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# Basic lighting quantities


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# 1 Summary

The aim of this paper is to review the definitions, the units and symbols as well as the intuitive meanings of the basic quantities that characterize a lighting system. More specifically, the following quantities will be considered:

- Luminous flux
- Luminous intensity
- Illuminance
- Luminance
- Luminous efficacy
- Reflectance
- Color rendering index (or Color rendition index)
- Chromaticity diagram
- Color Temperature
- Spectral Power Distribution
- Glare

This work is devoted to students that are interested in obtaining a basic and quick vision of the quantities used in lighting area and that are basic parameters for the design of lighting installations.

# 2 Introduction

Light is defined as the radiant energy that is capable of exciting the retina and producing a visual sensation [2]. Lighting installations are nowadays inherent to our daily life and they should be designed taking into consideration important factors as the type of activity carried out in the corresponding premise as well as user comfort, among other.

When designing indoor or outdoor lighting installations, it is strongly necessary to be aware of the meaning of the different quantities that characterize a lighting system. Moreover, when selecting a specific light source, among the available options, it is crucial to know the basic lighting parameters that serve to characterize it, in order to select the most suitable alternative. Concepts as luminous flux, illuminance, luminance, spectral power distribution, color rendition, etc… should be very familiar to the designer in order to guarantee a proper design of the installation or an appropriate selection of the light source.

The present paper is a compendium that covers the basic lighting quantities that are commonly employed in the light sources characterization as well as in the design of lighting installations. The work intends to accompany each rigorous definition with an intuitive explanation of the meaning of each quantity, providing illustrative pictures and graphs that clarify the explanations. The specific quantities that are considered in this paper are: Luminous flux, Luminous intensity, Illuminance, Luminance, Reflectance, Luminous efficacy, Spectral Power Distribution, Color rendition, Color Temperature, Chromaticity diagram and Glare.

# 3 Objetives

The following learning objectives are pursued in this paper:

- To define the basic lighting quantities.
- To describe the underlying intuitive meaning of each quantity.
- To recognize the units and symbol of each lighting quantity.
- To explain the usefulness of each quantity in the design process of a lighting system.

# 4 Development

The basic quantities that characterize a lighting system are defined in this Section. The intuitive meaning of each quantity is also included. Symbols and units are also provided:

- **Luminous flux (Φ):** is the total amount of light energy radiated from a light source in all directions per unit time (Fig. 1). In the International System of Units (SI), the luminous flux is measured in lumens (lm). Luminous flux is often used as an objective measure of the useful light emitted by a light source [3].

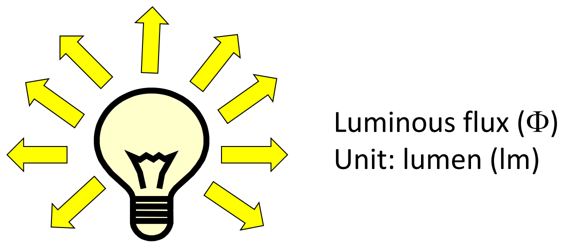



Fig. 1. Luminous flux.

The luminous flux accounts for the eye sensitivity by weighting the power at each wavelength with the luminosity function (see Fig 2). This function represents the response of the eye to different wavelengths. The luminosity function is broadly known as photopic curve - chromatic perception at normal state, and scotopic curve - achromatic perception at low level of illuminance [4]. The luminous flux is a weighted sum of the power at all wavelengths within the visible band (the light outside the visible band does not contribute).

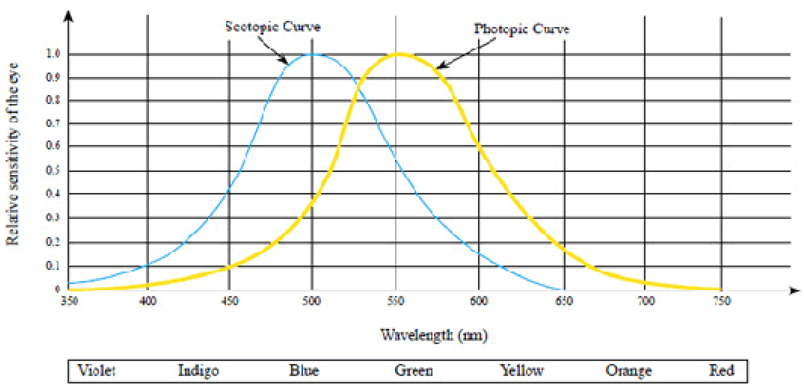



Fig. 2. Luminosity function: approximate relative sensitivity of the average human eye to different wavelength. Source: [4].

- **Luminous intensity (I):** is the luminous flux per unit solid angle in each direction. The luminous intensity is a measure of light emitted by a light source in a particular direction. A certain light source will have a different luminous intensity for each direction considered. In the International System of Units (SI), the luminous intensity is measured in candela (cd) that is equivalent to lumen/steradian.

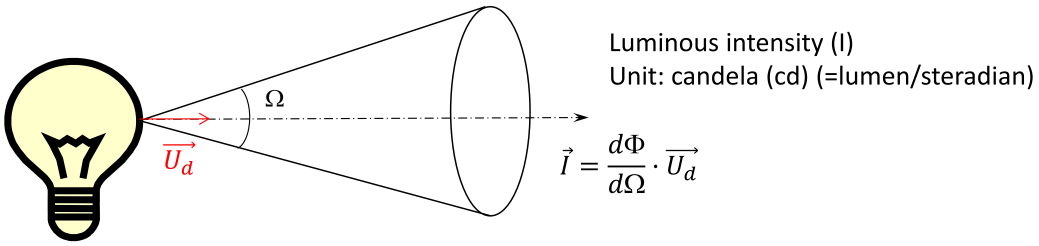



Fig. 3. Luminous intensity

- **Illuminance (E)**: is the total luminous flux incident on a surface, per unit area. This is, is the luminous flux density on a surface. The illuminance is a measure of how much the incident light illuminates the surface. It is the basic design quantity for indoor lighting installations. Lux is the international unit of illuminance; 1 lumen per square foot equals 1 footcandle, while 1 lumen per square meter equals 1 lux.

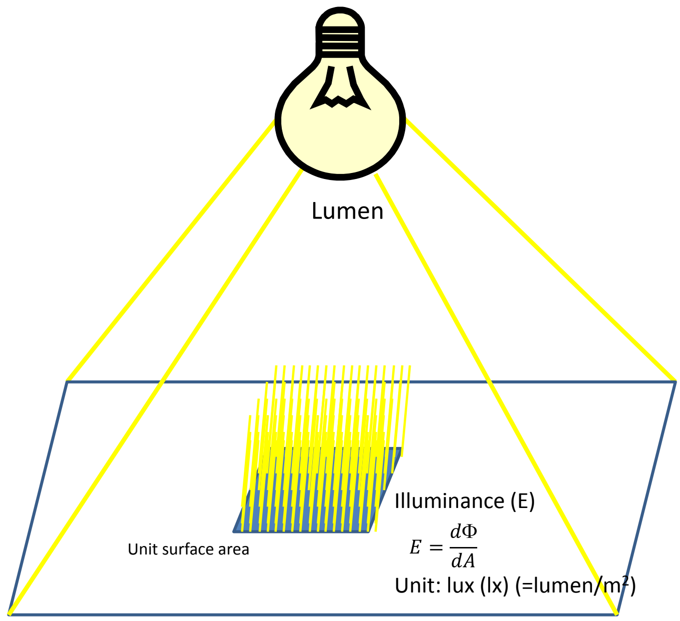



Fig. 4. Illuminance

- **Luminance (L):** is the luminous intensity per unit area of light travelling in a given direction [5]. It is defined as the quotient between the luminous intensity emitted by a certain surface in a given direction divided by the projection of the surface in that direction [1]. The unit for luminance in the SI is the candela per square metre (cd/m2). The eye sees 'luminance', the technical term for the brightness of a surface. It is dependent on the illuminance on the viewed surfaces, the reflective properties of the surfaces and the position of the observer [6]. Fig. 5 illustrates the intuitive meaning of the exposed lighting quantities.

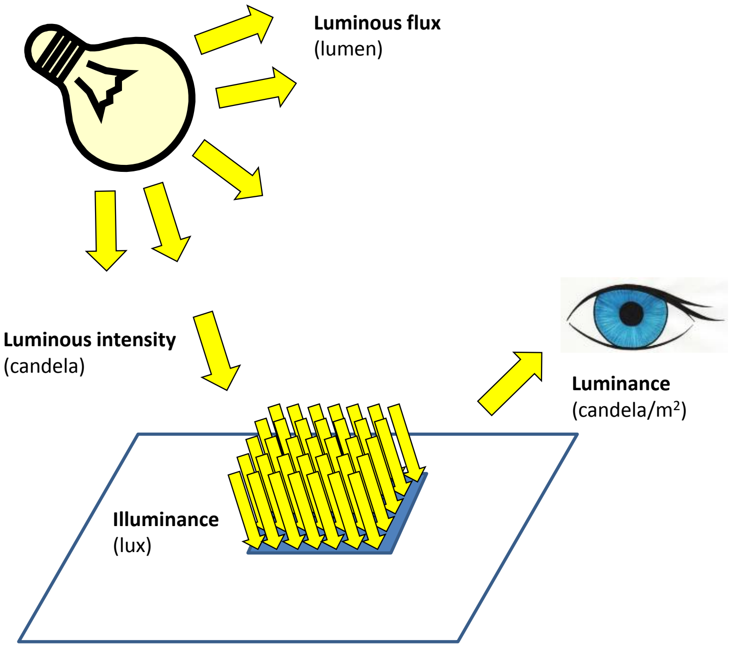



Fig. 5. Illustrative representation of different lighting quantities

- **Luminous efficacy:** is the ration of the luminous flux emitted by a light source (in lumen) and against power that it demands (in watts). It measures the efficiency with which the source provides visible light from electricity. The luminous efficacies (lm/W) of typical lamps are displayed in Table I.

Table I. Luminous efficacy of different lamps. Source: [7].

| Light Source | Lumen/Watt (lm/W) |
|---|---|
| Sodium lamp - Low pressure | 200 lm/W |
| Sodium lamp - High pressure | 150 lm/W |
| Fluorescent lamp | 45-104 lm/W |
| Metal halide lamp | 85-115 lm/W |
| Halogen lamp | 16 lm/W |
| Light bulb | 8-10 lm/W |
| White LED | 26-100 lm/W |

- **Reflectance:** the ratio of the reflected flux to the incident flux, according to the definition of the Illuminating Engineering Society of North America (IESNA). It expresses the percentage of luminous flux that is reflected back from a certain surface; the rest is either transmitted or absorbed by that surface [2].

- **Color rendering index (or colon rendition index) (CRI):** measures the ability of a light source to reproduce faithfully the color of various objects that are lit by a reference light source. The International Commission on Illumination defines it as follows: "Effect of an illuminant on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant". CRI ranges from 0 to 100 (the CRI=100 corresponds to a black body).

  Different light sources have different values of CRI; while incandescent lamps reach very high values (close to 100), low-pressure sodium lamps have very reduced CRIs. Mercury vapor lamps usually have intermediate values of CRI that vary depending on the specific family. LED lights can reach very high CRI values, higher than 80 and, in some cases, close to 100. The International Commission on Illumination proposes a classification of the light sources in four groups depending on their CRI (see Table II).

  In the design of indoor lighting systems, the required CRI will depend upon the activity that will be carried out in the premise; this will determine the specific type of lamps to be used in the lighting of the premise (see Table II).

Table II. Color rendering groups. Source: [8].

| Color rendering groups | General Color Rendering index (CRI) | Typical application |
|---|---|---|
| 1A | CRI>90 | Whenever accurate color rendering is required, e.g. color printing inspection |
| 1B | 80<CRI<90 | Whenever accurate color judgments are necessary or good color rendering is required for reasons of appearance, e.g. display lighting |
| 2 | 60<CRI<80 | Whenever moderate color rendering is required |
| 3 | 40<CRI<60 | Whenever color rendering is of little significance but marked distortion of color is unacceptable |
| 4 | 20<CRI<40 | Whenever color rendering is of no importance at all and marked distortion of color is acceptable |

- **Chromaticity diagram:** allows representing all colors as a weighted sum of three 'primary' colors. For the light sources, there are three basic colors (red, green and blue), so every other can be obtained as a combination of all these three. Every light source can be represented as a point in the chromaticity diagram ('color point') that informs on its content in the three basic colors [1]. Fig. 6 depicts the C.I.E. chromaticity diagram.

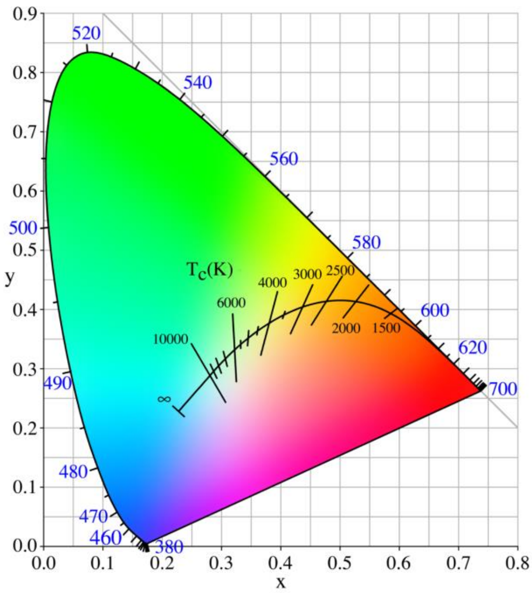



Fig. 6. CIE 1931 chromaticity diagram. Source: [9].

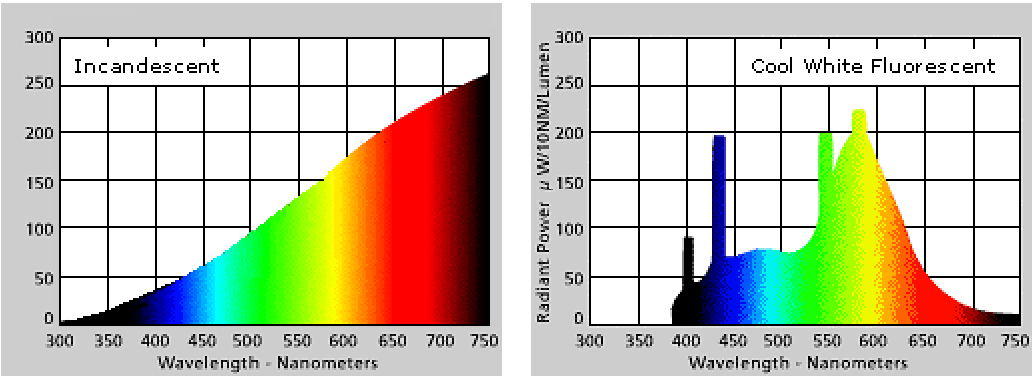
- **Color temperature:** is defined as "the absolute temperature of a blackbody whose chromaticity most nearly resembles that of the light source" [2]. This definition is strictly valid for incandescent light sources, but not for discharge lamps. For these latter, we use the concept of *correlated color temperature* (CCT), that is a specification of the color appearance of the light emitted by a lamp, relating its color to the color of light from a reference source when heated to a particular temperature, measured in degrees Kelvin (K) [2].

  The CCT gives a good indication of the general appearance of the lamp (but does not provide information on its specific spectral power distribution). Hence, two lamps may appear to have the same color but have quite different effects on the lit object colors. According to the CCT, the light sources can be classified in warm (CCT<3200K), intermediate (CCT) or cool (CCT>4000 K) [2].Table III shows typical CCT values for some common light sources.

Table III. CCT values for common light sources. Source: [2].

| Light source | Correlated Color temperature |
|---|---|
| Tungsten Halogen | 3000 K |
| "Cool White" Linear Fluorescent | 4200 K |
| High Pressure Sodium | 1900 K |
| "Warm" Compact Fluorescent | 2700 K |

- **Spectral Power Distribution:** IESNA defines the Spectral Power Distribution (SPD) as "a pictorial representation of the radiant power emitted by a light source at each wavelength or band of wavelengths in the visible region of the electromagnetic spectrum (360 to 770 nanometers)" [2]. The manufactures of lamps provide SPD curves of some light sources. Fig. 7 depicts the SPD of two different lamps with very different distributions of their radiant power versus wavelength.




(a) (b)

Fig. 7. SPD of: (a) incandescent lamp and (b) Cool white fluorescent lamp. Source: [2]

- **Glare:** According to IESNA, the glare is the sensation caused by luminances within the visual field that are sufficiently greater than the luminance to which the eyes are adapted, which causes annoyance, discomfort, or loss in visual performance and visibility. The glare can be classified either by origin (in direct /indirect (or reflected) glare) or by effect on the users (disability/discomfort glare) [2].

# 5 Conclusions

This work presents a simple compilation of some of the basic quantities that serve to characterize a lighting system. Concepts as luminous flux, luminance, illuminance, luminous intensity, luminous efficacy, reflectance, spectral power distribution, color rendering index (or Color rendition index), color Temperature, chromaticity diagram and glare are reviewed. Their formal and intuitive explanations are given. Also, their corresponding units and symbols are included. Finally, additional details about their use and importance in the design process of lighting systems are given.

# 6 References

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