

1. **LIGHT** is radiant energy that is capable of exciting the retina and producing a visual sensation. This definition is most meaningful for display professionals, although it differs from the definition frequently used by physicists. Our definition excludes ultraviolet (UV) and infrared (IR) wavelengths. UV is shorter in wavelength than light as we've defined it, and IR is longer. The visible wavelengths of the electromagnetic spectrum extend from about 380 to 770 nm. The unit of light energy is lumen second.

2. **LUMINOUS FLUX** is visible power, or light energy per unit of time. It is measured in lumens. Since "light" is visible energy, the lumen refers only to visible power. One watt of radiant power at 555 nm - the wavelength at which the typical human eye is most sensitive - is equivalent to a luminous flux of 680 lumens. One can measure the visible energy of radiation, but measuring the visible power is more common.

3. **LUMINOUS INTENSITY** is the luminous flux per solid angle emitted or reflected from a point. The unit of measure is the lumen per steradian, or candela (cd).

(The steradian is the unit of measurement of a solid angle.) The Intensity control on an oscilloscope adjusts the magnitude of the luminous intensity and, consequently, the luminance and the brightness of the light output. Luminance and brightness are defined below.

4. **LUMINANCE** is the luminous intensity per unit area projected in a given direction. The SI unit is the candela per square meter, which is still sometimes called a nit. The footlambert (fL) is also in common use ( $1 \text{ fL} = 3.426 \text{ cd/m}^2$ )

5. **BRIGHTNESS** is a subjective attribute of light to which humans assign a label between very dim and very bright (brilliant). Brightness is perceived, not measured. Brightness is what is perceived when lumens fall on the rods and cones of the eye's retina. The response is non-linear and complex. The sensitivity of the eye decreases as the magnitude of the light increases, and the rods and cones are sensitive to the luminous energy per unit of time (power) impinging on them.

Luminance is the measurable quantity which most closely corresponds to brightness. The

luminance photometer and the human eye both have a lens and both receive light from specific directions. The photometer has a single photodetector - maybe three for color - while the eye has a very large number of sensors (rods and cones). One may think (loosely) of each cone in the fovea - the area near the center of the retina - as being part of a human light meter using a common lens.

6. **ILLUMINANCE** is the luminous flux incident on a surface e per unit area. The SI unit is the lux, or lumen per square meter. The foot-candle (fc), or lumen per square foot, is also used (1 fc = 10.764 lux). An illuminance photometer measures the luminous flux per unit area at the surface being illuminated without regard to the direction from which the light approaches the sensor.

Using cosine correction to correct for changes in the illuminated area of a surface as a function of angle of incidence guarantees that the measured value of illuminance is independent of the direction from which the light approaches the sensor.

Let's try to say that again in a more intuitive way. If you aim a flashlight perpendicular to a nearby surface, it produces a circle of light on the surface. Tilt the flashlight and the illuminated spot increases in area and becomes elliptical in shape. The same luminous flux is now spread over a larger area as the angle between the axis of the flashlight and the normal to the surface increases. For a given luminous flux, the illuminance decreases as the illuminated area increases.

If you have an illuminance photometer handy, make an illuminance measurement with the light directly over the sensor. Now make a measurement with the light off axis by a given number of degrees from the normal. The off-axis reading should be equal to the on-axis reading times the cosine of the angle. If it is, the meter is cosine corrected. This experiment requires the meter sensor to be small compared with the projected area.

### Luminance vs. Illuminance

The luminance of the sun is approximately  $10^9$  cd/m<sup>2</sup> (300 x 10<sup>6</sup> fL). This can be measured by aiming a luminance photometer at the sun. (Use an appropriate neutral-density filter to prevent damage to the photometer and your eyes!) The earth receives a very large luminous

flux from the sun. On a bright sunny day the illumination can be more than 100,000 lux (about 10,000 fc). The luminance of a cloudy sky can be nearly 35,000 cd/m<sup>2</sup> (about 10,000 fL) - or much lower if the clouds are dense and dark. If the clouds are sparse, on the other hand, sunlight may penetrate the clouds and produce readings much higher than 35,000 cd/m<sup>2</sup> when the meter is aimed in the direction of the sun .

Illuminance can be measured with a luminance photometer. A white reflectance standard is placed on the surface where the illuminance is to be measured. One foot-candle of illumination on the white standard reflects (lux) slightly less than 1 fL of luminance. The exact number can be obtained from the manufacturer of the reflectance standard. (In SI units, 1 lux on the reflectance standard produces almost 0.318 cd/m of luminance.) Because we are measuring illuminance, the units used in the measurement should be lux (or fc) even though we are using a luminance photometer to make the measurement. Many specification and data sheets incorrectly specify 10,000 fL of ambient instead of 10,000 fc. Such errors are common but they are not trivial. Light impinges upon an illuminance photometer very differently from the way it impinges upon a luminance photometer.

If a pilot looks out through the wind-screen at bright white clouds, he can measure the luminance of the clouds if he has a luminance photometer with him. If he has an illuminance photometer, he can measure the amount of skylight illuminating the surface of the display in his aircraft or the surface of his face. Particular values of cloud luminance, illuminance on the display, and illuminance on the pilot's face could substantially reduce the display contrast perceived by the pilot for a given contrast of the display luminance.

### **Energy vs. Power**

The basic unit of measurement used in photometry is the lumen; in radiometry, it's the watt. Both units are measures of energy per unit time. Most light measurements involve lumens, but we are sometimes interested in a total quantity of luminous energy - that is, power (usually measured in lumens) multiplied by time. If, for example, we wanted to know the quantity of light energy from a photoflash falling on a surface, we would integrate the luminous flux falling on the area of interest over the period of time from the beginning to the end of the flash.

### **Luminance vs. Brightness**

A photometer and a pilot's eyes are receiving light from the same point on a display's screen. Measuring the luminance of the light from that point is straightforward and highly repeatable. We can go a step further and take a second measurement at a different point on the screen. We can then calculate the contrast between the two points. The pilot's perception of brightness, however, is complicated by human visual phenomena such as time-dependent light and dark adaptation, simultaneous contrast, lateral inhibition (Mach effect), dazzle (contrast overload), and color. The pilot's perception of display contrast is intimately related to his perception of brightness.

The concept that is now known as "luminance" was for many years designated by the term "brightness." This led to much confusion between the objective concept of "brightness" as intensity per unit of projected area, and the subjective concept of "brightness" which referred to a sensation in the consciousness of a human observer. The newer term, "luminance" was adopted to avoid this confusion. - from Optics by Francis Weston Sears (Addison-Wesley, 1949)

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Brightness, Luminance, and Confusion

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