# “Why is it so dark in here?”

## Perception of Brightness at Low Light Levels in Museum Environments

**Malcolm Innes, 2011**

Many museum and gallery exhibits are fragile objects that would not survive repeated handling. Even where this is not the case, it is generally frowned upon for visitors to touch exhibits. As a result, vision is by far the most important sense for museum visitors.

One limit on human visual acuity is the availability of light, with better vision requiring higher illuminance. However, the bright light that allows us to understand the intricacies of an exhibit can also harm it. Many organic materials can be damaged by exposure to ultra violet, infra red and visible light. The display of light-sensitive exhibits is a compromise between the need to preserve the object (ideal conditions being complete darkness) and the visitor's need to see and appreciate detail (where ideal conditions may sometimes be considered to be daylight). Conservation lighting standards set strict limits on the amount of light and the length of exposure. One common result is the dull warm glow of conservation lighting that museum visitors complain about so regularly.

Working extensively in museum and gallery environments, the author’s personal observation has been that exhibits illuminated to 50lux with undimmed low voltage tungsten halogen will normally appear brighter than exhibits illuminated to 50lux with dimmed LV TH. This is not an effect of poor adaptation as the effect is noticeable after hours or only a minute in the low light gallery.

The author’s 18 years of experience of conservation lighting led to the recognition that, at low light levels, there is a strong correlation between colour temperature and perceived brightness. This is evidenced when curators dim down lighting schemes measured at below 50lux because they claim "it looked too bright to be 50lux", believing that a dim orange light signifies conservation levels.

The author’s highly speculative rationale for the observed effect was related to the observor’s expectations of natural light. Warm tones in daylight relate to relatively low light levels such as sunrise and sunset, while the high light levels of mid-day produce a much cooler light. Given our millennia of evolution before the advent of electric light, are we predisposed to expect warm light to be dim and cool light to be bright?

Chris Cuttle has described the study of white light sources with differing spectral composition as “an area that is rich with anecdotal evidence and quasi-scientific findings.” [i]My own totally un-scientific musings do nothing to help clear the waters, but they did provide the inspiration to try and find some answers.

I was interested to discover if this perception effect was repeatable and measurable under test conditions or if it could be explained by existing research?

Studies in 1941 by Kruithof [ii] suggested that people preferred low illuminances to be warm and higher illuminances to be cooler. The famous Kruithof curve diagram suggests a gradual increase in preferred colour temperatures as illuminances increase. According to this study, at 2,000lux, the range of preferred colour temperatures was between 3,500K and 10,000K, with the median being 6,750K. At 200lux, the median was 3,000K and at 50lux it was 2,350K.

In low light galleries I was observing a noticeable effect when comparing two exhibits illuminated with dimmed and undimmed LV TH sources. The light sources were identical and produced the same illumination (50lux), only the CCT was different (2,600K vs 3,000K). It was clear to me that the higher colour temperature was preferable, in as much as it made the exhibits appear brighter. This did not seem to agree with the Kruithof curve.

Studies based on the gallery environment by Scuello et al [iii] found that, at 200lux, observers preferred a CCT of 3,600K. This result was not affected by chromatic adaption to sources at 2,800K, 3,600 or 5,800K. A later paper by Scuello et al [iv] further challenges the received wisdom of the Kruithof curve by finding an observer preference for 3,700K that remained consistent over a range of illuminances from 50lux-2,000lux. The authors suggest that this could be down to this being perceived as the point where the light source was perceived as neutral - neither warm nor cool.

It should be noted that other studies have settled on different results. Pinto et al [v] found a preference amongst observers for 5,100K. This study used hyperspectral images of paintings recreated on computer monitors to simulate different illuminants of different CCTs. However, the paper does not measure the validity of viewing a self luminous CRT monitor image compared to the externally illuminated painting in a gallery. As a lighting designer with a general dislike of high CCT light sources, I am always amazed how terrible a computer screen looks when the colour temperature is set to a level that would be perfect for interior illumination. I would therefore need to be further convinced that this result has a direct relationship with a real art gallery.

So, is the observed effect a physiological or psychological function of the human visual system? Or could the effect be explained as an error of measurement?

When we use an illuminance meter to measure the two exhibits, we get a reading of 50 lux for each one. However, this is not an absolute measure of radiant power, simply a measure against the 'CIE Curve' $V(\lambda)$ , a standard that is based on the human visual response under photopic conditions. Is this an appropriate scale to measure exhibits that are illuminated to a maximum of 50lux?

As we know, our state of visual adaption, photopic, mesopic or scotopic, is related to the amount of light received at the eye. Illuminance levels on exhibits or room surfaces are not a direct indication of the amount of light received at the eyes. Illuminance (E) and reflectance (R) combine to produce exitance (M) - a measure of how much light is available to the eyes. Cuttle [vi] notes that photopic vision begins at exitance levels greater than about 10lm/sq. m. So, for low light display environments with an average reflectance of mid grey (R=0.2), the threshold of photopic vision would be 50lux (i.e. 50lux x 0.2 = 10lm/sq. m exitance). This would require the average illuminance of all the visible room surfaces to be 50lux. However, in an environment where the exhibits, normally intended to be the brightest objects in the field of view, are illuminated to a maximum of 50lux, the average illumination and exitance will be much lower. By this reasoning, the instinct of the conservation specialist lighting designer would be confirmed, '50lux' galleries can easily produce lighting conditions well below photopic conditions and thus the normal rules of interior lighting may not apply.

Whether they give values in lux or foot candles, illuminance meters are often misunderstood in museum environments. Museums and galleries use restricted light levels because light sensitive materials are damaged by exposure to light energy. But, measuring the lux level on an exhibit does not provide a measure of the light energy (flux) reaching the exhibit. Instead, the meter provides a measure of lumens - light radiation relative to the photopic spectral sensitivity of standardised human visual response. As Cuttle insightfully says, "instead of being a physical quantity, the lumen is a psychophysical quantity." [vii]

It is well known that, in Scotopic lighting conditions, the human visual system is more sensitive to the blue end of the spectrum than under Photopic conditions. Although even very low light galleries should not approach scotopic levels (exitance of less than 0.003 lm/sq.m), the visual system is likely to be more sensitive to the blue end of the spectrum than the 'photopic' illuminance meter that we are measuring with.

In his 2006 paper, Steve Fotios [viii] notes that V(λ) based measurements can give, "an incorrect prediction of the comparative brightness of interior spaces lit by sources of different spectral power distribution." Although Fotios was referring to studies comparing dissimilar sources such as Sodium, Mercury and Metal Halide, this statement also seems to fit with observations of dimmed vs undimmed tungsten halogen.

Fotios & Cheal's [ix] paper on lamp spectrum effects at mesopic levels concludes that spatial brightness is influenced by the spectral power distribution of the light source. The authors also found that the proposed CIE mesopic photometry system (CIE 2010) is reflected in their results. It seems that the lighting designer and curator's main tool for preventing excessive light damage is not as helpful as we would like to think in low light museum environments.

Instead of the lumen, Cuttle [x] proposes a different metric for museum environments that quantifies the damage potential of a light source, rather than its relationship to V(λ). This metric affords different damage potential to different wavelengths of lights, a feature that cannot be recorded with traditional illuminance meters.

So, why do low light galleries appear so dark to so many visitors? One obvious answer has always been that age defines the maximum sensitivity of our eyes and the dimming after our mid twenties is quite dramatic. A 45 year old observer may need 300 lux to replicate the visual effect of 50 lux seen by a typical 25 year old. [xi] And yet, it is clear from many research sources that there is more to the perception of brightness than just the age of the viewer. At the exitance levels present in many low light galleries, interactions between illuminance level and colour temperature do affect the perception of brightness. At these illuminance levels, the lux meters we use to measure the light does not represent what we actually experience. Despite the wealth of study directed at the conservation sciences over many decades, it is clear that there is still much that can be done to improve the quality of conservation lighting for both visitor experience and exhibit protection. Much of our received wisdom needs to be re-evaluated by both lighting designers and museum professionals and these professions need to work together to create better lighting for our museums.

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[i] C. Cuttle, Comment 2 on 'Lamp colour properties and apparent brightness: a review' by S Fotios, Lighting Research and Technology, 33, p180, 2006

[ii] A.A. Kruithof, Tubular Luminescence Lamps for General Illumination, Philips Technical Review, 6, p65-73, 1941

[iii] M. Scuello, I. Abramov, J. Gordon, S. Weintraub, Museum Lighting: Optimising the Illuminant, Colour Research and Application, 29, p121-127, (2004)

[iv] M. Scuello, I. Abramov, J. Gordon, S. Weintraub, Museum Lighting: Why are some illuminants preferred?, Optical Society of America, 21, 2, p306-311, (2004)

[v] Pinto, Linhares, Nascimento, Correlated colour temperature preferred by observers for artistic paintings, Optical Society of America, 25, 3, pp623-630 (2008)

[vi] C. Cuttle, (Light for Arts Sake, Butterworth-Heinemann, Oxford, UK, 2007), P18

[vii] Cuttle, p15

[viii] S.Fotios, Chromatic adaption and the relationship between lamp spectrum and brightness, Lighting Research and Technology, 38, 1, pp3-17, (2006)

[ix] S.Fotios, C. Cheal, Predicting amp Spectrum Effects at Mesopic Levels Part 1:Spatial Brightness, (2011)

[x] C. Cuttle, New opportunities for LEDs in museum display lighting, PLD-C, Berlin, 2009

[xi] Cuttle, p27