2.5.4 Luminous colour and colour rendering

Apart from luminance, which is perceived as brightness, the eye also registers an impression of colour based on the spectral composition of the perceived light. The light itself can also be seen as being coloured (luminous colour). Colour is, however, also produced through the capacity of various materials to absorb specific spectral ranges, thereby changing the spectral composition of the light which they reflect (object colour).

There are various systems by which colours are described.

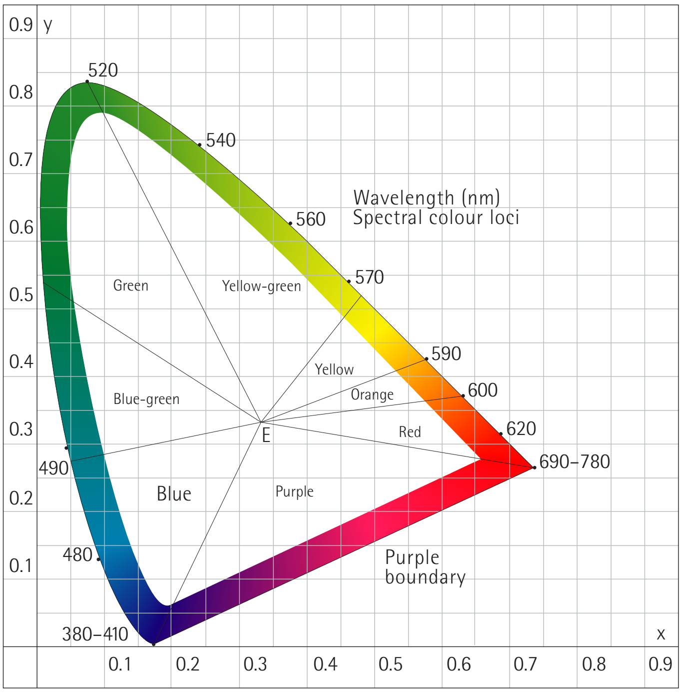
The Munsell system or the DIN colour chart arrange object colours according to brightness, hue and saturation, which produces a comprehensive colour atlas in the form of a three-dimensional matrix. Brightness is referred to in this case as the reflecting coefficient of an object colour; hue is the colour tone, and the term saturation refers to the degree of colour strength from pure colour to the non-coloured grey scale.

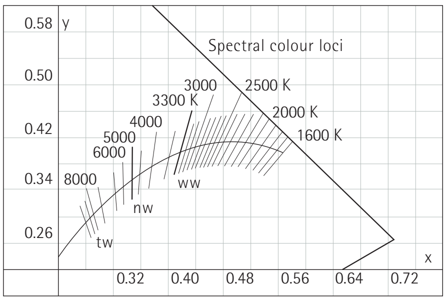
In the CIE's standard chromaticity diagram object colours and luminous colour are, however, not arranged according to a three-dimensional catalogue. They are calculated or measured according to the spectral composition of the illuminant for luminous colours, or the reflectance or transmittance of the object for object colours, and presented in a continuous two-dimensional diagram. This system disregards brightness as a dimension, with the result that only hue and saturation can be determined using this diagram.

The CIE chromaticity diagram represents a plane that comprises all actual colours and satisfies a number of other conditions. The plane is surrounded by a curved borderline, along which the colour loci of the saturated spectral colours lie. The point of lowest saturation is located in the centre of the plane, and is referred to as the white point. All degrees of saturation of a colour on the saturation scale can now be found on the lines that run between the white point and the spectral colour loci. Additive combinations of two colours also lie along the straight lines that link the respective colour loci.

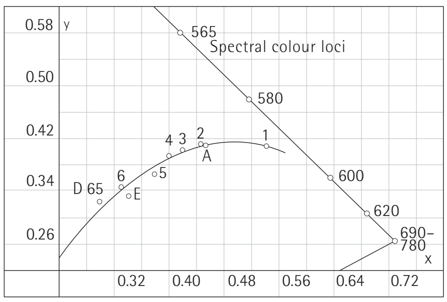
A curve can be drawn inside the coloured area to show the luminous colour of a Planckian radiator (black body) at different colour temperatures; this curve can be used to describe the luminous colour of incandescent lamps. To be able to describe the luminous colour of discharge lamps, a series of straight lines of correlated colour temperatures is entered on the graph, starting from the Planckian radiator curve. With the aid of this array of lines it is also possible to allocate luminous colours that are not present on this curve to the colour temperature of a

The CIE's chromaticity diagram. The spectrum locus links the colour loci of all saturated spectral colours. The purple boundary forms the line between the long-wave and short-wave spectral range. The white point E marks the point of least saturation. The borderlines that separate the different colour regions fan out from the white point. The chromaticity of any real colour can be defined using the x/y coordinates in the chromaticity diagram.



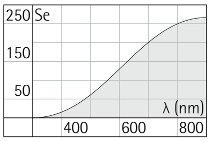


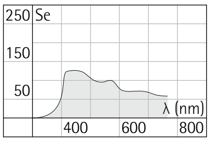
Section of the chromaticity diagram with the curve relating to the Planckian radiator and the series of straight lines marking the colour loci of the same correlated colour temperature between 1600 and 10000 K. The ranges given are the luminous colours of warm white (ww), neutral white (nw) and daylight white (dw).



Section of the chromaticity diagram with the curve relating to the Planckian radiator and the colour loci of standard illuminants A (incandescent light) and D 65 (daylight) plus the colour loci of typical light sources: candlelight (1), incandescent lamp (2), halogen lamp (3), fluorescent lamps in ww (4), nw (5) and dw (6).

Spectral distribution $S_e(\lambda)$ of standard illuminants A (incandescent light, above) and D 65 (daylight, below).





Correlated colour temperature T of typical light sources.

Light source	T (K)
Candle	1900–1950
Carbon filament lamp	2100
Incandescent lamp	2700–2900
Fluorescent lamps	2800–7500
Moonlight	4100
Sunlight	5000–6000
Daylight (sunshine, blue sky)	5800–6500
Overcast sky	6400–6900
Clear blue sky	10000–26000

Colour rendering	
Category	R_a index
1 A	$R_a > 90$
1 B	$80 \leq R_a \leq 90$
2 A	$70 \leq R_a < 80$
2 B	$60 \leq R_a < 70$
3	$40 \leq R_a < 60$
4	$20 \leq R_a < 40$

Colour rendering categories and their inherent R_a indices.

thermal radiator. It is possible to differentiate between three main groups of luminous colours here: the warm white range which resemble most closely colour temperatures below 3300 K, the neutral white range between 3300 and 5000 K and the daylight white range which resemble most closely colour temperatures above 5000 K.

The colour of illuminated objects is the result of the spectral composition of the light falling on a body and the ability of the body to absorb or transmit certain components of this light and only reflect or absorb the remaining frequency ranges.

In addition to the resulting, objective calculable or measurable colour stimulus the colour adaptation of the eye also plays a role in our actual perception of things around us. The eye is able to gradually adapt to the predominant luminous colour – similar to the way it adapts to a luminance level – which means that in the case of a lighting situation that comprises different luminous colours virtually constant perception of the scale of object colours is guaranteed.

The degree of deviation is referred to as the colour rendering of the light source. Colour rendering is defined as the degree of change which occurs in the colour effect of objects through lighting with a specific light source in contrast to the lighting with a comparative reference light source. It is therefore a comparison of the similarity of colour effects under two types of lighting.

Since the eye can adapt to different colour temperatures, colour rendering must be determined in relation to luminous colour. One single light source cannot therefore serve as the source of reference; the standard of comparison is rather a comparable light source with a continuous spectrum, be it a thermal radiator of comparable colour temperature, or daylight.

To determine the colour rendering of a light source the colour effects of a scale of eight object colours are calculated under the types of lighting to be evaluated as well as under comparison standard lighting, and the two then compared. The quality of the colour rendering established is expressed as a colour rendering index, which can be related to both general colour rendering (R_a) as well as the rendering of individual colours. The maximum index of 100 represents optimum colour rendering, and lower values correspondingly less adequate colour rendering.

The quality of colour rendering is divided into four categories, in Germany according to DIN standards. These stipulate the minimum requirements for colour rendering for lighting in workplaces. Colour rendering categories 1 and 2 are further subdivided – into A and B – to allow a differentiated evaluation of light sources.

Colour rendering category 1 is required for tasks which involve the evaluation of colours. For the lighting of interior spaces, offices and industrial workplaces with demanding visual tasks the minimum colour rendering category required is 2, whereby colour rendering category 3 is sufficient for industrial workplaces. Colour rendering category 4 is only permitted when the lowest of requirements are to be met at illuminance levels of up to 200 lux.

The colour rendering quality is an important criteria when choosing a light source. The degree of colour fidelity, therefore, by which illuminated objects are rendered in comparison to reference lighting. In some cases the index for the rendering of a specific colour has to be taken into account, e.g. in the field of medicine or cosmetics, when skin colours have to be differentiated.

Apart from the rendition quality the choice of luminous colour is also of critical importance for the actual effect of colours. Blue and green colours will appear grey and dull under incandescent light despite its excellent colour rendering properties. The same colours will be seen as clear and bright under daylight white fluorescent light – although its colour rendering properties are not so good. The same applies the other way round for the rendition of yellow and red colours.

The lighting designer's decision as to which light source to select therefore depends on the given situation. Some investigations indicate that a warm colour appearance is preferred at low illuminance levels and in the case of directed light, whereas cold colour appearances are accepted for high illuminance levels and diffuse lighting.

In the case of display lighting the colours of the illuminated objects can be made to appear brighter and more vivid through the purposeful application of luminous colour – if necessary, using average colour rendering. This way of purposefully emphasizing colour qualities can also be applied in retail lighting.

The lighting under which a customer decides which articles he wishes to purchase should not deviate significantly from the lighting conditions the customer is accustomed to.