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Standard Terminology of Solar Energy Conversion[1]

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1. Scope

1.1 This terminology pertains to the conversion of solar energy into other forms of energy by various means, including thermal absorption (i.e., solar thermal) and the photovoltaic effect (i.e., photovoltaics).

1.2 This terminology also pertains to instrumentation used to measure solar radiation.

1.3 This terminology also pertains to glass for solar energy applications.

1.4 Fundamental terms associated with electromagnetic radiation that are indicates as derived units in Standard IEEE/ASTM SI 10 are not repeated in this terminology.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C162 Terminology of Glass and Glass Products
C1048 Specification for Heat-Strengthened and Fully Tempered Flat Glass
C1651 Test Method for Measurement of Roll Wave Optical Distortion in Heat-Treated Flat Glass
D1003 Test Method for Haze and Luminous Transmittance of Transparent Plastics
D1245 Practice for Examination of Water-Formed Deposits by Chemical Microscopy
D4865 Guide for Generation and Dissipation of Static Electricity in Petroleum Fuel Systems
D5544 Test Method for On-Line Measurement of Residue After Evaporation of High-Purity Water
D7236 Test Method for Flash Point by Small Scale Closed Cup Tester (Ramp Method)
E349 Terminology Relating to Space Simulation
E490 Standard Solar Constant and Zero Air Mass Solar Spectral Irradiance Tables
E491 Practice for Solar Simulation for Thermal Balance Testing of Spacecraft
E927 Specification for Solar Simulation for Photovoltaic Testing
E948 Test Method for Electrical Performance of Photovoltaic Cells Using Reference Cells Under Simulated Sunlight
E816 Test Method for Calibration of Pyrheliometers by Comparison to Reference Pyrheliometers
E1021 Test Method for Spectral Responsivity Measurements of Photovoltaic Devices
E1036 Test Methods for Electrical Performance of Nonconcentrator Terrestrial Photovoltaic Modules and Arrays Using Reference Cells
E1125 Test Method for Calibration of Primary Non-Concentrator Terrestrial Photovoltaic Reference Cells Using a Tabular Spectrum
E1171 Test Methods for Photovoltaic Modules in Cyclic Temperature and Humidity Environments
E1362 Test Method for Calibration of Non-Concentrator Photovoltaic Secondary Reference Cells
E1462 Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules
E2236 Test Methods for Measurement of Electrical Performance and Spectral Response of Nonconcentrator Multijunction Photovoltaic Cells and Modules
E2527 Test Method for Electrical Performance of Concentrator Terrestrial Photovoltaic Modules and Systems Under Natural Sunlight
F1863 Test Method for Measuring the Night Vision Goggle-Weighted Transmissivity of Transparent Parts
G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials
G130 Test Method for Calibration of Narrow- and Broad-Band Ultraviolet Radiometers Using a Spectroradiometer
G138 Test Method for Calibration of a Spectroradiometer Using a Standard Source of Irradiance
G167 Test Method for Calibration of a Pyranometer Using a Pyrheliometer
G173 Tables for Reference Solar Spectral Irradiances: Direct Normal and Hemispherical on 37° Tilted Surface

[1] This terminology is under the jurisdiction of ASTM Committee E44 on Solar, Geothermal and Other Alternative Energy Sources and is the direct responsibility of Subcommittee E44.01 on Terminology and Editorial.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

G197 Table for Reference Solar Spectral Distributions: Direct and Diffuse on 20° Tilted and Vertical Surfaces
IEEE/ASTM SI 10 American National Standard for Metric Practice

2.2 *ISO Standard:*[3]

ISO 9060 Specification and Classification of Instruments for Measuring Hemispherical Solar and Direct Solar Radiaiton

2.3 *WMO Document:*[4]

WMO-No. 8 Guide to Meteorological Instruments and Methods of Observation, Seventh ed., 2008, World Meteorological Organization (WMO), Geneva

3. Adjectives for Electromagnetic Radiation

3.1 Properties and quantities associated with electromagnetic radiation vary with:

3.1.1 The direction and geometric extent (solid angle) over which the incident or exitant flux, or both, is evaluated, and

3.1.2 The relative spectral distribution of the incident flux and the spectral response of the detector for exitant flux.

3.2 Adjective modifiers can be used to indicate the geometric, spectral, and polarization conditions under which radiometric properties and quantities are evaluated. The adjectives defined in this Terminology are: **conical, diffuse, direct, directional, hemispherical, luminous, normal,** and **spectral**.

3.3 For reflectance and transmittance, the direction and geometric extent of both the incident beam and exitant beam must be specified.

3.4 For emittance, only the exitant beam need be specified, and for absorptance, only the incident beam need be specified.

3.5 Radiometric properties also vary with the polarization of the incident flux and the sensitivity to polarization of the collector-detector system for flux incident or exitant at angles greater than about 15° from normal.

3.6 An instrument used for solar energy measurements or a solar energy receiver will usually determine the directions and geometric extents, such as a pyranometer, a pyrheliometer, or a flat-plate solar thermal collector.

4. Terminology

ELECTROMAGNETIC RADIATION AND OPTICS

absorptance, *n*—ratio of the absorbed radiant or luminous flux to the incident flux. **E349**

absorption, *n*—transformation of radiant energy to a different form of energy by interaction with matter. **E349**

aerosol, *n*—any solid or liquid particles, with a nominal size range from 10 nm to 100 µm, suspended in a gas (usually air). **D5544**

aerosol optical depth, *AOD*, *n*—a measure of the **extinction** caused by **aerosols** in the atmosphere relative to the **zenith** and modeled with Ångstrom's **turbidity** formula.

DISCUSSION—Although it varies with wavelength, it is common to report aerosol optical depth at a single wavelength only, especially 0.5 µm.

air mass, *AM*, *n*—relative optical mass (see **optical mass, relative**) calculated using the density of air as a function of altitude.

$$AM \approx l_s/l_z = sec\theta_z, for\ \theta_z \leq 1\ \text{rad}\ (60°) \quad (1)$$

DISCUSSION—Eq 1 is a simple approximation of the **optical mass, relative** (see Eq 5) that uses the ratio of the path length along the sun vector (l_s) to the path length along the zenith (l_z) (see **sun vector, zenith**, and **zenith angle, solar**). Other solutions are more complicated and take factors such as refraction and local air pressure into account.

DISCUSSION—The abbreviation **AM** is also commonly used to refer to a particular standard solar spectral irradiance, such as those in Standard E490, Tables G173, and Table G197. Thus, **AM0** can indicate the extraterrestrial spectral irradiance table in Standard E490, and **AM1.5** the hemispherical spectral irradiance table in Tables G173. Using AM1.5 in this way is discouraged because air mass is but one of many variables that modify solar spectral irradiance such as clouds, aerosol scattering, and water vapor absorption; note that both Tables G173 and Table G197 use an air mass value of 1.5, but differ greatly. The distinction between a spectral irradiance and a path length ratio should be made clear whenever these abbreviations are used.

air mass one, *AM1*, *n*—a relative optical mass (see **optical mass, relative**) that is equal to one. Because of the way in which relative optical mass is defined, AM1 always denotes a vertical path at sea level.

air mass, optical—see **optical mass, relative**.

air mass, pressure corrected, AM_p, *n*—an approximation of **air mass** for locations above sea level that uses the ratio of the local barometric pressure *P*, to the standard sea level atmospheric pressure P_0 = 101.325 kPa (see Eq 2).

$$AMp \approx \frac{P}{P_0} AM \quad (2)$$

air mass ratio—see **optical mass, relative**.

air mass, relative optical—see **optical mass, relative**.

air mass zero, *AM0*, *n*—the absence of atmospheric attenuation of the solar irradiance at one astronomical unit from the sun. **E491**

albedo—discouraged in favor of the preferred term, **reflectance**.

angle of incidence, rad or °, *n*—the angle between a ray and the normal vector to the plane on which the ray is incident; especially the angle between the sun vector and the normal vector.

angle of reflection, rad or °, *n*—the angle between the direction of propagation of a reflected ray and the normal vector to the surface of interest at the point of reflection.

angle of refraction, rad or °, *n*—the angle between the direction of propagation of a refracted ray and the normal vector to the interface of interest at the point of refraction.

altitude angle, solar—see **elevation angle, solar**.

attenuation—see **extinction**.

[3] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.

[4] Available from World Meteorological Organization, http://www.wmo.int.

azimuth angle, solar, ψ[rad or °], *n*—the angle between the line of longitude (or geographical meridian) at the location of interest and the horizontal component of the **sun vector**. By convention, the azimuth angle is positive when the sun is east of the line of longitude and negative when it is west of the line of longitude.

beam, *n—of radiant energy*, a collection of rays confined to a specific path.

blackbody, Planckian radiator, *n*—a thermal radiator which completely absorbs all incident radiation, whatever the wavelength, the direction of incidence, or the polarization. This radiator has, for any wavelength, the maximum spectral concentration of radiant exitance at a given temperature. **E491**

Bouguer's Law, *n*—an expression of the **extinction** of radiation in a medium that states the intensity exponentially decreases due to both scattering and absorption as it passes through the medium (see Eq 3), where τ_λ is the wavelength-dependent **extinction optical thickness**. The ratio of I to I_0 is equal to the atmospheric transmittance, T, and τ_λ is equal to the summation of the extinction optical thicknesses associated with each individual scattering or absorption process $\tau_{i\lambda}$.

$$I = I_0 exp(-\tau_\lambda) = I_0 exp\left(-\sum_{i=1}^{n} \tau_{i\lambda}\right) \quad (3)$$

DISCUSSION—Bouguer's Law is also known as Lambert's Law or Beer's Law.

circumsolar diffuse radiation—**see radiant energy, circumsolar**.

conical, *adj*—describing a solid angle larger than an infinitesimal element and less than a hemisphere (2π sr); the geometry of the solid angle must be described in context.

diffuse, *adj—describing radiometric quantities*, indicates flux propagating in many directions, as opposed to a collimated beam.

diffuse, *adj—describing solar irradiance*, the global hemispherical irradiance minus the direct beam irradiance.

diffuse, *adj—describing reflectance*, the directional hemispherical reflectance minus the specular reflectance.

DISCUSSION—**Diffuse** has been used in the past to refer to hemispherical collection (including the specular component) or irradiation, with equal radiance for all directions over a hemisphere. This use is deprecated in favor of the more precise term **hemispherical**.

diffusion, *n*—change of the spatial distribution of a beam of radiation when it is deviated in many directions by a surface or a medium. **E349**

direct, *adj—describing solar radiation*, a collimated beam.

directional, *adj*—of or relating to a direction in space.

DISCUSSION—For optical properties, over an infinitesimal solid angle, the property is assumed constant. The variation in optical property with respect to changing azimuth (counter-clockwise) and incidence angle (from the surface normal), with respect to a reference mark on a sample, is the directional response.

elevation angle, solar, α [rad or °], *n*—the complement of the solar zenith angle, i.e. $\pi/2 - \theta_z$ radians. See **zenith angle, solar**.

emission, *n*—release of radiant energy. **E349**

emissive power—discouraged in favor of the preferred term **radiant exitance**.

emittance, ε, *n*— for a sample at a given temperature, ratio of the radiant flux emitted by a sample to that emitted by a blackbody radiator at the same temperature, under the same spectral and geometric conditions of measurement.

extinction, *n*—the attenuation of radiant energy from an incident beam by the processes of molecular absorption and scattering caused by atmospheric constituents.

DISCUSSION—Scattering by air molecules can be modeled with **Rayleigh scattering**, and scattering by **aerosols** with Ångstrom's **turbidity** formula. Absorption processes are modeled with tables of measured absorption coefficients versus wavelength.

extinction coefficient, monochromatic, $k_{i\lambda}$[dimensionless], *n*—a measure of the **extinction** caused by a particular atmospheric constituent (see **Bouguer's Law** and **extinction optical thickness, monochromatic**).

extinction optical depth, monochromatic, [dimensionless], *n*—the product of the **extinction coefficient** $k_{i\lambda}$ for a particular atmospheric constituent times the path length to the top of the atmosphere, m_r, see **extinction optical thickness, monochromatic** and **optical mass, relative**.

DISCUSSION—Optical depth is sometimes used synonymously with optical thickness, but the preferred distinction between the two is that optical thickness refers to the extinction along the entire path through the atmosphere rather than the vertical path.

extinction optical thickness, monochromatic, $\tau_{i\lambda}$ [dimensionless], *n*—the product of the **extinction coefficient** $k_{i\lambda}$ for a particular atmospheric constituent times the path length through atmosphere, see **Bouguer's Law** and Eq 4, in which m_{act} is the **optical mass, actual**.

$$\tau_{i\lambda} = k_{i\lambda} \cdot m_{act} \quad (4)$$

hemispherical, *adj*—describing half of a sphere, i.e. a 2π sr solid angle.

incident angle—see **angle of incidence.**

index of refraction, *n*—the numerical expression of the ratio of the velocity of light in a vacuum to the velocity of light in a substance. **D1245**

infrared radiation, *n*—radiation for which the wavelengths of the monochromatic components are greater than those for visible radiation, and less than about 1 mm. **E349**

irradiance, E [$W \cdot m^{-2}$], *n—at a point on a surface*, radiant flux incident per unit area of the surface; the derived unit **heat flux density, irradiance** in Standard IEEE/ASTM SI 10.

irradiance, spectral, E_λ *or* $E(\lambda)$[$W \cdot m^{-2} \cdot nm^{-1}$ or $W \cdot m^{-2} \cdot \mu m^{-1}$], *n*—the irradiation at a specific wavelength over a narrow bandwidth, or as a function of wavelength; also, the derivative with respect to wavelength of irradiance.