

Photopic and Scotopic Lumens - 1: An Introduction

This is the first in a series of articles on the basic unit of light that is the foundation of the wide range of concepts and calculations that we lighting professionals use day in and day out: The lumen. There is renewed interest in the fact that there are *two* definitions of the lumen: one for daytime, high light level conditions, and one for nighttime, low light level conditions. These are photopic and scotopic lumens. Virtually all lighting applications today involve photopic lumens. Should they? What are the practical alternatives? How important are the differences? When, if at all, should we be using scotopic lumens as the basis for our work as lighting professionals? This series of eight articles will attempt to answer these questions by exploring the development of the lumen, the technical issues involved in its definition and use, and some recently proposed changes to our professional practice that are based on and involve the differences between photopic and scotopic lumens.

The most common use of the lumen is to express the total light emitting power of a light source and to express its efficacy. And so we speak of a 100 watt incandescent lamp being rated at 1690 lumens and having an efficacy of 16.9 lumens per watt. As a practical matter, we most often use units that are *derived* from the lumen, like luminous intensity and illuminance. These derived units are used to evaluate lighting equipment and what that equipment does to architectural spaces. Luminous intensity, measured in candelas and often called candlepower, describes how densely a source emits lumens in a particular direction. All the directions can be considered together and we have the candlepower distribution of a source. Illuminance, measured in footcandles or lux, describes how densely a source puts lumens onto a surface. Intensity is the universally used method to describe what luminaires *can* do and Illuminance is the universally used method to describe what luminaires *do* do. But they both depend on the lumen and as the lumen goes, so go the candela and the footcandle.

What is the lumen? That is essentially the same question as “how do you define light”? It obviously needs to have something to do with amount of physical radiant power, but it must also have something to do with the human visual system. By 1800 it was known that some radiant power could not be seen (infrared and ultraviolet radiation were discovered) and by 1875 it was known that different wavelengths of radiant power had different abilities to evoke a visual sensation. These two factors, radiant power and the human visual system, are brought together in the lumen to give a practical definition to light: radiant power assessed by its ability to evoke visual sensation. The lumen was first proposed as the basic unit of light in 1907 and the process for determining it was eventually defined by the International Commission on Illumination in 1924.

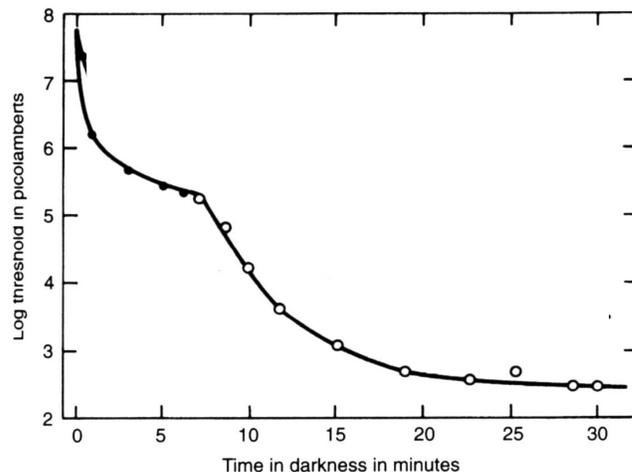
In 1800 William Herschel put some thermometers in and on either side of the spectrum of light produced by passing sunlight through a prism. He discovered a strong heating effect in the darkness beyond the red part of the spectrum. Similar experiments showed that light beyond the violet end of the spectrum was chemically active.



William Herschel and his spectral experiment

But there is usually complexity, if not trouble, whenever we mix physics with biology. The physical side of things – the radiant power of a light source – is simply enough defined and is well-behaved, but the biological side of things – the evoking of a visual sensation – is very hard to define and not at all well-behaved. One of the most obvious things about the visual system that changes is its sensitivity to light. The smaller the amount of light involved, the more sensitive the visual system becomes. The differences between daytime (high light level) vision and nighttime (low light level) vision are obvious to us all. This change in sensitivity is so great that it proved to be useful and necessary to have *two* definitions of light: one for high light levels, which is called photopic, and one for low light levels, which is called scotopic. And so we have photopic lumens and scotopic lumens. “Photopic” comes from one of the Greek word for light, and “scotopic” comes from the Greek word for darkness. The process for determining scotopic light was defined by the International Commission on Illumination in 1951. This process and the 1924 process for photopic lumens will be described in a subsequent article.

The range of sensitivity of the human visual system is very large. The ratio of sensitivity, greatest to least is about 1,000,000,000! This results from mechanical, chemical, and neural changes: pupil size, the chemical in the cells in the eye being used up, and neural processing in the brain. As a practical matter, the ratio of sensitivities for indoor to full moonlight is between 3 and 10.



As you sit in darkness, your visual system becomes more sensitive. After 30 minutes of darkness, you are about 100,000 times more sensitive to light. The curve shows how the threshold for detecting flashes of light falls (that is, the visual system is getting more sensitive). The knee in the curve is the point where the cones in your retina stop working and the rods take over.