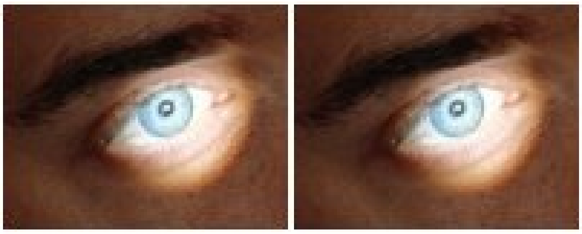
Principles of Photometry



Photometry is the measurement of electromagnetic radiation weighted by the human eye's response. This response changes with wavelength, and to an extent, from person to person. Internationally-agreed standard observer functions are therefore used in order to provide a consistent measurement base for photometry; the two most widely used are the *V*(*λ)* function, which applies for photopic vision (typical day-time light levels) and the *V'*(*λ*) for scotopic vision (low lighting levels). At intermediate light levels (mesopic or 'twilight' levels, such as found on lit roads at night), the CIE system of mesopic photometry is used to provide a smooth transition between these two functions.

In photometry, the word 'luminous' is used to indicate that measurements have been made using a detection system (called a photometer) that has a spectral response similar to that of a human eye. The two principal photometric scales maintained at NPL are of luminous intensity and luminous flux. Setting up appropriate geometries permits calibrations of other quantities, such as luminance from luminous intensity standards. NPL has extensive facilities available for the photometric measurement of both sources and detectors, including photometers, luxmeters, luminance meters and colour temperature meters. Services include the calibration of luminous intensity, illuminance, luminance, luminous flux and correlated colour temperature.

Luminous intensity measures the luminous output from a source in a specific direction into unit solid angle. The candela (one of the SI base units, abbreviation cd), is the unit of luminous intensity and is maintained at NPL using standard photometers and lamps with an uncertainty of ±0.2%. Working reference standards are calibrated against the standard photometers whose calibration derives in turn from the NPL spectral responsivity scale based on the cryogenic radiometer. Luminous intensity measurements are carried out on a photometric bench. They compare the output of test lamps with that of working reference standard lamps using a specially constructed filter-corrected silicon photodiode (photometer).

Illuminance, (measured in lux), at a point of a surface is the quotient of luminous flux incident on an element of the surface, by the area of the element. For a point source and a surface normal to the direction of view, illuminance equals luminous intensity divided by distance squared. Apparatus for illuminance measurements are similar to that for luminous intensity, but, instead of comparing lamps, the distances from light centres to the photometer are carefully measured for each lamp. The illuminance produced at the photometer by the standard is calculated using the inverse square law. The best measurement capability is ± 0.5%. This method can be used to calibrate photometers and luxmeters.

Total luminous flux (in lumen, lm) is a measure of the amount of light emitted from a source in all directions (i.e. the full solid angle of 4π steradians). The NPL total luminous flux scale is derived at the ± 0.3% level from the luminous intensity scale by use of a specially constructed goniometer. The reference goniophotometer has a maximum detector to source distance of 18 m, which can permit very high angular resolution of large sources such as luminaries and spotlights.

Luminance (in cd m^{-2}) is a measure of the radiation emitted in a given direction from a given area of a source and can be thought of as a correlate of the visual attribute of 'brightness'. The measurement scale is maintained in devices such as 'luminance gauges', which give a uniform field of luminance. The reference system at NPL uses a white diffuser of known

reflectance, illuminated normally by a luminous intensity standard at a measured distance.
A telephotometer designed to have a response close to the *V*(*λ*) function measures light reflected at 45º to the normal. The best measurement capability is ±1.5%.

Colour temperature is a specification system describing the colour of a source by reference to a Planckian radiator scale. The appearance of coloured materials depends on the spectral properties of the illuminating source, so lamp colour temperature is quoted in several standards. A common requirement is the use of CIE Source A, defined as a tungsten source with a correlated colour temperature of 2856 K. NPL offers calibration services for the correlated colour temperature of tungsten lamps and for the calibration of meters for colour temperature and chroma measurements.

In addition to services for the calibration of sources supplied by customers, NPL can supply calibrated tungsten and tungsten halogen lamps, including a range of lamps designed specifically for use as standards of luminous intensity or luminous flux.

Throwing Light on the Use and Abuse of Luxmeters

Luxmeters are a common sight in industry and science. Lighting engineers use them not only to check illuminance levels in offices and factories but also to make performance checks on the lighting used in transport, photographic and film studios, hospital operating theatres and so on. There are even applications in the aerospace industry, for materials testing and the design of cockpit displays in aircraft. However, it is seldom appreciated that while the digital displays on these instruments often indicate fractions of a per cent, the accuracy of meters used in most practical applications is seldom better than 10%.

The principal reason for this is the difficulty in matching the spectral response curve of the detector to the eye's response function, *V*(*λ*). This means that even if the meter has been accurately and traceably calibrated using a tungsten lamp - as recommended in most specifications - errors will occur when it is used to measure other types of source with a different spectral distribution, such as fluorescent lamps.

NPL has extensive expertise and specialist facilities available to address this problem. These range from advice and training in the optimum use of luxmeters, through accurate calibration of customers' meters to allow fully for the effects of the spectral mismatch, to the supply of special individually- designed photometers for applications where the very highest accuracies are required.

Calibration Facilities

- 8 m photometric bench
- 1.7 or 18 m goniometer
- Lamp characterisation system
- Traceable, stabilised power supplies
- High accuracy NPL-designed photometers
- Photometer spectral responsivity calibration facility
- Telephotometer
- Luxmeter calibration facility

Additional special measurement systems are also available to perform special measurements.

Training and Consultancy

We run hands on training courses in photometric techniques. We can also offer our expertise in consultancy services.