H22: Lamps and Colour

Each type of light source provides a different distribution of power within the spectrum. For example, daylight has more power in the blue/green part of the spectrum than in the orange red whereas an incandescent lamp has the reverse, more power in the orange/red than in the blue/green wavelengths. The type of light source influences the colour that we see when viewing an object surface. In order to see the colour of an object in the same way each time it is viewed, controlled viewing conditions are required.

Luminous efficiency

The luminous efficiency of a lamp is the amount of visually useful light (lumens) that the lamp gives for each unit of electrical energy it consumes (Watt). The eye is most sensitive to light at a wavelength close to the middle of the visible spectrum, as shown in Figure 1.

The maximum, luminous efficiency occurs for green light at a wavelength of 555 nm when 1 Watt of light energy gives 683 lumens of light. The maximum luminous efficiency, when all the radiated energy is light at 555nm, is 683 lumens/Watt.

If 1 Watt of light were emitted with wavelengths spread uniformly across the visible spectrum then it would have of luminous flux of about 200 lumens.

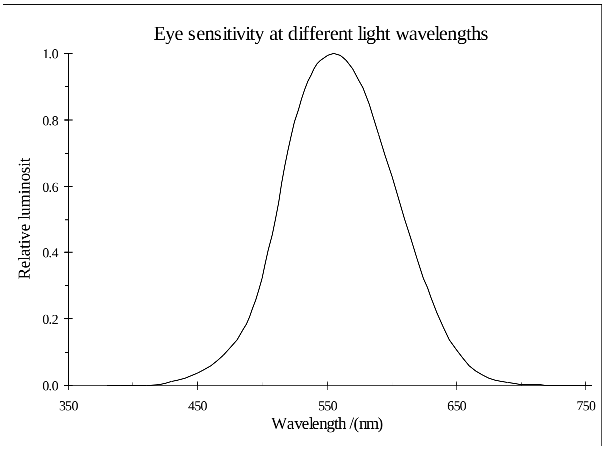

Figure 1: Relative luminous sensitivity at different wavelengths

Colour temperature

A characteristic of the quality of the light from lamps and light sources is the ***colour temperature***. This refers to the temperature of a special light source known as a ***black body radiator*** when it is emitting light that is equivalent in colour to the light from the lamp.

A black body radiator is an object, often a block of metal, containing a hollow cavity with surfaces that are a perfect absorber and radiator of radiation. When the black body is heated to a high temperature it becomes incandescent, and the spectral power distribution emitted from a small aperture in the cavity can be calculated very precisely from knowledge of its temperature alone.

At low temperatures, the black body radiation appears orange/red in hue, this moves through a neutral white to a blue colour as the temperature is increased. The colour temperatures of a range of types of light source are shown in Figure 2. At the given colour temperature the radiation from the aperture has the same chromaticity co-ordinates as the Illuminant.

Source of light	Colour temperature / (K)
Match Flame	1,700
Candle	1,800 - 1,950
40-Watt Bulb	2,650
100-Watt Bulb	2,850
500-Watt Bulb	2,950
Photo floods	3,200-3,400
Quartz Halogen Bulbs	3,250-4,200
Moonlight	4,000
Electronic Flash	5,500
Sunlight at Sunset	2,000
Sunlight 1 Hour Before Sunset	3,500
Late Afternoon Sunlight	4,300
Summer Noon Sunlight	5,400
Overcast Sky	6,000
Average Summer Daylight	6,500
Light Summer Shade	7,100
Full Summer Shade	8,000
Summer Skylight	8,000 - 30,000

Figure 2: Colour temperature of sources of light

Colour rendition index

The colour rendering of a lamp describes how close the colour appearance of a set of materials viewed under light from the lamp is to the colour appearance of the materials viewed under a standard type of lamp. The standard illuminant is either D65 (daylight) or A (tungsten light), depending on the colour temperature of the lamp being tested.

A colour-rendering index of 100 is perfect match of the colour appearance. An index of less than 60 is poor and the nature of the light from the test lamp is distorting the colour.

CIE standard illuminants

A set of standard illuminants has been established by the international commission of lighting (CIE). Each standard illuminant is representative of a common source of light or a common type of lamp. The illuminant is defined by a spectral power distribution S(l), which is given by the CIE as a table of relative power values at evenly spaced wavelengths from 300 nm to 830 nm.

Standard daylight (D65)

The nature of daylight changes with the time of day, the season of the year and the location on the globe. Daylight is blend of light directly from the sun (Sunlight), light from the blue sky (Skylight) and light reflected by the clouds, buildings and other surroundings. D65 represents average daylight, a blend of sunlight and skylight, and is a good representation of the quality of the natural light inside a room with a large, north-facing window. The spectral power distribution is shown in Figure 3.

Standard sunlight (D50)

A representation of sunlight (D50), is shown in Figure 4, notice that there is far less power in the short (blue) wavelength end of the spectrum, this is because less light from the blue sky is included in the D50 definition.

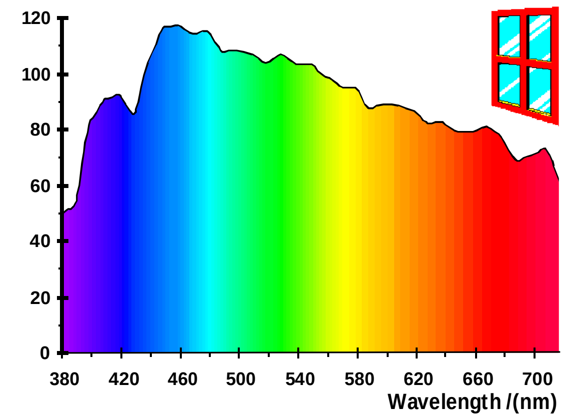

Figure 3: Average daylight spectrum, D65

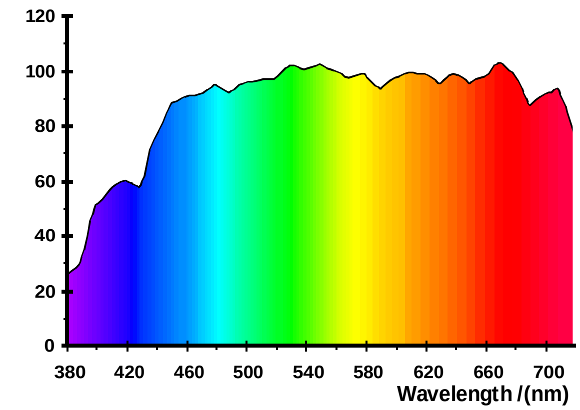

Figure 4: Average sunlight spectrum, D50

Incandescent lamp (A)

An incandescent lamp is represented by Illuminant A. The standard is representative of a gas filled, coiled coil, tungsten filament lamp operating at a colour temperature of 2856K.

Light from an ordinary domestic bulb of between 40 to 100 Watts in power would be similar to this type of illumination. Figure 5 shows that, for this type of lamp, there is great deal of power emitted in the red part of the spectrum compared to the blue. This is the opposite top the distribution of power in average daylight D65.

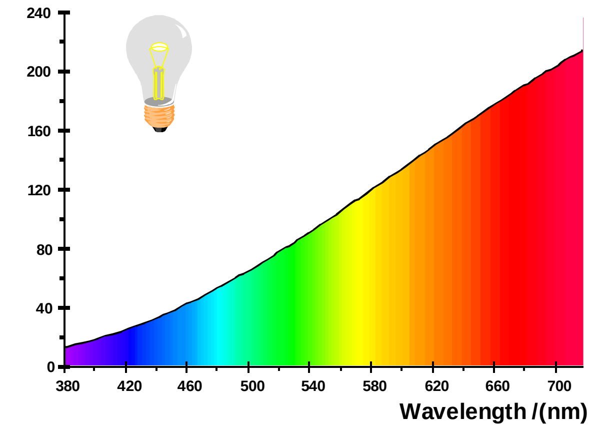

Figure 5: Incandescent lamp spectrum, A

Fluorescent lamps (F2, F7, F11)

Fluorescent lamps were introduced in the late 1930's and they have become very common, especially in factories, shops and offices. The lamp tube contains a low-pressure mercury arc that emits light in narrow bands of wavelengths in the visible and UV parts of the spectrum. The inner surface of the tube is coated with fluorescent compounds that convert the UV light emitted by the arc to useful visible light. The spectrum of such a lamp contains several prominent lines emitted by the mercury gas and a broad background spectrum from the fluorescent compounds, as shown in Figure 6.

Cool white fluorescent: F2

The CIE have defined 12 fluorescent illuminants F1 to F12. Figure 6 illustrates the power distribution from F2, which represents a cool white fluorescent type of tube that is common in shops and offices.

Three band lamp: F11

Also of interest is F11which represents a high efficiency three-band lamp. This type of lamp is often known in the UK by the name TL84, a Phillips Colour 84 lamp that is used in a large number of High Street clothing stores. Figure 7 shows that in these lamps, a high proportion of the light is emitted in three narrow bands in the red, the green and the blue spectral regions. This leads to high electrical efficiency as well as reasonable colour rendering.

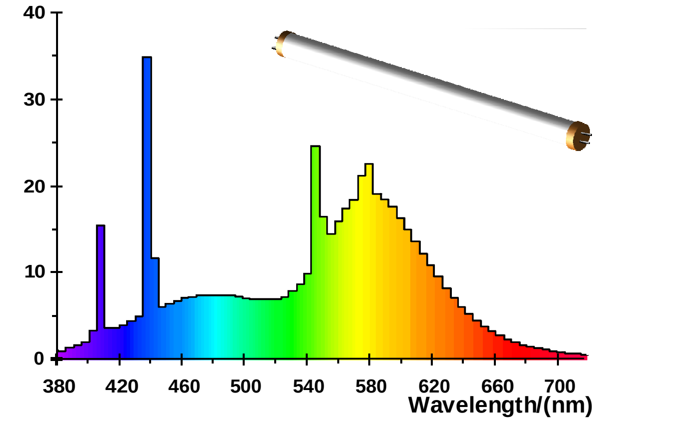

Figure 6: CWF fluorescent lamp, F2 (4230K)

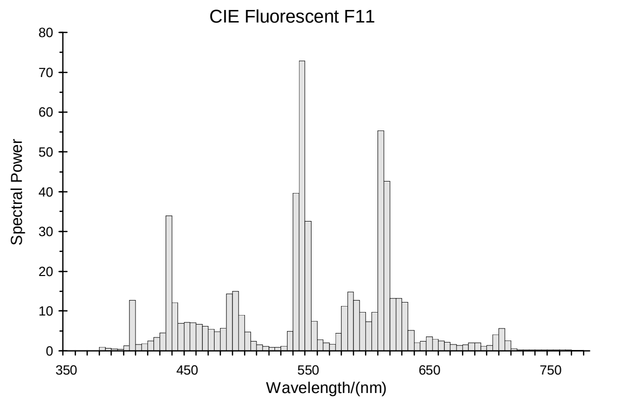

Figure 7: Three band lamp, (4000K)

Simulated daylight: F7

One of the most important standards is F7, a broadband fluorescent lamp with a colour temperature of 6500, the same as D65. This type of lamp is commonly found in lighting cabinets and viewing booths to simulate D65 illumination.

The spectral power distribution, shown in Figure 8, has a broad background band of wavelengths and, although the lamp has a excellent colour rendering, the lamp has lower a luminous efficiency than the other fluorescent lamps (Table 1).

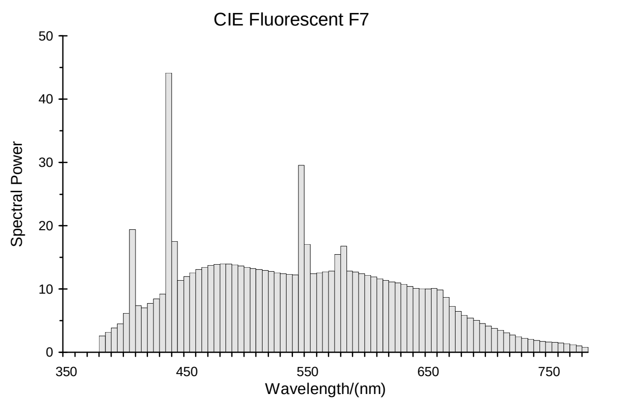

Figure 8: Broad band fluorescent (6500 K

Illumination levels

Typical illumination levels for the visual examination of a coloured surface are of order 1000 to 2000 lumens/m^2, which is the same as amounts of light falling on a surface in a brightly-lit room. For comparison, outdoor illumination levels in the UK are typically:

bright summer sunlight	44,000 lm/m^2;
overcast daylight	5,000 lm/m^2;
north facing skylight in open shade	4,400 lm/m^2.

The amount of light reflected from a surface is given in units of candela (cd) per square metre. The typical values for light reflected from white paper under different conditions are shown in Figure 9.

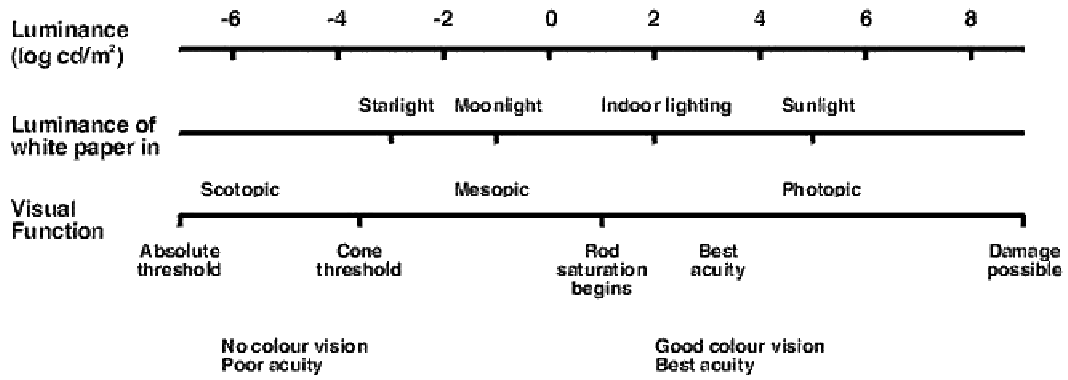

Figure 9: Intensity of light reflected by white paper in a variety of illumination conditions

Luminous efficiencies

Some types of lamp are more efficient than other types, as illustrated by the values shown in the Table 1.

The incandescent lamp, with the majority of its power emitted in the orange, red and infrared parts of the spectrum, has a very low efficiency. Whereas the fluorescent lamp is five or six times more effective than the incandescent lamp at converting electrical energy into useful light.

Table 1: Luminous efficiencies of 40 Watt lamps.

Lamp type	Colour Rendering	lumens / Watt
Tungsten filament, (A)	100	10
Day-light fluorescent (F7)	93	50
Cool white fluorescent (F2)	58	81
Three band fluorescent (F11)	85	93

Effect of light source on colour

Figure 3 to Figure 8 show the power distributions for different types of illumination. They show large differences in the amounts of light in the red, the green and the blue parts of the spectrum. These differences could be expected to change the colour appearance of the objects as the illumination changes.

Colour constancy

Our experience is that the colour change is not as large as would be expected. The effect is known as colour constancy and arises from the ability of the visual system to automatically take into account the colour of the illumination.

Figure 10 shows two different types of illumination falling on a plain paper sheet. We know that the visual impression of “White” is correct for both situations despite the large change in the nature of the light entering the eye. The effect is easily demonstrated in a viewing cabinet.

The explanation is that the visual system is able partly to adapt to the nature of the average illumination of the field of view. The visual system is able to discount the effect of the change in illumination, so that the “underlying” colour of the object is recognised.

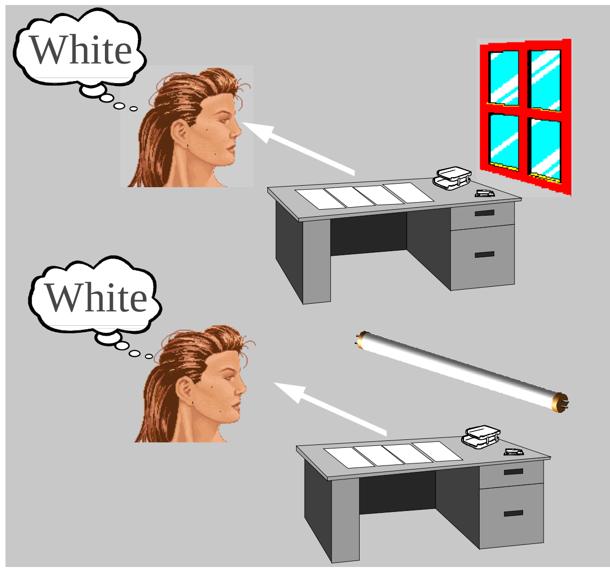

Figure 10: The impression of white is maintained, despite the change in the illumination

This process is not always complete, and some objects can change colour noticeably as the illuminant changes. Green, brown and lilac colours can show dramatic changes as the light source is changed from daylight to incandescent light or to fluorescent light. Objects that change their colour appearance when the nature of the illumination is changed are known as ***colour inconstant.***

Illuminant metamerism

Metamerism describes the effect that is sometimes seen when viewing two coloured objects, for example, a standard colour panel and trial colour panel. The two panels are judged similar in colour when viewed under light from the first source and quite different in colour when viewed under light from the second source, as illustrated in Figure 11.

Unfortunately, the three band types of fluorescent lamp emphasise the effect of metameric matched pairs of samples, where two samples match in colour when viewed under one illuminant but do not match when viewed under the other one.

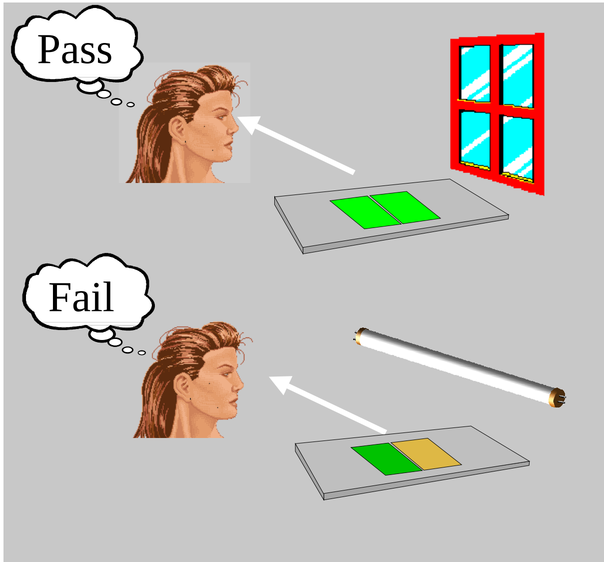

Figure 11: Illumination metamerism