

Brightness, Luminance, and Confusion

from *Information Display* March 1993

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Evaluating the technical performance of displays must involve photometry - the measurement of quantities associated with light. Unfortunately, many teachers of photometry tend to overwhelm and discourage their non-physicist students. But, in the spirit of light cuisine and Pepsi Light, we should be able to impart a basic working knowledge of practical photometry if we limit ourselves to a few essential concepts. How few?

The beginning of wisdom is to call things by their right names.

- Chinese Proverb

The process of communication involves a mutual agreement on the meaning of words.

- Charley Halsted

In reading many articles involving the measurement and perception of light, I found that just six photometric expressions - or "six light words" - form the nucleus of what professionals in the display business need to know. The words are those that appear most frequently in articles on displays and in government and manufacturers' display specifications. They are fundamental to the understanding of photometry. Understanding the concepts associated with these six words will create a solid foundation on which display professionals can work and grow. It will also reduce the need to call on experts for help in solving measurement problems.

SIX LIGHT WORDS

1. **LIGHT** is radiant energy that is capable of exciting the retina and producing a visual sensation. This definition is the one 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 the 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 ($1 \text{ fL} = 3.426 \text{ cd/m}^2$). The concept of luminance is challenging and deserves detailed discussion. First, let's look at what is meant by "projected area." Think of a slide projector containing a slide that is opaque except for a small clear spot at the center. When d_1 and d_2 are correctly related to the focal length of the lens, light passing from the lamp through the clear spot in the slide is focused by the lens onto the receiving surface (SEE [Fig. 1](#)). This in-focus image of the spot is the projected area. The size of the projected area can be adjusted by changing the focal length of the lens, d_1 and d_2 , and/or the size of the spot - the aperture - on the slide. Replacing the projection lamp with a photodetector and the projected area with a source of light - either self-luminous or reflected provides the basic elements of a luminance photometer (SEE [Fig. 2](#)).

Most luminance photometers' have special optics that allow the user to view the source and bring the projected area into focus. Any luminous flux that leaves the source - as defined by the projected area - and passes through the lens will also pass through the Aperture. That luminous flux will enter the photodetector and permit a luminance measurement. What is being measured is power - the rate at which energy is being transferred from source to detector - but there can be no power without energy.

To see how luminous intensity contributes to luminance, review the definition of luminous intensity and refer to (SEE [Fig. 3](#)). Each of the points - such as P1, and P2, - on the projected area emits luminous flux over a solid angle of 2 PI steradians. However, only that portion of the flux that falls within the cone defined by the effective area of the lens and the distance d , from the lens to the point on the source succeeds in arriving at the detector.

There is a little cone for every point on the projected area. Two cones of angles 1 and 2 are shown. For each point on the projected area, there will be a corresponding solid angle. The greater the projected area, the greater will be the luminous flux collected by the lens. The larger the lens diameter, the greater will be the luminous flux from each point collected by the lens and directed through the Aperture to the photodetector. P1 and P2 are two of the many points on the object source plane. The optics form the images P1' and P2' of these points at the aperture plane. A point on the source is focused by the lens onto the aperture plane. There is no need to focus on the photodetector because all of the light that passes through the aperture must fall on the photodetector. If the projected area were to be reduced to one-half, the number of little cones would be reduced to one-half and the luminous flux collected by the lens and arriving at the photodetector would be reduced by one-half. This assumes that the projected area is uniformly luminous. If the projected area is not uniformly luminous, the photodetector will average the luminous flux over the projected area.

The luminous flux collected by the photometer lens (and directed to the photodetector) is proportional to the projected area. This is important in, for example, measuring the luminance of a display. The placement of the projected area on the luminous source of a display - such as a symbol stroke - is important when making a luminance measurement.

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 ($1 \text{ fc} = 10.764 \text{ lux}$). 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^2 ($300 \times 10^6 \text{ fL}$). 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 $35,000 \text{ cd/m}^2$ (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 $35,000 \text{ cd/m}^2$ when the meter is aimed in the direction of the sun (SEE [Fig. 4](#)).

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 (SEE [Fig. 5](#)).

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 (SEE [cover photo](#)). 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)

Is there enough of a difference between luminance and brightness to justify the distinction? Has there ever been a case where a display had an incorrect specification, didn't perform properly, or cost too much because somebody said "brightness" when he or she should have said "luminance"? Many professionals in the display community say that they say "brightness" because many people don't know what "luminance" is. But to believe that the words brightness and luminance are essentially interchangeable ignores the clear distinction in the definitions of these two words, and the differing realities behind the words. If the luminance of a viewed light source is increased 10 times, viewers do not judge that the brightness has increased 10

times. The relationship is, in fact, logarithmic: the sensitivity of the eye decreases rapidly as the luminance of the source increases. It is this characteristic that allows the human eye to operate over such an extremely wide range of light levels (SEE [Fig. 4](#)).

"Luminance by any other name spells confusion"
- Ted Trilling

Unfortunately, the word "brightness" is frequently used in place of the word "luminance." An obvious **RED FLAG** is waving when you see "brightness" expressed in footlamberts: brightness is not a measurable quantity and therefore has no units. It would be most helpful to those who rarely work with photometric units if regular users would give the good example of distinguishing the various quantities properly.

Notes

(1) The International System of Units (or SI for Systeme Internationale) is the internationally standardized version of the metric system of units. Using SI units is strongly recommended. We have also included "English" units because they still appear frequently in specifications and literature.

(2) I refer frequently to photometers in this article. Readers may contact photometer manufacturers for details. One very helpful reference is Ken Miller's "Matching Photometers to Applications" (Information Display, Sept. 1989).

Acknowledgments

The author wishes to thank William Breitmaier and Ted Trilling for their contributions to this paper and for generating the illustrations. Thanks also go to Lt. Commander Tim Sestak (USN) for very helpful suggestions and to James Brindle for his support.

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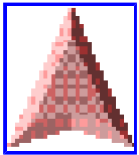
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A Response [LETTER](#) to Mr. Halsted's article.

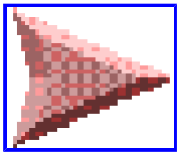
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