTOPIC—Refers to daylight levels of illumination (>100 candelas/meter^2), or the type of vision which is available when the eyes are adapted to these light levels. Photopic vision is mediated by the cones. Peak spectral sensitivity for photopic vision occurs at approximately 555 nm. Overall spectral sensitivity of photopic vision is lower than that observed for scotopic vision. Photopic vision becomes fully dark adapted (i.e., reaches maximum sensitivity) after 5 to 6 min in the dark.

3.4.5 SCOTOPIC—Refers to exceptionally low light levels (<0.001 candelas/meter^2), or the type of vision available when the eyes are adapted to these low levels of illumination. Scotopic vision is mediated by the rods, and is characterized by reduced contrast sensitivity, poor acuity, and achromatic vision. Peak spectral sensitivity for scotopic vision occurs at approximately 505 nm. Overall spectral sensitivity of scotopic vision is higher than that observed for photopic vision. Dark adaptation of the scotopic system takes at least 20 min, and may continue for 30 to 40 min.

3.4.6 SPECTRAL SENSITIVITY—The sensitivity of the visual system to various wavelengths of light. Spectral sensitivity curves plot sensitivity (1/absolute threshold) as a function of wavelength. The spectral sensitivity function is different depending on which aspect of the visual system is tested (for example, photopic versus scotopic).

3.5 Constancy and Contrast Effects

3.5.1 ADAPTATION—A change in sensitivity as a result of continued or repeated exposure to stimuli of similar nature or magnitude. Adaptation may result in increased sensitivity (as is the case with dark adaptation), or in decreased sensitivity (which can result in aftereffects, such as successive color contrast).

3.5.2 AFTEREFFECT—The effect of a past stimulus on the present perceptual experience. Aftereffects are brought about by prolonged or repeated exposure to a particular stimulus or stimulus quality (such as color or constant motion in one direction). This adaptation results in reduced sensitivity to that particular quality, giving rise to illusory perceptions which are in the opposite or complimentary direction. For example, after viewing a bright green slide for several minutes, you may see a reddish patch on an otherwise white wall; viewing something that has a constant downward motion (such as a waterfall) may cause stationary objects to appear to move upwards.

3.5.3 AFTERIMAGE—A visual sensation which persists for a short time after exposure to some intense stimulus. Afterimages may be positive or negative, either reproducing or being complementary to the preceding experience.

3.5.4 CONSTANCY EFFECTS—The general tendency for perceptions to remain constant under a variety of conditions. In short, perceptions remain constant although the actual physical stimulation is different (compare to contrast effects).

3.5.5 CONTRAST EFFECTS—Perceptual effects that result from the interaction of two or more areas of stimulation so that the presence of one affects the appearance of the other. For example, a particular gray patch may appear to change color, or to be lighter or darker, depending on its surrounding area. Contrast effects are varying perceptions to the same physical stimulus (compare to constancy effects). See color contrast and lightness contrast.

3.5.6 LIGHTNESS CONSTANCY—The tendency for the perceived lightness of an object to remain constant despite variations in the level of illumination. For example, when viewing an object indoors there will be much less light reflected back to the eye than when the same object is viewed in natural sunlight. However, the brightness of the object will remain constant.

3.5.7 LIGHTNESS CONTRAST—A perceptual phenomenon where the apparent brightness or lightness of an area is influenced by the lightness of adjacent areas. For example, the same gray patch will appear lighter when surrounded by a black area, but will appear darker when surrounded by white. An example of lightness contrast is the perception of black in a television image. The actual image cannot be any darker than the lightness of the screen when the television is turned off. It is assumed that lateral inhibition is primarily responsible for this effect.

3.5.8 MACH BANDS—A perceptual phenomenon which results in the enhancement of contrast at borders where there is an abrupt change in luminance. Mach bands are the illusory bands that appear at the border—a thin 'darker' band on the dark side, and a thin 'lighter' band on the light side. It is assumed that lateral inhibition at the level of the retina is primarily responsible for this effect.

3.5.9 MOTION AFTEREFFECT (WATERFALL ILLUSION)—The perception that a stationary object is moving. This occurs after prolonged viewing of movement in one direction. The aftereffect produces apparent movement in the opposite direction.

3.5.10 SIMULTANEOUS CONTRAST—A contrast effect that results from the interaction of two or more adjacent areas, presented simultaneously, such that the presence of one affects the appearance of the other. See contrast effects, lightness contrast, color contrast, and successive contrast.

3.5.11 SIZE AFTEREFFECT—A change in the perceived size of an object after viewing an object of a different size.

3.5.12 SIZE CONSTANCY—The tendency for the perceived size of an object to remain constant despite changes in the size of the retinal image of the object as viewing distance changes.

3.5.13 SUCCESSIVE CONTRAST—A contrast effect in which there is a change in the appearance of an object or area as a result of what was viewed immediately before it. Successive contrast usually refers to a type of color contrast where viewing a colored stimuli results in an afterimage in the complimentary color. See color contrast.

3.5.14 TILT AFTEREFFECT—A temporary change in the perceived orientation of lines after prolonged exposure to lines of a similar, but not identical, orientation.

3.6 General Perception

3.6.1 APPARENT MOVEMENT—An illusion of motion brought about by certain patterns of stationary stimuli; motion pictures are a familiar example.

3.6.2 BRIGHTNESS—The subjective experience of light intensity.

3.6.3 CRITICAL FLICKER FREQUENCY (CFF)—The highest perceptible rate of temporal changes in light intensity (flicker). When this rate is exceeded, separate flashes of light blend together perceptually, and appear as a constant light. The human CFF is around 60 Hz.

3.6.4 DARK ADAPTATION—Adjustment of the eyes to low levels of illumination which results in increased sensitivity to light. Photopic vision (mediated by the cones) reaches its maximum sensitivity after about 5 min, whereas the scotopic sensitivity (mediated by the rods) may continue to increase for 30 to 40 min.

3.6.5 LIGHT ADAPTATION—An adjustment of the visual system to an increase in illumination, the result of which is reduced sensitivity to light.

3.6.6 OPTICAL ILLUSION—An image which causes a misinterpretation or perceptual error.

3.6.7 PARALLAX—The apparent relative movement of objects in the field of vision as the point of view is shifted laterally. Objects nearer to the observer than the point fixated seem to move against the direction of the shift; objects beyond the point fixated move with the shift. Also refers to the apparent difference in rate of movement of two objects actually moving at the same velocity but at different distances from the observer.

3.6.8 PARALLAX (BINOCULAR)—The apparent displacement or difference in apparent location of an object as seen from two different points not on a straight line with the object, for example, a pointer apparently displaced on a scale when the head is moved in relation to it. (Also operates monocularly.)

3.6.9 VISUAL PERCEPTION—The integrated conscious response and interpretation of the total visual stimulus situation. This response may be modified or interpreted in terms of stored physiological and psychological remnants of past experience which are brought to bear in that situation.

3.7 Pattern Recognition

3.7.1 CONTRAST—The difference in luminance (lightness or brightness) between two areas. Providing sufficient contrast is the most important element for ensuring pattern recognition (i.e., being able to read a display, or recognize a symbol). When reporting contrast values, it is advisable to specify the equation used to determine those values. See contrast ratios for the various equations used to quantify contrast.

3.7.2 CONTRAST RATIOS—Equations used to quantify the luminance differences between two areas. All of the following equations are nonequivalent, valid, and common. It is advisable to specify which equation was used when reporting contrast values.

a. Contrast = (light – dark)/light
b. Contrast = (light – dark)/dark
c. Contrast = (dark – light)/light
d. Contrast = (dark – light)/dark
e. Contrast = light/dark
f. Contrast = (light – dark)/(light + dark) (Michelson or modulation contrast)

3.7.3 CONTRAST SENSITIVITY FUNCTION (CSF)—The relationship between the minimum contrast required and the nature of the pattern to be detected. Specifically, it is the reciprocal of the contrast required to detect the presence of a pattern as a function of the pattern's spatial frequency. (See multichannel model.) It has been found that an individual's CSF is a better predictor of performance on visual tasks (such as recognizing street signs) than traditional measures of acuity.

3.7.4 FORM PERCEPTION—(See Pattern Recognition.)

3.7.5 LANDOLT RING (LANDOLT C)—Similar in appearance to the letter C, Landolt rings are used to test visual acuity. The thickness of the ring and the break in its continuity are each one-fifth of its overall diameter. The ring is rotated so that the gap appears in different positions and the observer is required to identify the location of the gap.

3.7.6 MULTICHANNEL MODEL—A model of visual processing that assumes the visual system performs a Fourier transform on incoming images, thereby reducing complex patterns into their simple (sinusoidal) spatial frequency components.

3.7.7 PATTERN RECOGNITION—The detection, discrimination, and recognition of the spatial characteristics of stimuli (e.g., the size, shape, and visual textures).

3.7.8 SNELLEN ACUITY (SNELLEN FRACTION)—One of several measures of visual acuity. The assessment uses standard charts of letters of various sizes. Acuity is expressed as the distance at which a given individual can read the letters correctly, compared to the distance a standard 'normal' person could read the same letters. For example, a person with 20/40 vision can barely read at a 20 ft distance what the 'normal' person can read at 40 ft.

3.7.9 VERNIER ACUITY—One of several measures of visual acuity. It is defined as the smallest detectable misalignment between two vertical lines placed one above the other. Vernier acuity is usually expressed in seconds of arc of visual angle.

3.7.10 VISUAL ACUITY—The ability to clearly perceive spatial detail. Traditional assessments of acuity, such as the Snellen chart and Landolt rings, employ high contrast patterns of various sizes. The test then establishes the smallest pattern or critical detail of a pattern that can be detected, and compares this to a standard, 'normal' observer. Visual acuity is a function of the brightness, contrast, and other characteristics of the objects viewed, as well as the state of adaptation, location of the retinal image, and other characteristics of the observer.

3.8 Color Vision and Perception

3.8.1 ACHROMATIC—Lacking hue (color), achromatic objects can vary in luminance (brightness) from white through any gray to black. Examples of achromatic objects include black and white TV images and gray scales.

3.8.2 BEZOLD-BRUCKE EFFECT—When luminance is increased, all chromatic colors, except a certain invariable blue, yellow, green, and red, appear increasingly like blue or yellow and decreasingly like green or red.

3.8.3 CHROMA—Short form for Munsell chroma, an index of saturation of the perceived color.

3.8.4 COLOR CONSTANCY—The tendency of an object's apparent color to remain unchanged despite changes in the spectral composition of the light falling on and reflected by the object. For example, when an object is viewed under fluorescent lights versus sunlight, the wavelength composition of the light being reflected back to the eyes is very different. Yet, over a wide range of situations, the color of the object does not appear to vary.

3.8.5 COLOR CONTRAST—A perceptual phenomenon in which a change in color appearance is brought about by the interaction of two different areas, at least one of which is colored. In the case of a color-achromatic pair, the colored area induces a complimentary hue or tint in the achromatic area. For example, a bright green patch may make an adjacent gray patch appear slightly reddish. Simultaneous color contrast occurs when the areas in question are adjacent; successive color contrast occurs when the areas in question are presented sequentially. Successive color contrast is a type of aftereffect.

3.8.6 COMPLIMENTARY COLORS—Any two colors that, when mixed together in appropriate proportions, produce gray or white.

3.8.7 HUE—The dimension of color perception most commonly denoted by such names as red, yellow, green, blue, etc. The most closely related physical characteristic to hue is wavelength.

3.8.8 MONOCHROMATIC—Referring to a single hue or color.

3.8.9 MUNSELL SYSTEM—A system of classifying and designating color attributes of object in terms of perceptually uniform color scales for the three variables: hue, value, and chroma. ("Color-Order Systems," in 3.12.3.)

3.8.10 NEGATIVE AFTERIMAGE—An afterimage which is the opposite of the initial stimulus. This includes images of complimentary colors and lightness reversals. For example, the afterimage produced by a red stimulus will appear green; the afterimage produced by a blue stimulus will appear yellow; the afterimage of black blocks separated by white grid lines will be white blocks separated by black grid lines.

3.8.11 POSITIVE AFTERIMAGE—Brief afterimage with approximately the same hues as the original. (Also called homochromatic afterimage.)

3.8.12 PURKINJE SHIFT—It is the gradual change in the perceived *relative* brightness of different colors as illumination changes from daylight to twilight. For example, red objects appear much darker than other colored objects at night, but may appear as bright or brighter than the same objects during the day. On the other hand, green and blue objects which appear darker than other objects during the day may appear brighter at night. This reversal of relative brightness is what is referred to as the Purkinje shift. The shift is a result of the change in spectral sensitivity associated with the transition from cone (photopic) vision to rod (scotopic) vision.

3.8.13 SATURATION—The dimension of color perception which is most closely related to the purity of the light. Narrow-band light tends to appear saturated. On the other hand, the more white light which is added to the mixture, the less saturated the stimulus will appear.

3.8.14 TRICHROMATIC—Refers to a 'three-color' system or a type of color vision arising from three different cone types. Normal human color vision is trichromatic.

3.9 Color Vision Deficiencies

3.9.1 COLOR DEFICIENCY—A term used to describe a variety of impairments of color vision. These range in severity from anomalous trichromatic vision (slightly abnormal color vision), to dichromatic vision (partial color blindness), to monochromatic vision (complete color blindness). The most common form of color deficiency is anomalous trichromatism; the rarest is monochromatism.

For both anomalous trichromats and dichromats, the most common problem is some form of red-green deficiency, while blue-yellow deficits are rare. Considering all types of color deficiencies, the total incidence rate of color deficiencies is still fairly low. The highest rates occur for Caucasian males (8 to 10% of this population has some form of color deficiency). Across population groups, males are up to 10 times more likely to be color deficient.

There are several steps one can take to prevent problems for individuals with color deficiency. First and foremost, provide ample luminous contrast. Second, avoid using red and green, or blue and yellow in pairs. Finally, whenever possible employ mid-spectrum colors while avoiding deep reds and deep blues.

3.9.2 ANOMALOUS TRICHROMATISM—The most frequent but least severe form of color deficient vision. Anomalous trichromats, like individuals with normal color vision, have three cone types. However, one of the cone types function abnormally. It should be noted that not all anomalous trichromats demonstrate impaired color discrimination. There are two major types of anomalous trichromatism: protanomaly and deuteranomaly. Both of these are red-green color deficiencies.

3.9.2.1 *Protanomaly*—A type of anomalous trichromatism. Protanomaly is caused by abnormalities in the cones sensitive to long wavelengths of light, and results in a mild form of red-green color deficiency. Color discrimination is usually impaired from red to yellowish-green, with the extent of the problem varying for different individuals. In addition, protanomalous individuals—like protanopes—are not able to see longer wavelengths of light (deep reds).

3.9.2.2 *Deuteranomaly*—The most common type of anomalous trichromatism. Deuteranomaly is caused by abnormalities in the cones sensitive to medium wavelengths of light, and results in a mild form of red-green color deficiency. Color discrimination is usually impaired from red to yellowish-green, but the extent of the problem varies for different individuals.

3.9.3 DICHROMATISM (PARTIAL COLOR BLINDNESS)—A deficiency in color vision caused by the absence of one of the three cone types. There are three major types of dichromatism: protanopia, deuteranopia, and tritanopia. Both protanopia and deuteranopia are red-green deficiencies, while tritanopia is a blue-yellow deficit. The most common form of dichromatism is deuteranopia; the rarest is tritanopia.

3.9.3.1 *Protanopia*—One of the three major forms of dichromatism (partial color blindness), caused by the absence of cones sensitive to long wavelengths of light. Like deuteranopia, protanopia is a red-green color deficiency, resulting in an inability to discriminate colors from medium wavelengths ("green") through long wavelengths ("red"). Unlike deuteranopes, protanopes have a shortened visible spectrum, and are entirely unable to see deep, saturated reds.

3.9.3.2 *Deuteranopia*—The most common of the three major forms of dichromatism (partial color blindness), caused by the absence of cones sensitive to medium wavelength of light. Like protanopia, deuteranopia is a red-green color deficiency, resulting in an inability to discriminate colors from medium wavelengths ("green") through long wavelengths ("red"). Unlike protanopia, there is no shortening of the visible spectrum at the red end.

3.9.3.3 *Tritanopia*—The rarest of the three major forms of dichromatism (partial color blindness), caused by the absence of cones sensitive to short wavelengths of light. Tritanopes are unable to discriminate colors from short wavelengths ("blue") through medium wavelengths ("yellow").

3.9.4 MONOCHROMATISM (COMPLETE COLOR BLINDNESS)—The most severe form of color deficient vision, monochromatism is exceptionally rare. Monochromats demonstrate a complete inability to discriminate colors.

3.10 General Vision

3.10.1 ACCOMMODATION—The process by which the eye changes focus from an object at one distance to an object at another distance.

3.10.2 AMETROPIA—The refractive condition which, with accommodation relaxed, parallel rays do not focus on the retina; a condition representing the manifestation of a refractive error, specifically myopia, hypermetropia, or astigmatism, hence, a deviation from emmetropia.

3.10.3 ASTIGMATISM—Asymmetrical curvature of refractive surfaces of the eye which result in inaccurate focusing of parallel rays of light on the retina.

3.10.4 BLINDNESS—Generally legally defined in the United States as visual acuity for distant vision of 20/200 or less in the better eye, with best correction or visual acuity of better than 20/200 if the widest diameter of field of vision subtends an angle no greater than 20 degrees. (Some states include up to 30 degrees.) (A measure of 20/200 visual acuity means that a person can see at a distance no greater than 6.5 m [20 ft] what one with normal sight can see at 65 m [200 ft].)

3.10.5 BLINK RATE—The frequency with which the eyelids cover the eye under specified conditions.

3.10.6 CONVERGENCE—Process of varying the rotation of the eyes, as the object observed approaches the viewer, to allow image to be formed at corresponding regions of the two retinas; that is, the turning of the two eyes toward each other so that their respective lines of sight meet at a common point in space, the point of the object being focused on.

3.10.7 DIOPTER—The amount of accommodation exerted by the eye is expressed in diopters, the unit used for designating the refractive power of a lens. The power of a lens in diopters is the reciprocal of its focal length in meters (D = 1/F). A one-diopter lens focuses parallel rays at a point 1 m away from it.

3.10.8 EMMETROPIA—The refractive state of the eye when, with the lens of the eye at rest (least convex), parallel rays are brought to focus on the retina (no refractive error).

3.10.9 FARSIGHTEDNESS—(Also known as hyperopia or hypermetropia.) A condition in which objects are focused behind the retina. Because of this refractive problem, individuals with hyperopia may have difficulty focusing on near objects.

3.10.10 HETEROPHORIA—A term used to denote a tendency to imperfect coordination of the various muscles which move the two eyes so as to maintain binocular single vision.

3.10.11 HYPEROPIA OR HYPERMETROPIA—(See Farsightedness.)

3.10.12 INTERPUPILLARY DISTANCE (IPD)—The distance between the centers of the pupils at the described point of fixation.

3.10.13 IRIS—The circular pigmented ring of color that gives the eye its characteristic color and controls the size of the pupillary opening.

3.10.14 MYOPIA—(See Nearsightedness.)

3.10.15 NEARSIGHTEDNESS—(Also known as myopia.) A condition in which objects are focused in front of the retina. Because of this refractive problem, individuals with myopia may have difficulty focusing on far objects.

3.10.16 OCULAR DOMINANCE—Visual perceptions of most people tend to be more or less dominated by the vision of one of the eyes.

3.10.17 OPHTHALMOLOGY—The branch of medicine dealing with the structure, function, and diseases of the eye.

3.10.18 PRESBYOPIA—The age related decline in the ability to bring near objects into focus, which is due to changes in the lens of the eye and its ability to accommodate (i.e., change shape).

3.10.19 PURSUIT EYE MOVEMENTS—Smooth, voluntary eye movements, made while tracking moving objects. These movements are typically of much longer duration and considerably lower velocity than saccades.

3.10.20 SACCADIC EYE MOVEMENTS (SACCADES)—Rapid, abrupt movements of the eyes, which function to change fixation from one location to another. Saccades are high velocity movements (20 to 600 degrees/s), of short duration (20 to 100 ms).

3.10.21 STEREO ACUITY—The ability to perceive binocularly the solidity and relative distances of objects. Stereo acuity is defined arbitrarily as the degree of binocular perception of apparent depth induced by stereoscopic means. This is differentiated from the discrimination of real depth or the relative distances of objects viewed as they are actually oriented in space relative to each other.

3.10.22 STEREOPSIS—The capacity for three-dimensional vision. It is a function of the two eyes acting in unison, but each receiving slightly different views of solid objects. However, other cues besides binocular vision may contribute to stereopsis, permitting some degree of depth to be perceived monocularly.

3.10.23 VIEWING ANGLE—The angle between the observer's line of sight when looking straight ahead and the line of sight when viewing a particular object (or area); it is the extent the eyes or head must rotate to look directly at that object.

3.10.24 VISIBILITY—The clarity with which an object can be seen. Also the characteristic of an object and its surroundings, including background and media through which light must be transmitted, indicating its probability of being seen. The visibility of an object is a function of many factors, including its size, illumination and contrast, as well as the visual abilities of the person viewing the object.

3.10.25 VISUAL ANGLE—The angle subtended by an object of vision at the nodal point of the eye. The magnitude of this angle determines the size of the corresponding retinal image, irrespective of the size or distance of the object.

3.11 Light Measurement

3.11.1 ANGSTROM (A)—Unit of wavelength equal to 10^{-10} m (one ten-billionth meter).

3.11.2 BLACKBODY RADIATOR—An ideal surface which completely absorbs all incoming light, and emits light that varies in spectral distribution (i.e., color) with changes in temperature.

3.11.3 CIE (COMMISSION INTERNATIONALE DE L'ECLAIRAGE)—An international organization that has developed many of the photometric and colorimetric standards.

3.11.4 CIE STANDARD ILLUMINANT—Standard light sources with specific spectral power distributions used for light measurement. The most common CIE standard illuminants are A (which is representative of incandescent light) and D65 (which is representative of normal sunlight).

3.11.5 CIE STANDARD OBSERVER—The concept of standard observer is used to define visual response functions intended to be representative of a "normal" observer. It does not refer to any specific observer. Rather, it is based on data averaged from many observers under specific experimental conditions. This approach was used by the CIE in developing the photopic and scotopic luminous efficiency functions (which are the basis of photometric measurement), as well as the 1931 RGB colorimetric system. Many subsequent colorimetric functions, including the 1931 CIE XYZ, CIE L*a*b* and CIE L*u*v*, are mathematical transformations based on the same standard observer data as the 1931 RGB system.

3.11.6 DOMINANT WAVELENGTH—The wavelength of the monochromatic stimulus that will match a given sample of color when mixed with a suitable proportion of white and adjusted appropriately in intensity.

3.11.7 ILLUMINANCE—Illuminance is the amount of light (or luminous flux) striking a given area of a surface. Specifically:

$$\text{Illuminance of a surface (in lux)} = \text{Luminous Flux (in lumens)} / \text{Solid Angle (in steradians)}$$

The SI unit of measurement for illuminance is the lux (lx), where 1 lux = 1 lumen per meter squared. Other units of measurement include the phot (ph), the milliphot (mph), and the footcandle (fc). Illuminance is irradiance evaluated with regard to its visibility to a standard human observer.

3.11.8 LIGHT—Light is radiant energy evaluated with respect to its ability to stimulate the sense of sight of a human observer. In other words, it is visible electromagnetic energy (electromagnetic energy with wavelengths in the range of approximately 400 to 700 nm).

3.11.9 LUMINANCE—Luminance is the intensity of emitted or reflected light from a surface, in a given direction, per unit area. The SI unit of measurement for luminance is the nit (nt), where 1 nit = 1 candela per meter squared. Other units of measurement include the stilb (sb), apostilb (asb), lambert (L), millilambert (mL), and footlambert (fL). Luminance is radiance evaluated with regard to its visibility to a standard human observer.

3.11.10 LUMINOUS—Emitting or reflecting light (see light). Pertaining to electromagnetic radiation as perceived by the eye; that is, with the contributions at wavelengths weighted according to the luminous efficiency function $V(\lambda)$. The term is often used to differentiate between the total energy and that energy which is perceived by the eye. For example, *radiant* transmittance or reflectance refers to the total amount of electromagnetic energy transmitted or reflected, whereas *luminous* transmittance or reflectance refers to only the radiation seen by the eye.

3.11.11 LUMINOUS EFFICIENCY FUNCTION—$V(\lambda)$—The function describing the relative sensitivity of the eye to radiant energy of different wavelengths.

3.11.12 LUMINOUS FLUX—The rate of light flow per unit time, usually expressed in lumens. Luminous flux is radiant flux evaluated with regard to its visibility to a standard human observer.

3.11.13 LUMINOUS INTENSITY—The light producing power of a source (the amount of light *leaving* a source) within a given area. Specifically:

Luminous Intensity (in candelas) = Luminous Flux (in lumens) ⁄ Solid Angle (in Steradians)

Luminous intensity is radiant intensity evaluated with regard to its visibility to a standard human observer.

3.11.14 NANOMETER (nm)—A unit of length equal to one billionth (10^{-9}) of a meter.

3.11.15 PHOTOMETRY—The prediction of apparent brightness, based on the measurement of radiant energy corrected for its perceptibility to humans. Photometers use special filters that seek to replicate human spectral sensitivity. Photometers attempt to measure perceived brightness (a psychological quality), as opposed to radiometers which measure actual physical intensity.

3.11.16 RADIANT ENERGY—Radiant energy is electromagnetic energy, which includes gamma rays, X-rays, microwaves, UV radiation, infrared radiation, radar, TV and radio signals. In addition, a very narrow band of electromagnetic energy (wavelengths of approximately 400 to 700 nm) constitutes the visible spectrum (i.e., light). For example, *radiant* transmittance refers to the total amount of electromagnetic energy transmitted, whereas *luminous* transmittance refers to only the radiation seen by the eye.

3.11.17 RADIOMETRY—The measurement of radiant energy.

3.11.18 SI UNITS—The standard international units of measurement as determined by the International System (Systeme Internationale d'Unites). For illuminance, the SI unit is the lux (lx), where 1 lux = 1 lumen per meter square; for luminance, the SI unit is the nit (nt), where 1 nit = 1 candela per meter squared (cd/m^2). The SI photometric base unit is the candela.

3.11.19 ULTRAVIOLET RADIATION—The radiation beyond the violet end of the visible spectrum with wavelengths less than 400 nm. It is divided, for convenience, into: UVA—transmitted by glass, 400 to 320 nm; UVB—sunburning region of sunlight, 320 to 280 nm; UVC—transmitted by quartz, 280 nm.

3.11.20 WATT—The SI unit of measurement of radiant flux. Radiant flux is the radiant energy emitted per unit time (as compared to lumens, which is a measure of luminous flux).

3.11.21 WAVELENGTH—Wavelength is the straight line distance between a point on one wave to the corresponding point on the next wave. When measuring light, wavelength is usually expressed in nanometers (10^{-9} m) or angstroms (10^{-10} m). The wavelength of visible radiation (light) is most closely related to the perceptual attribute known as hue.

3.12 Colorimetry

3.12.1 CIE CHROMATICITY COORDINATES—The proportions of CIE tristimulus values required to define a color. They are designated as x, y, and z, and are the ratios of the tristimulus values X, Y, and Z in relation to their sum (X+Y+Z). Specifically:

x = X/(X+Y+Z)
y = Y/(X+Y+Z)
z = Z/(X+Y+Z)

The x and y chromaticity coordinates are the x and y axes of the 1931 CIE chromaticity diagram. The z coordinate is never plotted. Since x+y+z must equal 1, z is redundant given x and y.

3.12.2 COLORIMETRY—The prediction of color appearance, based on the measurement of radiant energy corrected for its effect on human color vision. Colorimeters use special filters to mimic the spectral sensitivity of the different cone types found in the eye. Colorimeters attempt to measure perceived color, as opposed to spectroradiometers which measure the actual wavelength composition of light.

3.12.3 COLOR-ORDER SYSTEMS—A systematic method for ordering colors. Color-order systems employ a set of material standards representative of the whole set of colors under consideration, and provide a notational or consistent naming practice to facilitate color identification and communication. The most common color-order system is Munsell.

3.12.4 COLOR SPACE (COLOR SCALE)—A mathematical model used to quantify and predict color perception. The models are usually 3-dimensional, and are most commonly based on data from color-matching studies. The first color scale to be used widely in industry was the 1931 CIE XYZ system. The current industry standards, CIE L*a*b* and CIE L*u*v*, are transformations of the 1931 system. Both CIE L*a*b* and CIE L*u*v* were attempts to provide a color space of uniform perceptual units, such that equal distances within the color space—ΔE—would correspond to equal changes in color perception. However, two important limitations of these color spaces are often overlooked. First, they were designed to predict small differences (just-noticeable differences) in color appearance; they were not intended to predict large differences across the color space. Second, both CIE L*a*b* and CIE L*u*v* assume opaque colored objects. However, by industry convention CIE L*a*b* is used for surface color (opaque) objects, while CIE L*u*v* is used for displays and other self-luminating stimuli.

*3.12.4.1 CIE L*a*b* (1976 CIELAB)*—A three-dimensional model of color appearance, used widely in industry to measure and predict the appearance of colored objects. CIELAB is a transformation of the 1931 XYZ System. (See Color Space.) L*, a*, and b* represent the coordinates of the CIELAB three-dimensional model, where L* is principally a luminous factor.

*3.12.4.2 CIE L*u*v* (1976 CIELUV)*—A three-dimensional model of color appearance, used widely in industry to measure and predict the color appearance of displays. CIELUV is a transformation of the 1931 XYZ System. (See Color Space.) L*, u*, and v* represent the coordinates of the CEILUV three-dimensional model, where L* is principally a luminous factor. CIE L*u*v* values are NOT equal to CIE L'u'v' values.

3.12.4.3 CIE RGB System (1931 RGB System)—This is the first model of color perception developed by the CIE, and is based on the color-matching behavior of the CIE standard observer (see Color Space). RGB stands for the three primaries used by this system for color-matching—red (700 nm), green (546.1 nm) and blue (435.8 nm). However, when using the RGB primaries there exist some colors which require 'negative' amounts of one of the primaries (i.e., at least one of the primaries will have a negative tristimulus value). In order to overcome this, the CIE developed the 1931 XYZ system which is a mathematical transformation of the RGB system.

3.12.4.4 CIE XYZ System (CIE 1931 standard colorimetric system, or 1931 XYZ System)—This is the first model of color perception to be used widely in industry, and is based on the color-matching behavior of the CIE standard observer (see Color Space). It is a transformation of the 1931 RGB system, with these notable differences:

a. For all color-matching solutions, the tristimulus values are always positive,
b. The XYZ primaries of the system are imaginary—they do not correspond to any actual wavelength, and
c. The Y primary is defined so that it represents luminance only, while X and Z have no luminance.

3.12.5 SPECTROPHOTOMETER—A device for measuring reflected or transmitted radiant energy as a function of wavelength. It cannot be used for measuring emitted light. (For emissive displays, such as a CRT, a spectroradiometer should be used.) Spectrophotometers compute relative values of a sample (such as a paint chip) by comparing the sample plus background illumination to the background alone. In addition, most spectrophotometers provide for the calculation of photometric and colorimetric parameters as part of their data output.

3.12.6 SPECTRORADIOMETER—A device for measuring the absolute values of emitted radiant energy as a function of wavelength. A spectroradiometer can also be used as a spectrophotometer (to provide measures of reflected or transmitted energy), but the reverse is not true. In addition, most spectroradiometers provide for the calculation of photometric and colorimetric parameters as part of their data output.

3.12.7 TRISTIMULUS VALUES—The relative proportion of three reference lights of different colors required to match a given colored light. The CIE tristimulus values are designated as X, Y, and Z.

3.13 Photometric Measurement Units

3.13.1 LUMINOUS INTENSITY AND LUMINOUS FLUX

3.13.1.1 Candela (cd)—The candela is a unit of luminous intensity or power of a light-producing source. One candela is defined as the luminous intensity of 1/60th of 1 cm^2 of a blackbody radiator operating at the freezing point of platinum (2046 °K). The candela is the photometric base unit in the SI system of units (also known as candlepower).

3.13.1.2 Candlepower—Candlepower is another name for luminous intensity when expressed in candelas.

3.13.1.3 Lumen (lm)—The lumen is a measure of luminous flux, and is derived from the candela. It is the luminous flux emitted by a point source of uniform intensity of one candela within a steradian (unit solid angle).

3.13.1.4 Troland—A unit of retinal illumination equal to that produced by viewing a surface having a luminance of 1 cd/m^2 through a pupil having an area of 1 mm^2. Originally called photon by Troland and later renamed in his honor to differentiate it from a photon of light energy.

3.13.2 ILLUMINANCE

3.13.2.1 Footcandle (fc, fcd)—The footcandle is a unit of illuminance equal to 1 lumen per square foot. The preferred (SI) unit of illuminance is the lux (or lumen per meter squared). 1 fc = 10.76 lux. 1 lux = 9.290 x 10^{-2} fc.

3.13.2.2 Lumens per Meter Squared (lm/m²)—See lux (1 lm/m^2 ≡ 1 lux).

3.13.2.3 Lux (lx) Lux—or lumens per meter square—is the SI (Systeme Internationale d'Unites) photometric unit of illuminance. A one candela light source 1 m from a surface produces one lux of illumination on that surface. (Illuminance is the amount of light striking a surface.)

3.13.2.4 Milliphot (mph)—The milliphot is a unit of illuminance. 1 mph = 10 lux. 1 lux = 10^{-1} mph.

3.13.2.5 Phot (ph)—The phot is a unit of illuminance. 1 ph = 10^4 lux. 1 lux = 10^{-4} mph.

3.13.3 LUMINANCE

3.13.3.1 Apostilb (asb)—The apostilb is a unit of luminance equal to 10^{-4} lamberts or (1/π) nit. The preferred (SI) unit of luminance is the nit (or candelas per meter squared). 1 asb = 3.183 x 10^{-1} nit. 1 nit = 3.142 asb.

3.13.3.2 Candelas per Meter Squared (cd/m²)—See nit (1 cd/m^2 ≡ 1 nit).

3.13.3.3 Footlambert (fL)—The footlambert is a unit of luminance equal to (1/π) cd/ft^2. The preferred (SI) unit of luminance is the nit (or candelas per meter squared). 1 fL = 3.426 nit. 1 nit = 2.919 x 10^{-1} fL.

3.13.3.4 Lambert (L)—The lambert is the luminance of a perfectly diffusing surface emitting or reflecting 1 lm/cm^2 of surface area. The preferred (SI) unit of luminance is the nit (or candelas per meter squared). 1 L = 3.183 x 10^3 nit. 1 nit = 3.142 x 10^{-4} L.

3.13.3.5 Millilambert (mL)—The millilambert is a unit of luminance equal to 10^{-3} lamberts. The preferred (SI) unit of luminance is the nit (or candelas per meter squared). 1 mL = 3.183 nit. 1 nit = 3.142 x 10^{-1} mL.

3.13.3.6 Nit (nt)—The nit is the SI (Systeme Internationale d'Unites) photometric unit of luminance. Luminance is the amount of light being emitted or reflected from a surface. One nit is equivalent to one candela per meter squared (cd/m^2).

3.13.3.7 Stilb (sb)—The stilb is a unit of luminance. The preferred (SI) unit of luminance is the nit (or candelas per meter squared). 1 sb = 10^4 nit. 1 nit = 10^{-4} sb.

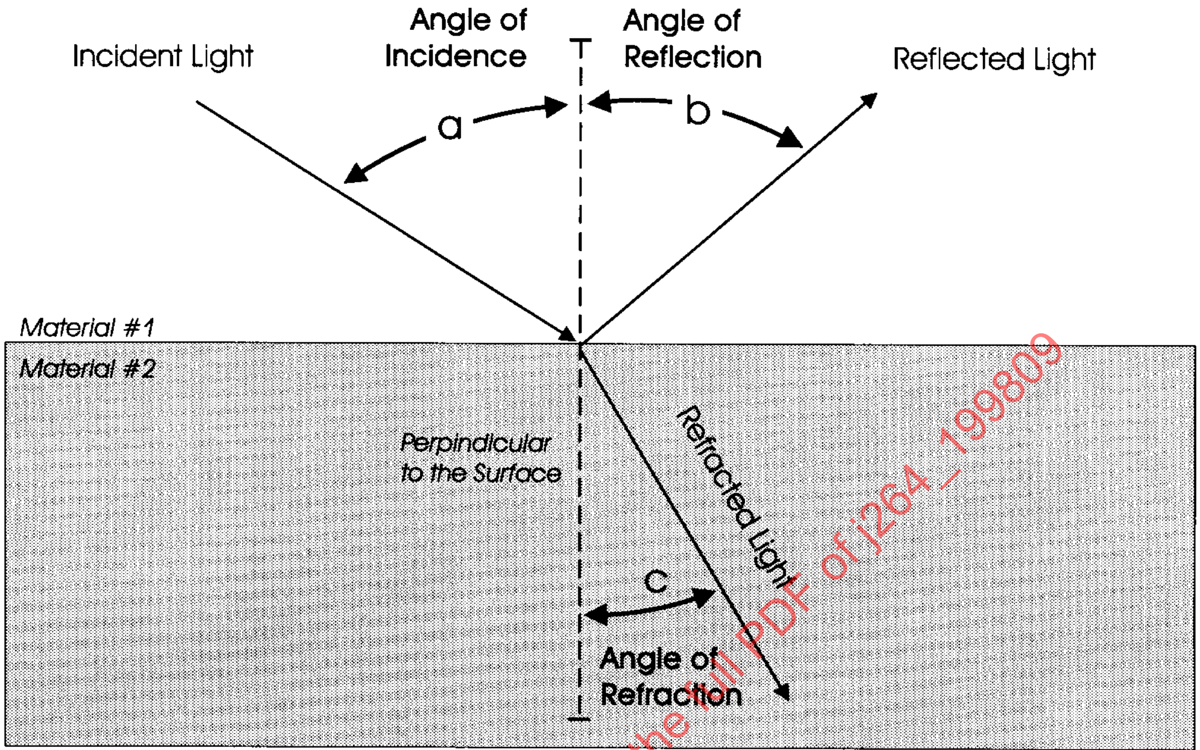
3.14 Optics

3.14.1 ABSORPTANCE—The ratio of the absorbed radiant or luminous flux to the incident flux.

3.14.1.1 Internal Absorption Factor—The ratio of the direct luminous flux absorbed by a transparent body during a single passage from the first surface to the second surface (difference between the flux leaving the first surface and that reaching the second surface) to the flux leaving the first surface.

3.14.2 ANGLE OF INCIDENCE—The angle formed between the incident light ray and the perpendicular to the surface at the point of incidence. (See Figure 1.)

3.14.3 ANGLE OF REFLECTION—The angle formed between the reflected ray and the perpendicular to the surface at the point of reflection. (See Figure 1.)



a. The angle between the incoming beam of light and the perpendicular to the surface is the ***angle of incidence***.
b. The angle between the reflected light ray and the perpendicular to the surfac is the ***angle of reflection***.
c. The angle between the refracted light and the perpendicular to the surface is the ***angle of refraction***.

FIGURE 1—ANGLE OF INCIDENCE, REFLECTION, AND REFRACTION

3.14.4 ANGLE OF REFRACTION—The angle formed between the refracted ray and the perpendicular to the surface at the point of refraction. (See Figure 1.)

3.14.5 BREWSTER'S ANGLE—If the electric vibration of the incident waves is parallel to the plane of incidence, and if the angle of incidence is such that the angle between the reflected and refracted beams equals 90 degrees, the entire beam is transmitted, and none of it is reflected.

3.14.6 CHROMATIC ABERRATION—Imperfection of an image produced by variations in the index of refraction of the elements of an optical system.

3.14.7 GLOSS—A property of a surface, associated with its spectral reflectance, that gives the surface a shiny or lustrous appearance. Measurement is based on the specular reflectance at a specified incident angle (typically 20, 60, or 85 degrees), with higher incident angles used for lower gloss specimens. A surface with a gloss value of 100 has a specular reflectance of 4%, the same as black glass.

3.14.8 INVERSE SQUARE LAW—The illumination (E), at a point in a plane perpendicular to the line joining the point and the source, is directly proportional to the luminous intensity (I) of the source in the direction of the point, and inversely proportional to the square of the distance (D) from the point to the source. For a point source, $E = I/D^2$.

3.14.9 LUMINESCENCE—Light emission that cannot be attributed merely to the temperature of the emitting body, but results from such causes as chemical reactions at ordinary temperatures, electron bombardment, electromagnetic radiation, and electric fields. Particular aspects of luminescence are referred to as fluorescence and phosphorescence.

3.14.10 NEUTRAL FILTER—Optical filter that does not alter the chromaticity of the light it transmits.

3.14.11 NEUTRAL WEDGE—Neutral optical filter with continuous graduation from low to high density.

3.14.12 OPAQUE—Having the property of obstructing the transmission of light so that objects lying beyond are not visible. The color properties of an opaque object (such as color paper) are primarily determined by its spectral reflectance. (Compare to translucent and transparent.)

3.14.13 PHOSPHORESCENCE—One form of luminescence. The ability of certain substances to continue to emit light long after the source of excitation energy has been removed.

3.14.14 PHOTOELECTROLUMINESCENCE—The use of light or other electromagnetic energy to create an electric current which, in turn, induces electroluminescence.

3.14.15 POLARIZATION—The process by which the electric field (E) component of light waves is oriented in a specific, uniform plane. Polarization is useful in selectively controlling light transmission (e.g., visual displays, sunglasses, etc.), and is used in various optical measurement devices.

3.14.16 RAYLEIGH EQUATION—Ratio of red to green required by each observer to match spectral yellow.

3.14.17 RAYLEIGH'S LAW OF SCATTERING—When heterogeneities of a transmitting medium have average dimensions somewhat smaller than the wavelength of the incident energy. The fraction of the incident flux scattered is inversely proportional to the fourth power of the wavelength.

3.14.18 REFLECTANCE—The ratio of the reflected radiant or luminous flux to the incident flux, under specified geometric and spectral conditions.

3.14.18.1 Total Reflectance—The ratio of the reflected radiant or luminous flux, reflected at all angles within the hemisphere bounded by the plane of the specimen, to the incident flux. Total reflectance is equal to the sum of diffuse and specular reflectance.

3.14.18.2 Diffuse Reflectance—The ratio of the flux reflected by a specimen to the incident flux, the reflected flux being measured at all angles except the specular angle. (See Figure 2.)

3.14.18.3 Specular Reflectance—The ratio of undiffused reflected flux to incident flux. (See Figure 2.)

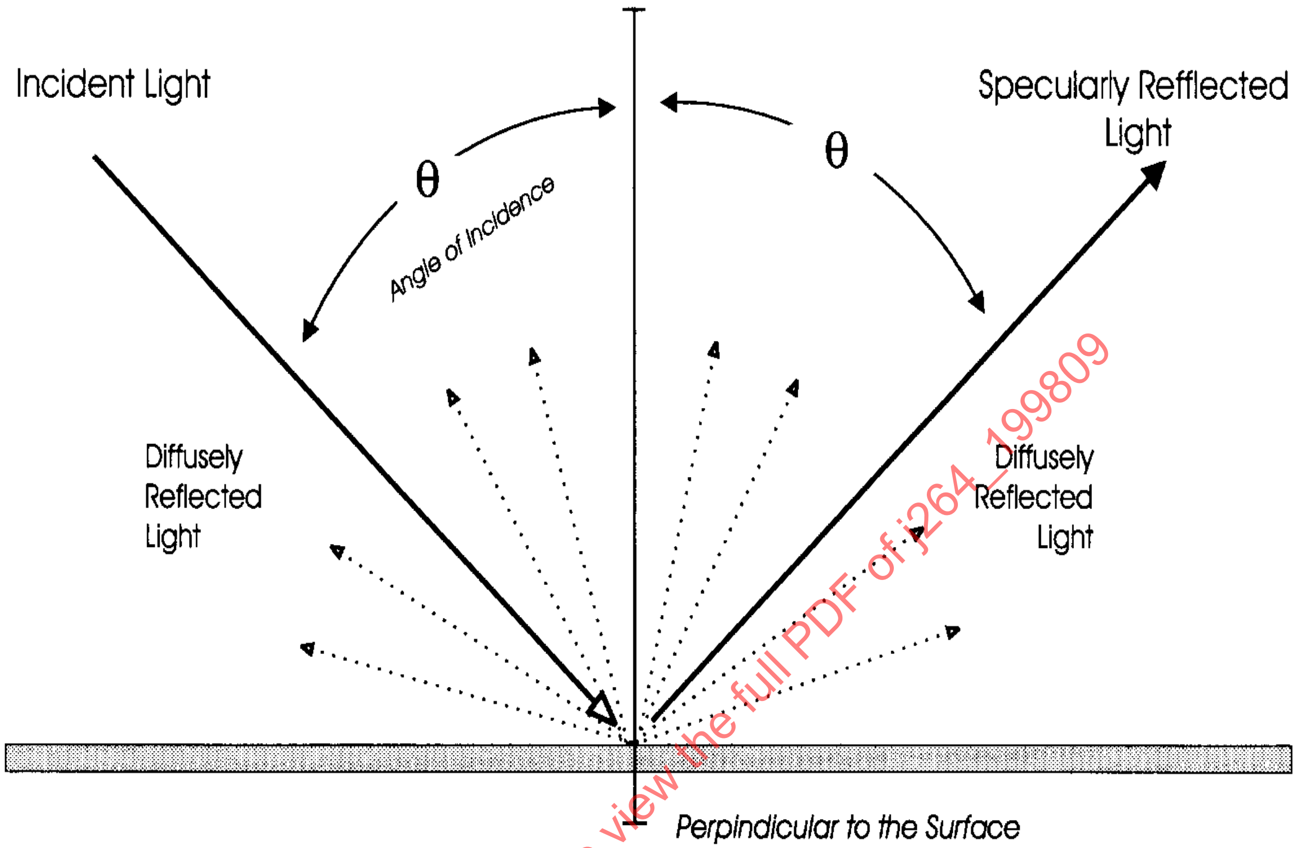
3.14.18.4 Reflectance Factor—The ratio of flux reflected by a surface in a given direction to the flux reflected in the same directions by a perfect reflecting diffuser under the same conditions of illumination.

3.14.19 REFRACTION—Deflection of radiant energy from a straight path in passing from one medium to another.

3.14.19.1 Index of Refraction—Ratio of sines of angles of incidence and refraction in transparent material. The ratio of the velocity of light in a vacuum to the velocity of light in a substance, at a specified wavelength.

3.14.20 RESOLVING POWER—The capability of an optical system to separate the images of two closely situated points in the object space.

3.14.21 SNELL'S LAW—Ratio of sines of angles of incidence and refraction is reciprocal of ratio of refractive indices of initial and final media.



Light which is reflected from a surface at the same angle as the angle of incidence, but on the opposite side of the perpendicular to the surface is called ***specularly reflected light***. Light reflected at any other angle (dotted lines) is referred to as ***diffusely reflected light***.

FIGURE 2—REFLECTED LIGHT

3.14.22 SOLID ANGLE—The solid angle, in steradians, of a surface seen from a point is numerically equal to its projected area on a sphere, centered at that point, divided by the square of the radius of the sphere. A sphere subtends 4π steradians at its center.

3.14.23 SPECTRAL DISTRIBUTION—Relative distribution of radiant energy or flux in the spectrum.

3.14.24 SPECTRUM—Spatial arrangement of components of radiant energy in order of their wavelengths.

3.14.25 SPECULAR—Pertaining to flux reflected from the surface of an object, without diffusion, at the specular angle. For example, a silvered mirror reflects specularly.

3.14.26 SPECULAR ANGLE—The angle between the perpendicular to the surface and the reflected ray that is (a) equal in value to the angle of incidence, (b) lies in the same plane as the incident ray and the perpendicular, and (c) lies on the opposite side of the perpendicular to the surface.

3.14.27 STERADIAN—Unit of solid angle, subtended at the center of a sphere of 1 m radius by 1 m^2 area on that sphere.

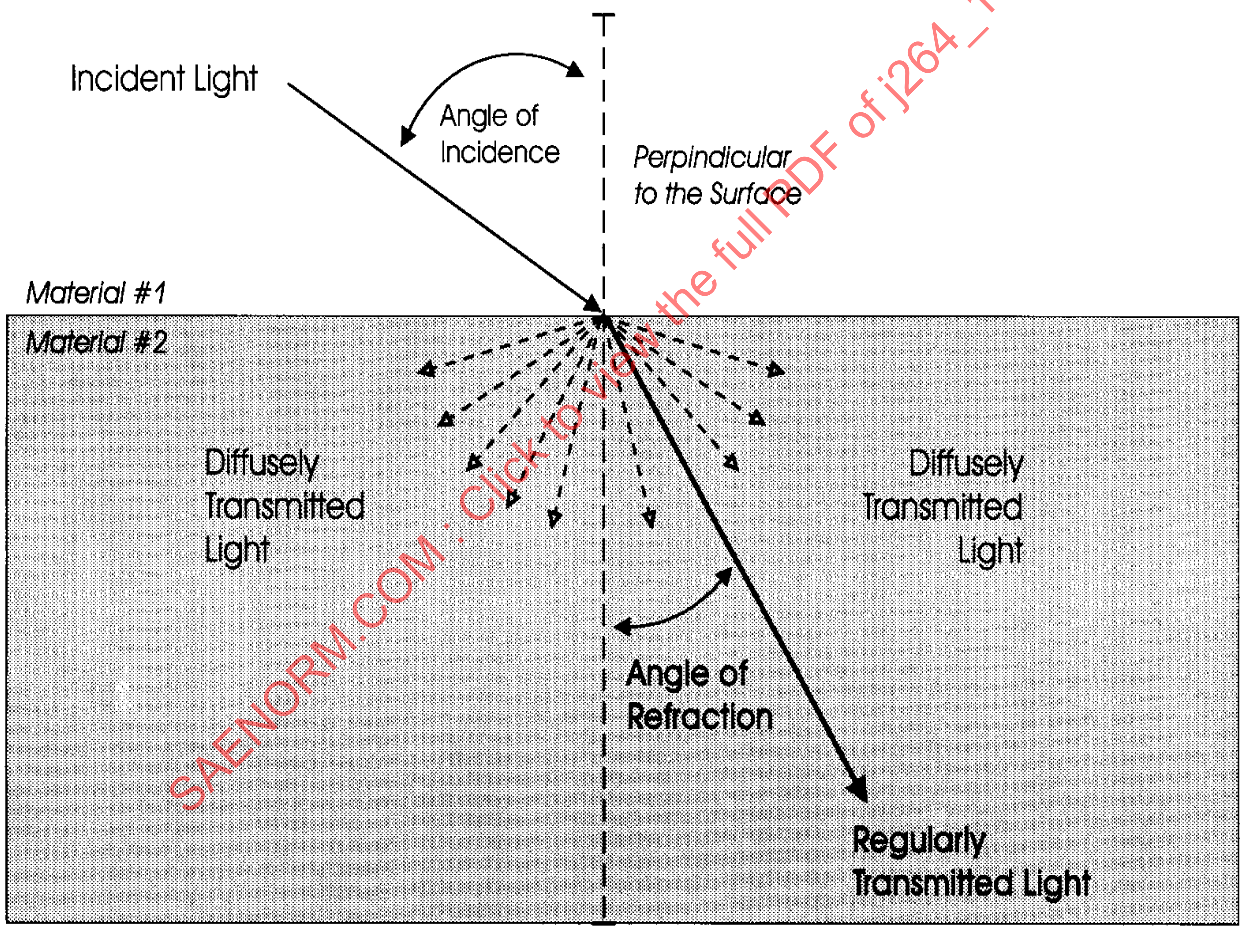
3.14.28 TRANSLUCENT—Transmitting and diffusing light so that objects beyond cannot be seen clearly. (Compare to opaque and transparent.)

3.14.29 TRANSMITTANCE—The ratio of transmitted radiant or luminous flux to incident flux, under specified geometric and spectral conditions.

3.14.29.1 Total Transmittance—The ratio of the flux transmitted at all forward angles to the incident flux. Total transmittance is equal to the sum of diffuse and regular transmittance.

3.14.29.2 Diffuse Transmittance—The ratio of the flux which is scattered in passing through a surface or medium to the flux which is incident at that surface or medium. (See Figure 3.)

3.14.29.3 Regular Transmittance—The ratio of undiffused transmitted flux to incident flux. (See Figure 3.)



Light which is transmitted through a medium at the angle of refraction (solid line) is called ***regularly transmitted light***. Light which is transmitted at any other angle (dashed lines) is called ***diffusely transmitted light***.

FIGURE 3—TRANSMITTED LIGHT

3.14.29.4 Luminous Transmittance—Ratio of the luminous flux transmitted by the object to the luminous flux incident.

3.14.29.5 Transmittance Factor—The ratio of flux transmitted by a specimen to the flux transmitted by the perfect transmitting diffuser under the same geometric and spectral conditions of measurement.

3.14.30 TRANSPARENT—Having the property of transmitting light without appreciable scattering so that objects beyond are entirely visible. The color properties of a transparent object (such as a glass filter) are determined primarily by its spectral transmittance. (Compare to opaque and translucent.)

3.15 Visual Displays

3.15.1 CRT (CATHODE RAY TUBE)—A display which produces light by high-energy electrons striking a phosphor inside a glass sealed vacuum tube. An electron beam is emitted from a cathode at the rear of the tube, accelerated, focused, and then positioned by magnetic deflection onto the phosphor coated viewing screen at the front of the tube. Advantages of CRT displays include high brightness, built-in light source, full color, wide viewing angle, high spatial resolution, outstanding color purity, and simple manufacturing.

3.15.2 EMISSIVE DISPLAYS—Displays in which electrical energy is converted into luminous energy. Examples include EL, LED, PDP, VF, and CRT. Alternatively, nonemissive displays, such as LCD and EC, require an external light source.

3.15.3 FLAT PANEL DISPLAYS—Displays having a very narrow depth, typically less than 15 mm. Individual pixels are electrically addressed, usually via a matrix of row/column lines, where one line is used for timing and the other for data input.

3.15.3.1 Electrochromic (EC)—A display in which the optical absorption properties, or color, of certain materials is changed by an externally applied electrical field or current. Typically these displays exhibit vivid color contrast between the electrochemical states, and only consume power when the state is changed.

3.15.3.2 EL Display (Electroluminescent)—Electroluminescence is the emission of light when an electric field is applied directly to a polycrystalline phosphor. EL can be used in segmented displays for alphanumeric characters, where each segment is a separate EL lamp. It can also be used for video-quality images using 'thin-film' technology.

3.15.3.3 LCD (Liquid Crystal Display)—A display in which a liquid crystal material is sandwiched between two sheets of glass which have been coated on the inside with a transparent conductive material. The crystals are aligned, and have a spiral twist of 90 degrees (twisted nematic or TN) or greater (super-twisted nematic or STN). When an electric field is applied, the crystals change their orientation, which in turn changes their light transmission properties. The liquid crystal material, by changing the alignment of the crystals, serves as a spatially addressable light filter. If the addressing matrix uses a transistor to regulate voltage at each pixel, it is called an active matrix LCD. Since the liquid crystal panel is a light filter (not a light emitter), LCDs require an external light source. The light must first be passed through a polarizing filter before entering the glass substrate.

3.15.3.4 LED (Light Emitting Diodes)—An LED is a single crystal semi-conductor diode which emits light when excited by a low voltage DC source. Usually LED displays are made up of several segments which can form alphanumeric characters. However, they can also consist of a single LED lamp (e.g., LED annunciators), or arrays of LEDs can be placed together to form large area flat-panel alphanumeric displays. The most common color is red, but other colors are available. LED technology cannot support video- or vector-quality displays.

3.15.3.5 *PDP (Plasma Display Panel)*—These displays consist of gas sealed between two layers of glass. Both layers of glass contain conductors, to which voltage can be applied. This results in ionization of the gas, which then glows. The ionized gas, or plasma, produces a brightness that is directly proportional to the current passing through the gas. The most common color is a bright, neon orange, produced from neon-argon plasma. Multi-colored PDPs usually generate ultraviolet light from the plasma, and then use it to excite colored phosphors. Plasma panels are typically dot matrix and can be used for video-quality displays.

3.15.3.6 *VF Display (Vacuum Fluorescent)*—A flat panel technology in which electrons, emitted in a vacuum from a series of filament wires and controlled by a grid, bombard a phosphor. This is similar to CRTs, except VF uses low voltage phosphors, and addresses the phosphors via a grid rather than magnetic deflection. VF can be used for segmented, alphanumeric displays, but it does not support video-quality images. The low-voltage phosphors required for automotive applications emit a blue-green color, but other phosphors, requiring a higher excitation voltage, are available.

3.15.4 HEAD-UP DISPLAY (HUD)—A virtual display appearing in the area seen through the windshield.

3.15.5 PIXEL—Short for picture element, it is the smallest addressable element in an electronic display.

3.15.6 STROBOSCOPE—Device for presenting a rapid series of exposures of a related sequence of visual stimuli. An illusion of continuous motion may be produced. Also used to stop apparent motion of a moving object.

4. Notes

4.1 Marginal Indicia—The change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

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