Lighting F.A.Q.

By Mikhail Dubinovskiy

What does "Candela", "Lumen", etc. mean?

The formal definition can be found in many handbooks, so here are informal and, hopefully more useful, definitions:

Luminous intensity (or **candlepower**) is the light density within a very small solid angle, in a specified direction. In other words, this is the total number of lumens from a surface emitted in a given direction. The unit of measure is **candela**. In modern standards, the candela is the basic of all measurements of light and all other units are derived from it. Candlepower measurements are often taken at various angles around the source and the results plotted to give a *candlepower distribution curve*. Such a curve shows luminous intensity (how "bright" the source seems) in any direction.

Luminous flux is the time rate of flow of light. The unit of measure is the **Lumen**. One lumen may be defined as the light flux emitted in one unit solid angle by a one-candela uniform-point source. The lumen differs from the candela in that it is a measure of light flux irrespective of direction. The lumen is used to express a quantity of light flux: total output of a source, output within a specific angular zone, amount of absorbed light, etc.

However, if you need to calculate something which is not related to the human eye, for example temperature increase due to absorbed light, do not use luminous flux, instead we need to use the correct unit of power, the Watt (see below).

Illumination is the density of luminous flux on a surface This parameter shows how "bright" the surface point appears to the human eye. The appropriate units of measure are **Footcandle** and **Lux**. One footcandle is the illumination produced by one lumen uniformly distributed over one square foot of a surface, or conversely this is the illumination at the point of a surface which is one foot from, and perpendicular to, a uniform point source of one candela. So, footcandles incident on a surface=Lumens/Area(sq.feet). Lux is used in the International System. Both have a similar objective, but meters are used for Lux and feet are used for Candelas. Therefore, one lux=0.0929 footcandles. Or, approximately, 1 Fc=10 Lux.

Luminance or **Brightness** is a luminous intensity of a surface in a given direction per unit of projected area of the surface. Luminance can be expressed in two ways: in candelas per unit area or in lumens per unit area. I don't want do go too into this subject, because it is so seldom used. There are many different standard units of measurement. For example: **Candela per square inch (cd/in^2) , Footlambert** (luminance of a surface emitting one lumen per square foot), **Lambert** (similar, but per square cm).

1 $cd/in.^2$ =452 Footlamberts

1 Lambert=929 Footlamberts=2.054 cd/in^2.

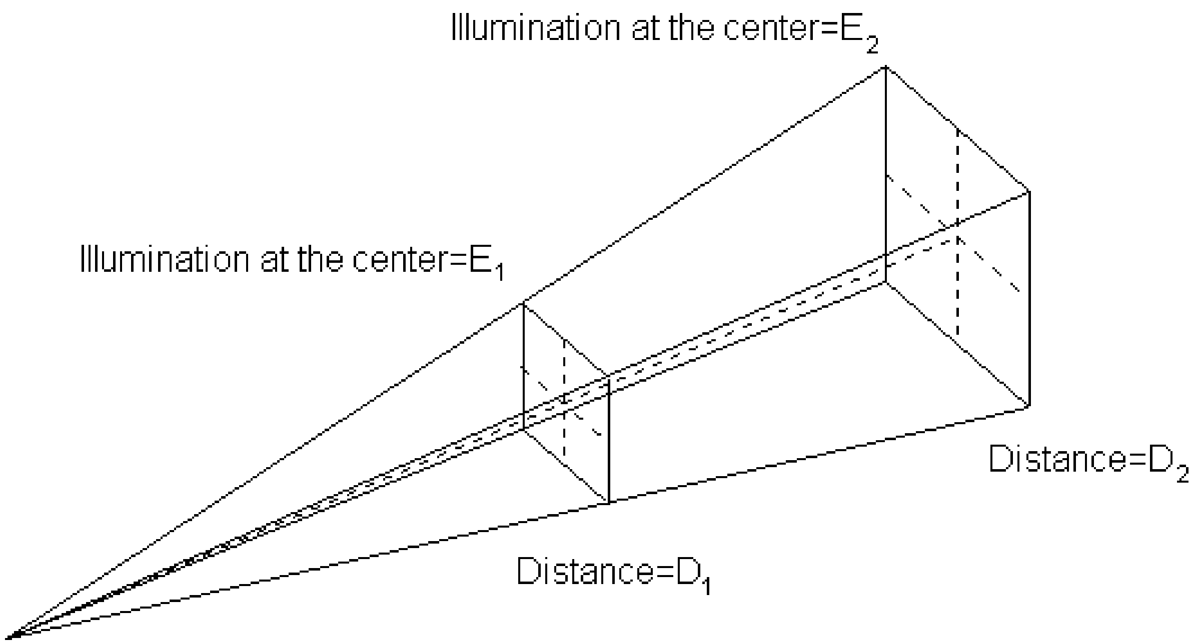
Actually, our eye sees brightness, not illumination. Every visible object has brightness. Usually, brightness is proportional to the object's illumination, so a well illuminated object seems brighter. For a perfectly diffusing reflecting surface:

Footlamberts = Footcandles * Surface Reflectance

Footcandle to Lux Conversion

One footcandle is the illumination produced by one lumen uniformly distributed over one square foot of surface, and lux is the illumination over one square meter of surface. Therefore, one lux=0.0929 footcandles. Or, approximately, 1 Fc=10 Lux.

What does "inverse square law" mean?



Point Source

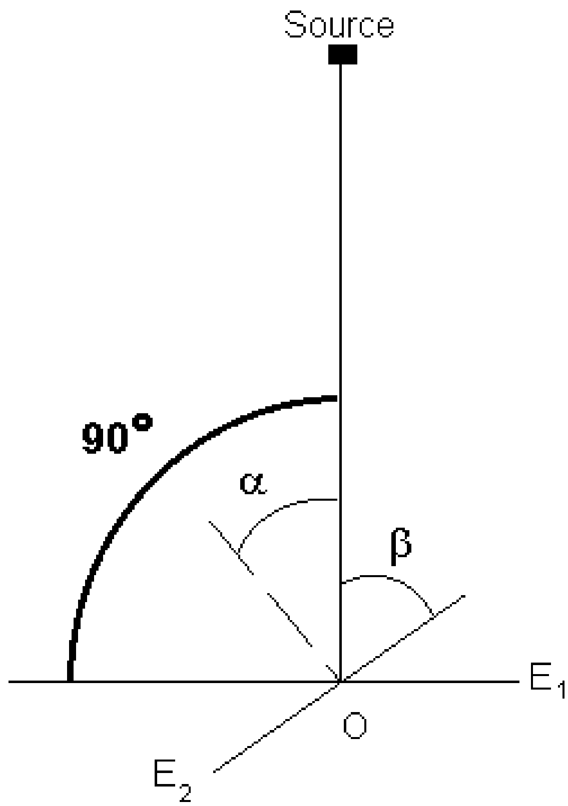
The inverse square law tells is that the illumination is inversely proportional to the square of the distance between the point source and the surface, i.e.:

$$E_1/E_2 = D_2^2/D_1^2$$

If you have a fixture (which can be treated as a point source if the distance from the surface is large) and you measure the illumination at 20 feet as 2000 Fc at the beam center, then at 40 feet the illumination is 500 Fc at the beam center.

What does "cosine law" mean?

Effective illumination is proportional to the cosine of the angle of incidence of the light on the surface (angle between the direction of the light and the perpendicular to the surface)



Illumination at the O point on surfaces 1 and 2:

$$E_2 = E_1 \cos \alpha = E_1 \sin \beta$$

Here are a few cases:

When the surface is tilted by an angle of 30º, the illumination is reduced by a factor of 0.87

45º - 0.71

60º - 0.5

What is the difference between Lumen and Watt?

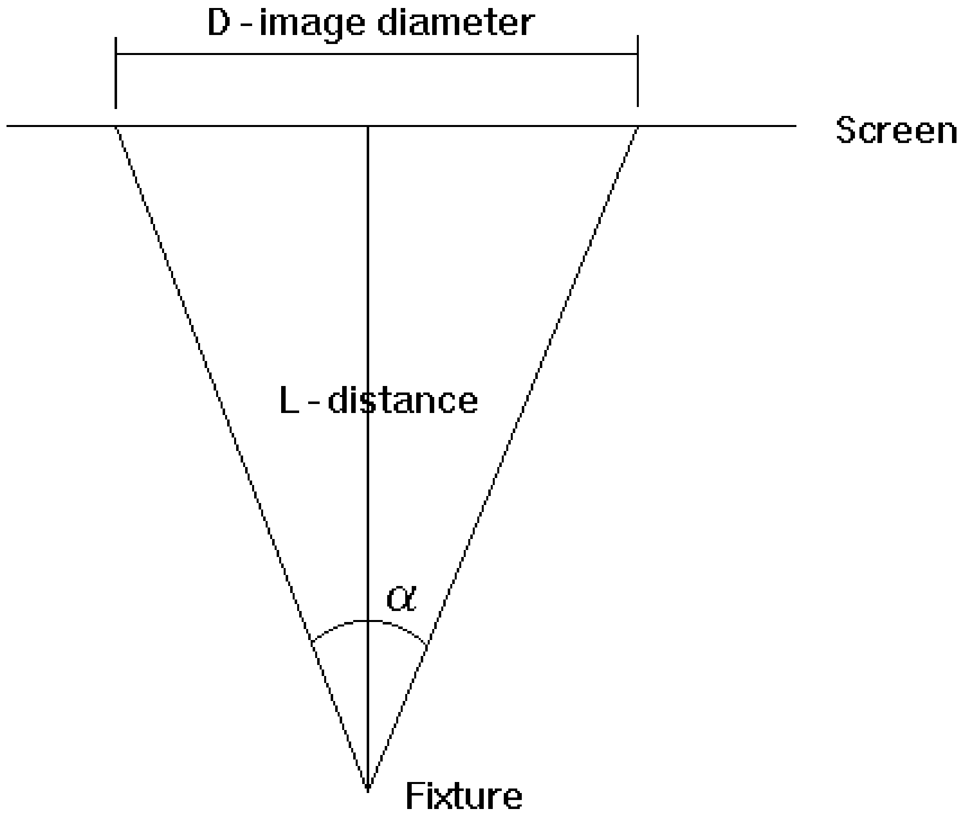
Lumen is a unit of the photometric system and Watt belongs to the radiometry system.

Both characterize a power of light flow. However, lumen is power "related" to the human eye sensitivity. Therefore, lights with the same power in watts, but different colors have different luminous fluxes, because the human eye has different sensitivity at different wavelengths. At a wavelength of 555 nm (maximum eye sensitivity) 1 Watt equals 683 Lm.

Very powerful sources of infrared radiation produce no lumen output, because the human eye can't see it. However, if you need to calculate total power absorbed by a surface (to estimate temperature increase, for example), you have to transfer lumen flux to watt. This can be done by using a spectral luminous efficiency curve, which can be found in many photometry handbooks.

How to calculate beam angle.

This is easy. If you know the distance from a fixture to the screen (much larger than fixture length) and the image diameter, then:



$$\alpha = 2 \arctan \frac{D}{2L}$$

In most practical cases the following approximation is true:

$$\alpha = 57.3 * \frac{D}{L}$$

Of course, both measurements must be in the same units (meters, feet, inches, etc.)

(Example: distance = 20 feet, image diameter=5 feet. Exact formula gives 14.25 º, second – 14.32º)

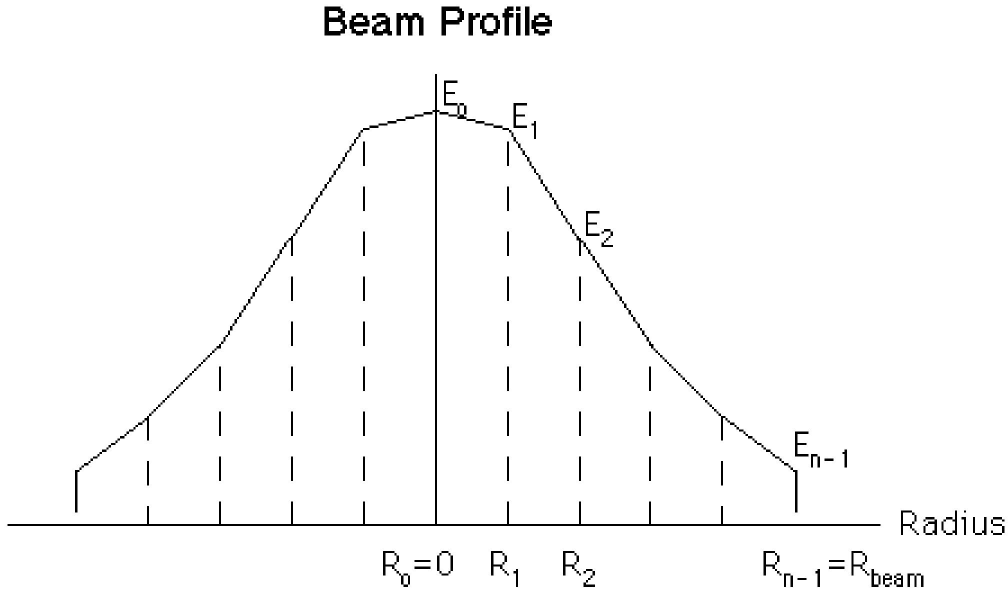
In the case of "soft edge" light image diameter, usually, is measured at point where illumination is 50% (beam angle) or 10% (field angle) of the center illumination.

How to calculate lumens output.

The best way is to use a photometric sphere, however the number of people who have one is much less than the number of people who want to know total lumen output (luminous flux) of a fixture.

Another way is to measure illumination (which is the density of luminous flux on a surface) at a number of points and then integrate the resulting values.

Assuming that the beam has axial symmetry (if not – you're in trouble. You have to measure many points all over the beam) and fixture beam angle is small (we can neglect cosine-cube coefficient from cosine-law and inverse-square-law, that is less than 5% for the 20º beam and 1% for the 10º beam), we have the following formula:



Beam radius is divided into n equal part (radiuses and illumination reading values are indexed from 0, at the beam center, to n-1, at the beam edge).

2 points (center and edge readings only):

$$P = 2.1R^2(E_1 + 0.5E_0)$$

3 points (center, middle, and edge):

$$P = 1.3R^2(E_2 + 1.2E_1 + 0.2E_0)$$

4 points:

$$P = 0.93R^2(E_3 + 1.5E_2 + 0.75E_1 + 0.125E_0)$$

5 points:

$$P = 0.72R^2(E_4 + 1.64E_3 + 1.09E_2 + 0.55E_1 + 0.09E_0)$$

8 points:

$$P = 0.43R^2(E_7 + 1.8E_6 + 1.5E_5 + 1.2E_4 + 0.9E_3 + 0.6E_2 + 0.3E_1 + 0.05E_0)$$

Here:
P - total lumens
R - beam radius
E - illumination

There is nothing magical about these equations. They are obtained by using integrating rules over the beam.

In the case of "soft edge" fixture, where the image size is taken at 10% of the center illumination (field angle), the first formula becomes very simple:

$$P = 1.26R^2E_{center}$$

To get the result in lumens, you should use proper units. If you use footcandles, then the radius must be in feet. If you use lux, then the radius must be in meters.

And last, it doesn't make any sense to calculate luminous flux with 2-3 digits after the decimal point by this method. Assumptions which were made (illumination distribution is perfectly symmetrical, etc.) inevitably result in some error in the final calculation, so instead of 14231.41 Lm it is more practical to use 14KLm.

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