Luminous flux density: the rarely mentioned photometric quantity

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Summary

In technical articles, we commonly see the "potency" of a light beam at a certain place in its travels quantified as the *illuminance* of the beam there.

But that is not apt. *Illuminance* is not a property of a beam of light at some place in its travels. It is a measure of the illumination afforded by a beam of light on some surface, having a certain orientation, at such a place.

What does properly characterize the "potency" of a beam of light at a certain place is its *luminous flux density*. Yet we almost never see that quantity mentioned.

Luminous flux density and *illuminance* have very similar definitions, and are closely related, so it is perhaps understandable that authors get them confused.

This article sorts that out.

1 ABOUT "POTENCY"

In photometrics we consider many quantitative measures of light, each with a different concept. As I discuss certain of these, I may first speak of the quantity as telling the "potency" of the light in a certain way. "Potency" is of course not an actual scientific term, but I use it to remind the reader of the general role of the quantity before introducing the actual specific technical quantity and term.

2 THE PHOTOMETRIC TRAIL–THE BASICS

2.1 Introduction

In this section I will introduce the various photometric quantities that are players in this drama, as we might encounter them in the "trail" of quantities followed by a derivation in a technical article.

2.2 Luminous intensity

The "trail" of photometric quantities ensuing from a light source often begins with considering the "potency" of the light emitted in a certain direction by a very small light source (ideally, a "point source").

The actual technical quantity for that is *luminous intensity*. This is defined as the amount of *luminous flux* (the "stuff" of light) emitted per unit solid angle[1] in the direction of interest.

2.3 Luminous flux density

Next, at some direction from the source, at certain distance from it, we often may be interested in the "potency" of the light beam at that place.

The actual technical quantity for that is *luminous flux density*. This is defined as the amount of luminous flux per unit area of a theoretical plane that the beam crosses at that place, it lying at right angles to the direction of travel of the beam (the direction from the source).

2.4 Illuminance

Next consider, at a certain direction and distance from such a source, an actual plane surface, oriented at some specific angle with respect to the direction of travel of the beam. We may be interested in the "potency" with which the beam of light illuminates that surface.

The actual technical quantity for that is *illuminance.* This is defined as the luminous flux incident per unit area of that surface.

3 THE PROBLEM

You may have never (or at least rarely) seen the term "luminous flux density" used to quantify the "potency" of a light beam at some place in its travels. Rather, you may have seen that quantity described in terms of the beam's *illuminance* at that place.

But in fact it is *luminous flux density*, not *illuminance,* that is the proper measure of the "potency" of a light beam at some point in its travels.

It is easy to see why he quantities *luminous flux density* and *illuminance* are often confused. They have the same unit and similar definitions. In fact the *luminous flux density* of a light beam at some place is the same as the *illuminance* that beam would cause on a

[1] As to why solid angle is involved, see section A.1 in Appendix A.

surface there that was perpendicular to the direction of travel of the beam.

The result is that commonly, when an author wishes to speak of the "potency" of a beam at a certain place, the quantity (perhaps reckoned by some equation) is spoken of as the "illuminance" of the beam there.

However. the quantity *illuminance* is not appropriate to quantify the "potency" of a light beam at a certain place. Rather, that is properly given by the quantity *luminous flux density*.

But, because of this inappropriate practice, we rarely read about the *luminous flux density* of a beam.

4 THE APPENDIXES

More detail on various of the matters discussed above is given in Appendix A.

A comparison of the situation discussed above with the corresponding situation in the parallel field of radiometry is given in Appendix B.

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Appendix A
Some further details

A.1 MORE ABOUT LUMINOUS INTENSITY

Luminous intensity is the measure of the "potency" of a very small light source (ideally, a "point source"), in a certain direction.

It is defined as the amount of luminous flux per unit solid angle[2] in the emission of light in that direction by that source.

Why "per unit solid angle"? Could we not just speak of the amount of luminous flux emitted in that direction? Well, the amount of space "in a certain direction" is just a line, and has zero cross-sectional area at any distance. Thus it could not contain any flux at all.

So instead we report the amount of luminous flux per unit of solid angle in the direction of interest (generally thinking in terms of an infinitesimal solid angle).

In the SI (the "modern metric system"), *luminous intensity* is conceptually denominated in the unit *lumen per steradian*, which however has it own name, *the candela*.[3] The SI symbol for *luminous intensity* is I_v[4].

A.2 MORE ABOUT LUMINOUS FLUX DENSITY

A.2.1 General

Luminous flux density is the measure of the "potency" of a light beam at a certain place in its travels.

It is defined as the amount of luminous flux per unit area of a theoretical plane crossed by the beam at that place, that plane lying perpendicular to the direction of travel of the beam (generally thinking in terms of an infinitesimal area).

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[2] Solid angle is the measure of the amount of "space' enclosed by a conical or pyramidal space as seen from its apex.

[3] Named (from the Latin for "candle") to "honor" the earlier (pre-SI) unit, the *candlepower*. The two units are similar in size: 1 candlepower is approximately 0.981 candelas.

[4] The symbols for all photometric quantities have the "v" subscript, for "visual". This is to distinguish them from the parallel qualities in radiometry (see Section Appendix B), which have the same symbols but with the subscript "e" (for "energy").

In the SI, *luminous flux density* is denominated in the unit *lumen per square meter*. There is however not a distinct scientific symbol for *luminous flux density*.

It is often indicated as E_v, actually the symbol for *illuminance*, this practice being one aspect of the prolem that is the theme of this article.

Note that this quantity is not predicated on the illumination the beam affords on some actual or hypothetical plane, merely on its "potency" as its passes through a completely theoretical plane.

In many "derivations" in the field of photometry, *luminous flux density* is treated as an unnamed "intermediate quantity" and is not spoken of directly (the equations just jumping all the way to the next stage of the trail, usually *illuminance*).

A.2.2 A reminder

Remember that *luminous flux density* describes the "potency" of a light beam at some place. It does not of itself describe the illumination afforded by a beam of light on an actual or hypothetical surface at some particular place, having some specific orientation with respect to the direction of travel of the beam (although of course it influences that quantity).

A.3 MORE ABOUT ILLUMINANCE

A.3.1 General

Illuminance is the measure of the illumination afforded by a light beam on a real or hypothetical surface struck by the beam at a certain place in its travels, which has a certain orientation with respect to the direction of travel of the beam.

It is defined as the amount of luminous flux "landing" per unit area of that surface (generally thinking in terms of an infinitesimal area).

In the SI, *illuminance* is denominated in the unit *lumen per square meter* (the same as luminous flux density). The SI symbol for illuminance is E_V [5].

Numerically, the *illuminance* caused on a plane surface of a certain orientation is the product of the *luminous flux density* of the beam at that place and the cosine of the *angle of incidence*, which is defined as between the "normal to the surface" (a line perpendicular to the

[5] A mnemonic for "E": think "ee-luminance".

surface) and the direction of travel of the beam (the direction from the source).

A.3.2 About that cosine

The cosine of the angle of incidence gets into the act not in some esoteric way but rather as a simple matter of geometry.

Suppose that we consider just the portion of the beam that crosses a region 1 mm square (with a cross-sectional area of 1 mm^2) in the theoretical perpendicular plane. That portion contains some amount of luminous flux. The ratio of that amount of luminous flux to that area is the *luminous flux density* of the beam at that place.

Now suppose that the beam strikes a surface oriented at an angle of 45° to the direction of travel of the beam. That square cross-section portion of the beam I spoke of lands on that surface over an region of size 1 mm × 1.414 mm [6,7] (an area of 1.414 mm^2). It is "spread out" in one direction because it strikes the surface at an angle.

The same amount of flux, now spread over an area 1.414 times as great, thus constitutes a flux density (flux per unit area) of only 0.707 times as much as the *luminous flux density* of the beam. That is, the *illuminance* on that "45°" surface is the *luminous flux density* of the beam at that place times the cosine of the angle of incidence, 45°, which is 0.707.

We see that the greatest *illuminance* that a beam could cause on a surface at a certain place would be numerically the same as the *luminous flux density* of the beam at that place. This occurs when the target surface is exactly perpendicular to the direction of travel of the beam (so the cosine of the angle of incidence is one).

A.3.3 A reminder

Remember that *illuminance* is the measure of the illumination afforded by a beam of light on a surface at some particular place and with some specific orientation with respect to the direction of travel of the beam. It is not a property of the beam itself (although its value of course depends on the *luminous flux density* of the beam).

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[6] Here and in what follows I will state the values to a precision of 3 decimal places.

[7] 1.414 is one over the cosine of 45°, which is 0.707.

Appendix B
A (slightly) different situation in radiometry

Radiometry is a field quite parallel to photometry, except that:

- In photometry, the "potency" of various things is based on the human visual response to light of differing wavelengths. Thus, if we had two instances of a light beam carrying the same total power, but having different wavelengths, they would be said to contain different total amounts of *luminous flux*.

- In radiometry, the "potency" of various "radiant" things is based on the power (or energy) contained, the wavelength not mattering.

In radiometric engineering, we often have the same "trail" of quantities I discussed above. Here, however, when we address the "potency" of a radio wave beam at a certain place, the common "scientific" description [8] is in terms of *radiant flux density* (exactly parallel to *luminous flux density* in the photometric field).

But there is no standard scientific symbol for *radiant flux density*! And in fact, most definitions of that quantity speak of the radiant flux being emitted by or received by a surface. [9]

Yet there is a perfectly good radiometric quantity for the radiant flux per unit area actually striking a surface (of some orientation): *irradiance*. Its scientific symbol is E_e. It is exactly parallel, in photometry, to the quantity *illuminance* (E_v).

Yet sometimes the term irradiance is (incorrectly) attached to what is really *radiant flux density*.

Thus we see that, while in radiometry *radiant flux density* will often be spoken of, it does not really have its full identity.

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[8] In practical radio engineering, another metric is often used to quantify the "potency" of a radio wave at some place in its travels. That is the "potency" of the electric field aspect of the wave.

[9] That can indeed be of interest. But there is a distinct radiometric quantity for that, *radiosity*, with symbol J_e.