# Candelas, Lumens and Lux

By

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A light introduction to illumination terms, ideas, and mathematics. Samples of the first two pages of each chapter.

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# How to use this book

This book is for people who are starting to learn about lighting engineering or who need to know the basics of the subject. I've made it as simple, using graphical explanations of mathematical and physical ideas. There *is* mathematics in this book, but nothing beyond high school level, a few formulas, a tiny bit of trigonometry, nothing you need to be scared of! As we've seen in the financial crisis of 2008/2009, mathematics without a concrete idea of what it is happening in the real world can lead to disaster. So this book has more drawings than formulas. There are some short quizzes with answers. The full working of the answers is given in the chapter itself and on this website:

**`http://www.ransen.com/Photometric/Answers.htm`**

It is really very useful for you to do these quick quizzes.

Once you have finished the book (and even as you are reading it) remember to use the index to look up ideas and terms which you are not sure about.

# 1. Candelas, Lumens and Lux

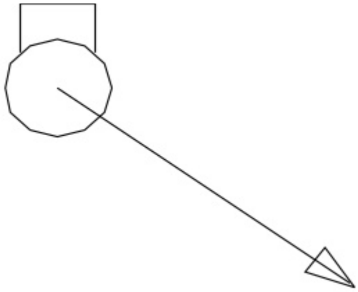
Light is a strange as everything else in the universe, but here I'll be talking about light rays, and drawing them, as if they are simple straight lines of white intensity. This is a justifiable simplification for practical purposes of this book.

Candelas are the units of luminous intensity and you can imagine them as very thin rays of light. So a single ray of light has its luminous intensity value, measured in Candelas. In the diagrams in this book imagine the length of the single thin ray to be proportional to the intensity of the light source in the direction of that ray. The abbreviation for candela is *cd*.

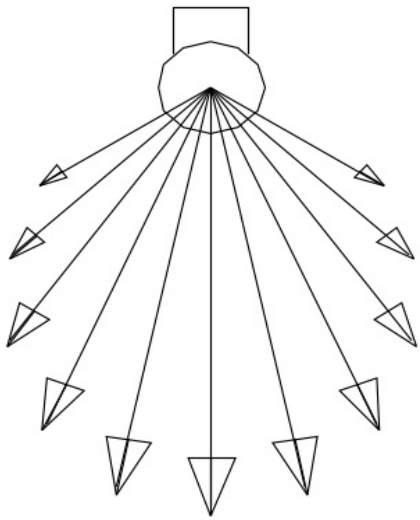
Lumens (abbreviated to *lm*) are the units of luminous flux. Imagine the flux from a luminaire (the technical name for a light source) to be the sum of the lengths of all the rays of light.

Think of *flux* (in Lumens) as an amorphous blobby *flow* of energy issuing the luminaire. Luminous intensity (candelas, cd) tells you how "strong" the light is in a given direction. See the page opposite.

(Sometimes kilolumen (klm) and kilocandela (kcd) are used. For example 13,000 lumen = 13 klm and 2kcd = 2,000cd)....



Luminous intensity is a single ray of light



Flux is the sum of the intensities

# 2. Luminance

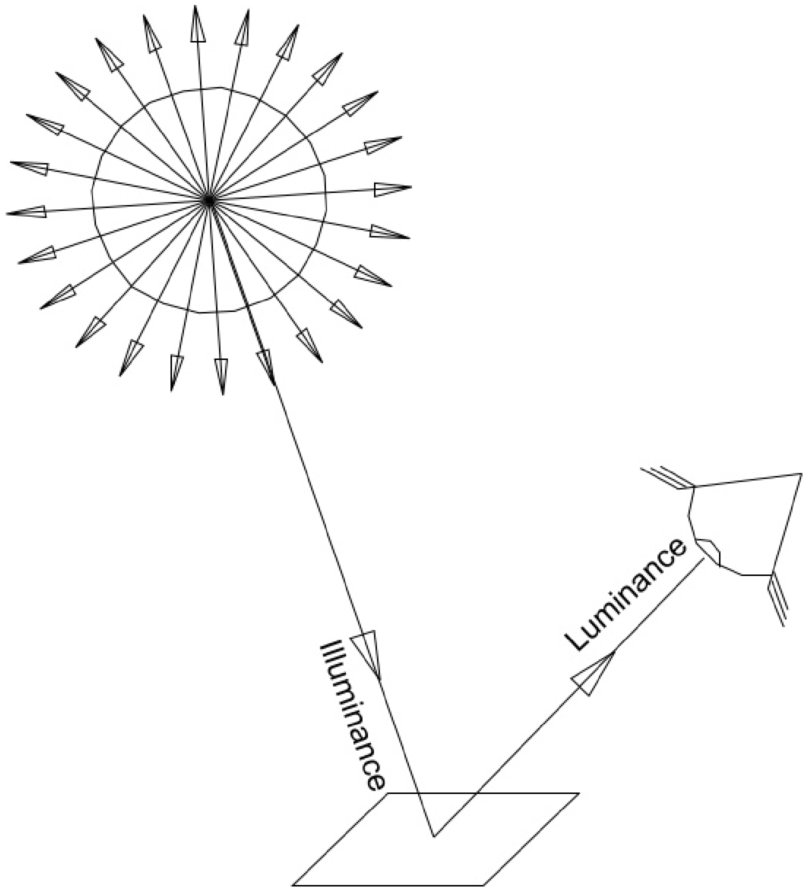
Luminance is apparent brightness, how bright an object appears to the human eye. So when you look at the world what you see is a pattern of varying luminances (if we ignore the colour component). What you see on the this page you are reading is the luminance of the black letters compared to the luminance of the white page. Luminance is measured in candelas per square meter ($cd/m^2$).

Since luminance is what we see, then light sources which we look at have luminance too. The luminance of the sun and the moon give us a good idea of the huge range of brightness which the human eye can handle.

Luminance of the sun: 1,600,000,000 $cd/m^2$

Luminance of the moon: 2500 $cd/m^2$

If you look at the sun you'll get 1,600 million candelas per square meter into you eye. That is why you should not look directly at the sun...




Luminance is what gets into your eye

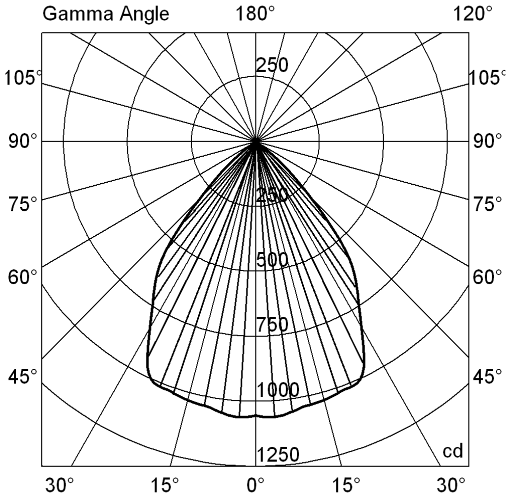
# 3. Photometries

If you are working in the lighting industry sooner or later you will come across photometric diagrams and you must know how to interpret them. This chapter is about how to look at a photometric diagram and get important information from it.

First we'll start off with the polar photometric diagram called "C-Gamma". On the opposite page at the top is a C-Gamma diagram with some of the luminous intensity "rays of light" left in. This makes the diagram more confusing than it needs to be and photometric diagrams always leave out those "rays" to give you a simpler diagram as shown at the bottom of the page. The point to remember is that the distance from the centre of the diagram to one of the points on the "outline" corresponds to a luminous intensity value, often in candelas, in the given direction.

These diagrams tell you immediately if most of the flux (the lumens, the "flow of light") goes upwards downwards or sideways. In the example opposite all the light flows in a downward direction.

C-Gamma diagrams are usually used for indoor and road lighting...


Gamma Angle
180°
120°
105°
105°
90°
90°
75°
75°
60°
60°
45°
45°
250
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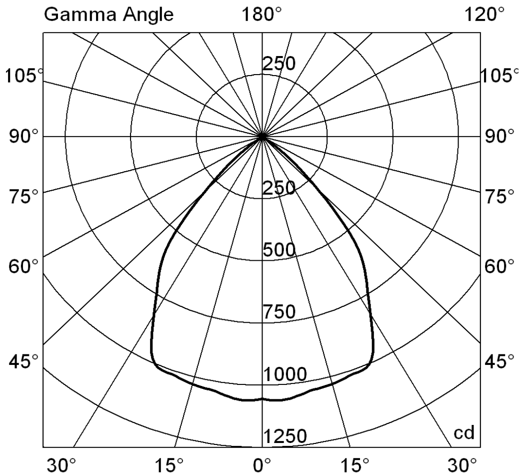
750
1000
1250
cd
30°
15°
0°
15°
30°


Gamma Angle
180°
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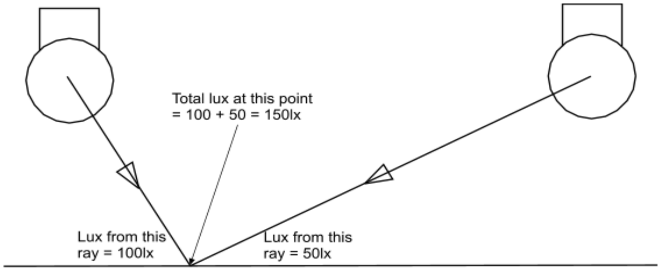
60°
45°
45°
250
250
500
750
1000
1250
cd
30°
15°
0°
15°
30°

# 4. Internal Lighting

Internal lighting includes, for example, underground car parks, classrooms, operating theatres, cinemas, homes and factories. The illumination requirements of all these areas will be very different.

At its simplest the illumination requirements can be specified as the average lux which arrives at a work surface But there are other things to consider, for example glare (see the whole chapter on glare) and uniformity, which means how evenly the light is distributed over the illuminated area. Imagine a room is illuminated to 300lx on *average*. If most of the lux is in the centre even though the average is acceptable, the uniformity is not.

Of course you can increase illuminance (and in fact uniformity) by adding further luminaires into a situation. Illuminance is additive, the illuminance at a given point is the sum of the illuminances from every luminaire in the room:



Here is a table of average lux values for given situations:

| Area | Minimum Lux | Maximum Lux |
|---|---|---|
| Retail Lighting | 400 | 500 |
| Office Lighting | 450 | 500 |
| Video terminal work | 100 | 200 |
| Classrooms | 300 | 750 |
| Hospital public areas | 100 | 200 |
| Hospital operating theatre | 1500 | 2000 |
| Hospital operating table | 50000 | 60000 |
| Sewing room | 1000 | 2000 |
| Electronic test room | 800 | 1200 |
| Factory assembly areas | 200 | 500 |

The values in the table above are taken from example national standards all over the world, but they give you a rough idea of the lighting levels required in various situations....

# 5. Glare

The first problem to solve when illuminating a room, a road or a tunnel is to make sure that the *quantity* of light on the important surfaces is right for the circumstances. The second problem to solve is uniformity. Glare could be called the third problem to solve. A brightly lit tunnel which dazzles the drivers could cause as many accidents as a badly lit tunnel. Road lighting is another example where it is important to avoid glare as much as possible.

Some restaurants use artistically placed low lights with tiny but fierce bulbs (hanging inches from your nose) in an attempt to give an intimate atmosphere. They give *me* a headache. Indirect glare in offices can make working at a computer a trying task. Naked light bulbs hanging just above the line from your eyes to the TV can spoil your favourite program.

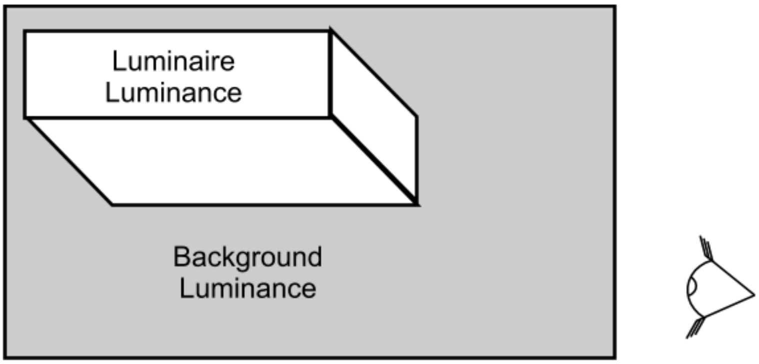
Apart from these human factors excessive glare means a waste of energy (and so money). There is no point in shooting (direct from the luminaire) tons of lumens into the eye of a person. The lumens are required on *what* the person is looking at.

The analysis of glare is the analysis of relative luminances, that is, what the eye sees.

There seem to be as many ways of specifying glare as there are stars in the sky.

Another way of defining glare is to say it has a contrast lowering effect of stray light in a visual scene. Simple glare calculations only take into account the luminance of the light source and its visible light emitting surfaces.

More complicated and realistic calculations also take into account the *background luminance*, i.e. they take into account the *contrast* in the visual scene...




Glare formulas often compare the luminaire luminance with the background luminance.

# 6. Roadway Lighting

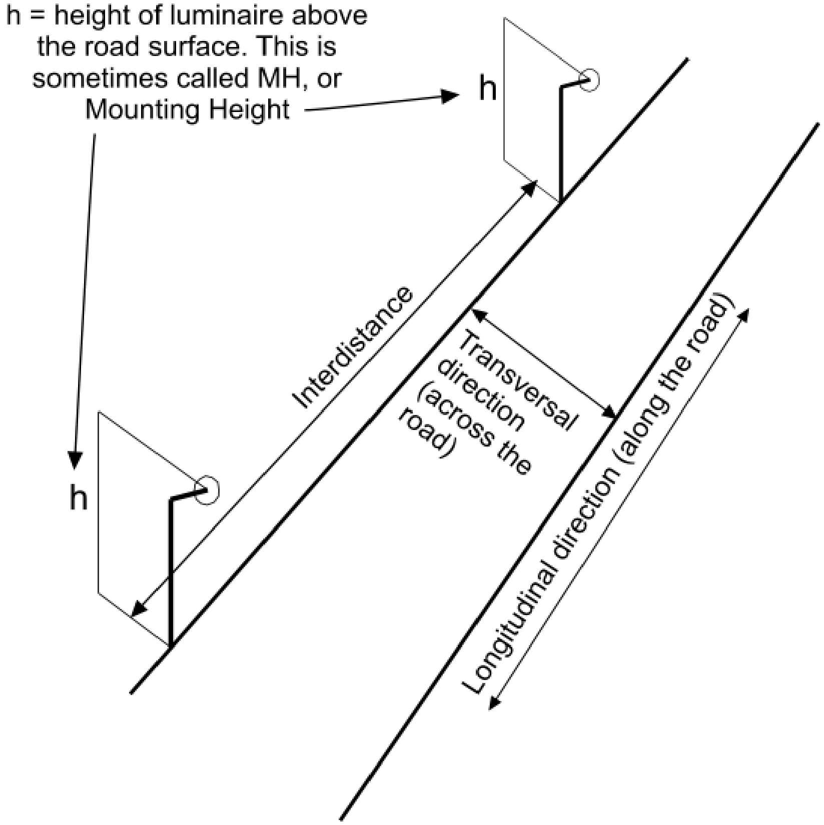
For good roadway lighting the following three points should be considered:

1. The luminance of the road (remember that luminance is what the eye perceives).
2. Uniformity of the lighting, how much the illumination vary along and across the road.
3. Glare, how much do the luminaires themselves shine into the eyes of the drivers.

Road lighting can also be a guide to drivers (illuminated signs) and a distraction (illuminated adverts).

Some experts have suggested that a luminance of between 1 and 2 $cd/m^2$ is ideal for safe driving, whereas less than 1 $cd/m^2$ is insufficient.

We'll use a transversal and longitudinal a lot in this chapter, and the diagram on the opposite page explains these terms, along with a few others. Note also MH and inter-distance...


h = height of luminaire above the road surface. This is sometimes called MH, or Mounting Height
h
h
Interdistance
Transversal direction (across the road)
Longitudinal direction (along the road)

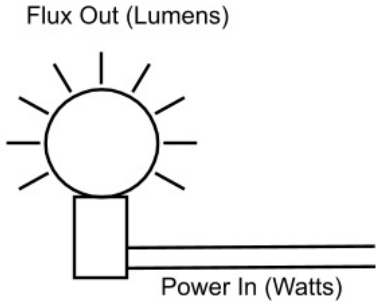
# 7. Light sources and efficiency

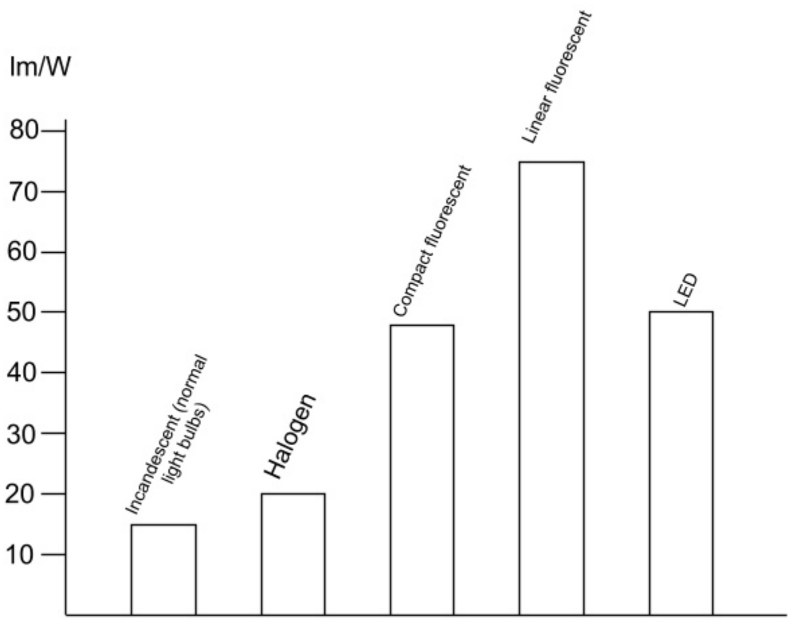
Luminous efficacy is a measure of how much of the electrical power supplied to the lamp is turned into luminous flux, this is illustrated at the top of the opposite page. Luminous efficiency, on the other hand, is a measure of how much of the radiant energy is visible to the human eye, as explained later.

Efficacy is a term often used when we calculate values which have units, in the the case of lighting the unit is lumens per watt. (Efficiency on the other hand is often used when what we are measuring is unitless, or at most has "percentage" as a unit)

As you can see from the graph on the opposite page linear fluorescent lights have a very good luminous efficacy, but LEDs are catching up...

$$\text{Luminous Efficacy} = \frac{\text{Flux Out (Lumens)}}{\text{Power In (Watts)}}$$




Luminous efficacy of different types of light sources

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