Light

Vision is one of the most important of our five senses. It is chiefly through sight that we understand our environment and gain instant knowledge which informs our actions and movements. Our ability to perform certain tasks is greatly dependent on how well we can perceive them. Unconsciously our perception of the visual scene greatly affects our moods, emotions and sense of well-being.

Why the Candela?

The efficiency and ease with which we see things depends on the level of light present. It is therefore important to develop a scientific system to measure light levels. This helps to determine how much light falls on what you are doing, and also aids the development and comparison of the myriad number of artificial light sources available today. Achievement of specified lighting levels is important in safety and regulation, ensuring that there is the recommended level of lighting in a laboratory or classroom, adequate illumination of road signs and the correct brightness levels for emergency lighting. It is also important in many leisure activities – television, photography and sports lighting to name a few.

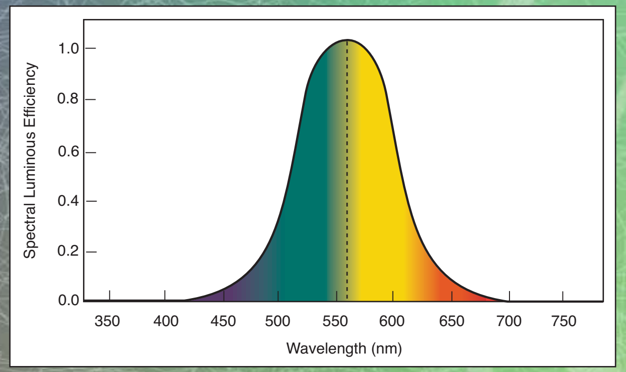
The S.I. (International System of Units) base unit chosen to carry out measurements of light is the 'candela'.

The Candela and the Eye

The power of optical radiation is measured in watts. However the eye cannot see all colours, or wavelengths, of light equally well and thus another unit is needed to assess the visual effect of optical radiation – this unit is the candela. The eye is most sensitive to light in the yellow-green region of the spectrum, close to the colour which corresponds to the peak output of sunlight reaching the earth's surface. It is less sensitive to red and blue light. A special function, known as the V(λ) function, has been agreed internationally to describe the way in which the eye responds to different colours of light.

The shape of the V(λ) function, the eye's approximate response as a function of the wavelength of light affects how we perceive different types of light source. For example, a 60 W tungsten bulb, a normal household bulb, consumes more than six times the electrical power of a 9 W compact fluorescent lamp but they are both perceived as producing approximately equal amounts of light giving out roughly the same number of candelas. This is because a lot of the power used by a tungsten bulb is given out in the infrared part of the spectrum where the eye has no response. The light given out by the fluorescent lamp corresponds more closely to the peak sensitivity of the eye.

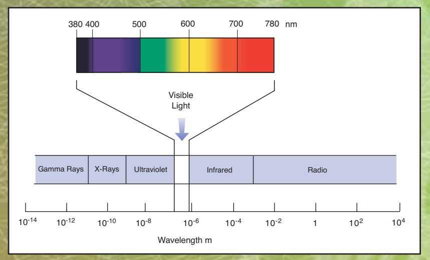
It is all very well defining the candela but it is of little value unless it can be used for real measurements of real sources like a tungsten lamp. This is known as realisation. The ways the candela has been realised historically and the way it is currently realised are described below.



Current Realisation of the Candela

The candela was re-defined in 1979 in terms of the watt because the use of a blackbody (as required by previous definition) was experimentally difficult and the temperature at which the experiments were carried out was far below that of modern light sources.

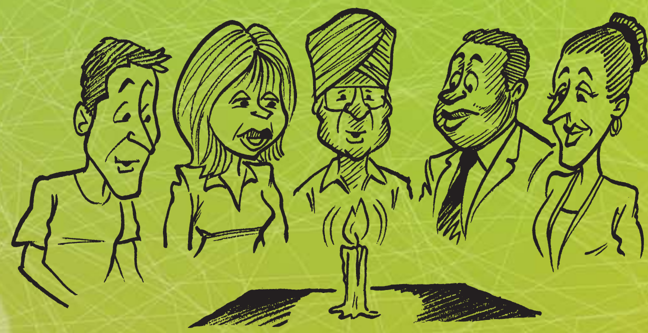
The radiometric realisation of the candela at NPL was successfully completed in 1985. This method, which utilises our ability to measure optical radiation very accurately, was based on the NPL cryogenic absolute radiometer, an instrument capable of measuring optical power (in watts) in a laser beam to an accuracy of better than 0.01%. The measured laser beam was used to calibrate a photometer, a detector with a filter to mimic the response of the eye, which was then used to measure the luminous intensity (in candelas) emitted by a tungsten lamp source with an accuracy of 0.1%. Other types of lamp could also be measured either directly, using the photometer, or by comparison with the tungsten lamps. This was by no means a simple experiment and many subsidiary measurements were necessary to accurately establish the candela.



The V(λ) Function

The V(λ) function describes the ability of visible light to produce a visual response. It is a definition of the relative sensitivity of the eye to different wavelengths, or colours, of light. It was established in 1924 through extensive experimental work at several laboratories, including NPL, and was defined on the data obtained from observers matching the brightness of different colours. The function has a maximum at the peak of the sensitivity of the eye, a wavelength of 555 nm (frequency of 540 x 10^{12} Hz, or yellowish-green.

The V(λ) function represents a mean of over 200 different people's eye response covering a wide range of ages, 18 to 60, and both sexes. Actual eye response varies from person to person and changes with age as the lens of the eye yellows. This means a standard person doesn't really exist – if one did it would probably be a woman in her late twenties. It follows, therefore, that real people see life in slightly different ways.



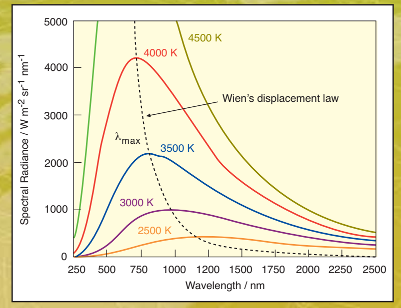
The History of the Realisation of the Candela

1860 The first realisation of the candela was made using candles made from sperm whale fat, known as spermacetti.

1898 The next step in the history of the candela is the development of reproducible gas lamps. These lamps burned a mixture of pentane gas and air in a wickless burner and were a major technological advance.

1909 The first successful attempt at establishing an internationally recognised unit was in the years leading up to 1909. In that year an agreement was signed jointly by NPL in the UK, the National Bureau of Standards (NBS) in the US and the Laboratoire Central d'Electricité in France adopting a unit, derived from a pentane lamp, but maintained with carbon filament lamps.

1940 Standards based on blackbodies, heated devices designed to simulate a perfect absorber and emitter of radiation, were first realised experimentally in 1930. By January 1, 1940, the unit of luminous intensity was defined in terms of the brightness of a blackbody radiator at the freezing temperature of platinum. This unit was termed 'the new candle' and was widely adopted around the world.



1948 In 1948 the 'new candle' became the candela and was adopted world wide. It was defined as: 'The magnitude of the candela is such that the luminance of a full radiator at the temperature of solidification of platinum is 60 candelas per square centimetre'.

1979 Current Definition of the Candela
In 1979 the candela was redefined in terms of the watt at only one wavelength of light. It is defined as "The luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 x 10^{12} hertz and that has a radiant intensity in that direction of 1/683 watts per steradian" (the steradian being a unit of solid angle).

If you have a measurement related scientific question contact us on: telephone 020 8943 6880 email: enquiry@npl.co.uk or visit our web site which has lots of measurement related information at http://www.npl.co.uk

Table comparing approximate luminance of various sources

Light source	Luminance (cd/m²)
Atomic fission bomb (0.1 millisecond after firing)	2 x 10^{12}
Lightning flash	8 x 10^{10}
Sun as observed from the earth's surface (at meridian)	1.6 x 10^{9}
Photoflash lamps	2.5 x 10^{8}
60 W 'opal' bulb	1.2 x 10^{5}
Sperm candle flame	1 x 10^{4}
Clear blue sky	4 x 10^{3}
Moon as observed from the earth's surface	3 x 10^{3}
Starlit sky	5 x 10^{-4}

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