Philips Lighting Academy

Basics of light and lighting

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Sharing knowledge, to build your business

This booklet is published by the Philips Lighting Academy: an organization dedicated to sharing the knowledge, skills and tools that help people sell innovative, high value lighting solutions.

We do this by providing a range of training courses. Each of which explores how innovative lighting solutions can help improve employee productivity while at the same time reduce the Total Cost of Ownership (TCO) of the lighting installation.

The title of this booklet is "Basics of light and lighting'. This is also the title, and subject matter, of our initial foundation course. Other courses explore new lighting regulations, environmental issues and new energy-saving products. All of the courses are designed to help you explain to your customers why innovative lighting will benefit them and how much money it will save them in the long term.

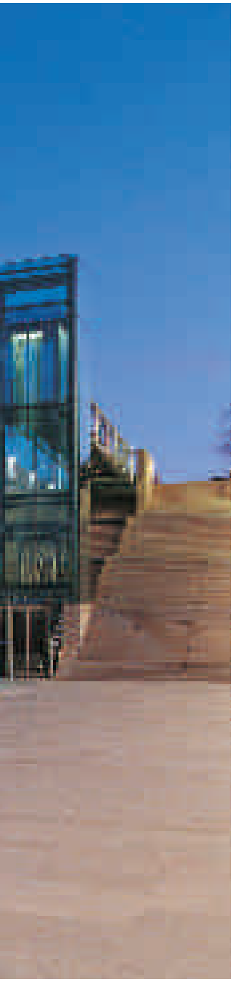
To build your business

We provide these courses to help you build your business. With the knowledge and skills needed to sell premium lighting solutions you will get higher profitability and more turnover. The initial costs to your customers may be slightly higher but within months they will start saving money thanks to the increased energy efficiency and extended service life of the lighting installation.

Everyone wins: you get more turnover and profit, and your customers get optimised lighting and lower long-term costs.

We wish you success.

Content



What is good Lighting?

Lighting plays a vital role in the quality of our daily lives. At work in offices, production- or logistical facilities, good lighting brings employee satisfaction, performance, comfort and safety. In shops, galleries and public places, it creates ambience and helps to accentuate the architectural environment. While in the home, it not only lights our tasks but builds a comfortable, welcoming atmosphere that makes our homes a pleasure to live in.

The question of what makes good lighting is one that continually occupies designers of lighting plans and installations. Basic requirements like lighting level, contrast, light distribution and colour rendering have to be taken into consideration for each situation in general and the activities that are taking place there in particular.

But good lighting goes beyond mere efficiency and functionality. It must also make the interior spaces where we live, work or stay agreeable: cool or warm, businesslike or convivial, happy or solemn, or any combination in between. Lately, more and more value is being attached to the emotional influence of lighting as an important atmosphere-providing factor, affecting mood, well-being and health.

And, not to be forgotten is the cost aspect. Regrettably, the lighting installation is sometimes among the last items to be considered when budgeting a building project, with the result that often cheaper alternatives are chosen just to keep total expenses within financial limits. The outcome may then be less than adequate: sub-optimal lighting conditions and decreasing employee productivity and motivation, leading to more errors and failures, or – even worse – accidents. Proper initial investment in a well-designed lighting installation usually repays itself not just in higher return-of-investment but also in lower total cost of ownership during its lifetime.

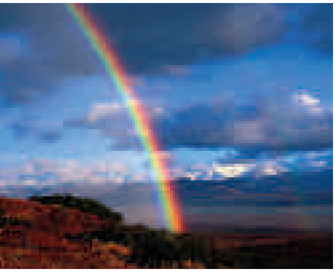
Clearly, good lighting does not come by itself. It requires weighing various factors and circumstances that are different for every project. But whether as part of a completely new project or of a renovation scheme, for best results it needs to be planned and designed from the very outset in close cooperation with experienced lighting application experts.

Good lighting is both a science and an art, combining knowledge of physics, engineering, design, physiology and psychology. With this booklet we provide you with an overview of some of the basics, but it is only a brief overview. Also, please realise that this booklet can only tell you what good lighting is, it cannot show you. And that's important, because we believe that the value of good lighting can only be grasped by personal observation and real experience. For this reason, the purpose of this booklet is to act simply as a reminder to your courses at the Philips Lighting Academy. I hope it regularly stimulates your interest in this fascinating subject.

Part One: Light

1. What is light?

Light is a form of energy manifesting itself as electromagnetic radiation and is closely related to other forms of electromagnetic radiation such as radio waves, radar, microwaves, infrared and ultraviolet radiation and X-rays.



Rainbows reveal the constituent colours of daylight

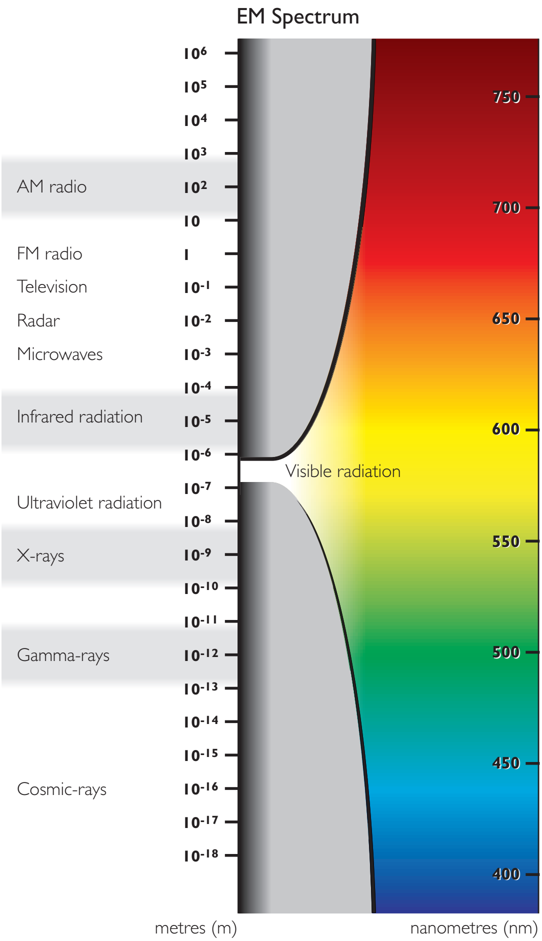
Radio telescopes pick up electromagnetic waves with a wavelength between 3 cm and 6 m

Wavelength and colour

The only difference between the several forms of radiation is in their wavelength. Radiation with a wavelength between 380 and 780 nanometres* forms the visible part of the electromagnetic spectrum, and is therefore referred to as light. The eye interprets the different wavelengths within this range as colours – moving from red, through orange, green, blue to violet as wavelength decreases. Beyond red is infrared radiation, which is invisible to the eye but detected as heat.

At wavelengths beyond the violet end of the visible spectrum there's ultraviolet radiation that is also invisible to the eye, although exposure to it can damage the eye and the skin (as in sunburn). White light is a mixture of visible wavelengths, as is demonstrated for example by a prism which breaks up white light into its constituent colours.

* A nanometre is a millionth of a millimetre



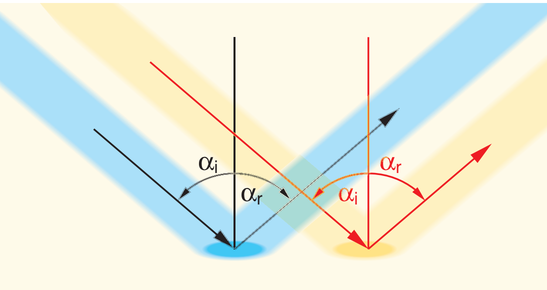
The dual nature of light

Describing light as an electro magnetic wave is just one way of looking at radiation and explains some of its properties, such as refraction and reflection. Other properties, however, can only be explained by resorting to quantum theory. This describes light in terms of indivisible packets of energy, known as quanta or photons that behave like particles. Quantum theory explains properties such as the photoelectric effect.

2. Behaviour

Reflection

Whenever light strikes a surface, three possibilities are open: it is reflected, absorbed or transmitted. Often a combination of two or even all three effects occurs. The amount of reflected light depends on the type of surface, angle of incidence and spectral composition of the light. Reflection ranges from less than a few percent for very dark surfaces like black velvet, to over 90% for bright surfaces such as white paint. The way the light is reflected also depends on the smoothness of the surface. Rough surfaces diffuse the light by reflecting it in every direction. In contrast, smooth surfaces like the surface of still water or polished glass reflect the light back undiffused, making the surface act as a mirror. A ray of light striking a mirrored surface at an angle to the perpendicular will be reflected back at the same angle on the other side of the perpendicular (in the same way as a non-spinning billiard ball rebounds from the cushion). This is the well-known law of reflection that is given as: angle of incidence = angle of reflection



angle of incidence = angle of reflection

Mirrored surfaces are very good for directing light beams to where we want them. Curved mirror reflectors are widely used for focusing light, dispersing it or creating parallel or divergent beams, and are all governed by the law of reflection.

Absorption

If the material's surface is not entirely reflecting or the material is not a perfect transmitter, part of the light will be absorbed. It 'disappears' and is basically converted into heat. The percentage of light absorbed by a surface (i.e. absorbance) depends on both the angle of incidence, and on the wavelength. The absorption of light makes an object dark to the wavelength of the incoming radiation. Wood is opaque to visible light. Some materials are opaque to some frequencies of light, but transparent to others. Glass is opaque to ultraviolet radiation below a certain wavelength, but transparent to visible light.

Transmission

Transparent materials transmit some of the light striking its surface, and the percentage of light that is transmitted is known as its transmittance. High transmittance materials such as clear water and glass transmit nearly all the light that's not reflected. Low transmittance materials, such as paper, transmit only a small percentage of this light.

The irising colours of the Peacock's tail feathers are caused by interference of light and not by pigments.

Refraction

If a light ray passes from one medium into another of different optical density (and at an angle other than perpendicular to the surface between the two media), the ray will be 'broken'. This behaviour is called refraction, and is caused by the change of speed of the light as it passes between transparent media of different optical densities.

Interference

The wave nature of light also leads to the interesting property of interference. A familiar example of this is when there is a thin film of oil floating on the surface of a pool. Sometimes the oil will display a brilliant pattern of colours or rainbows, even when illuminated by white light.

What is happening is that different parts of the oil film cause the different wavelengths in the white light to interfere and produce different wavelengths (=colours). Various colours are generated, depending on the thickness of the film where the interference occurs. Similar examples of interference are found when looking at soap bubbles, or at the surface of a CD.

3. Colour

Colour is the way we distinguish different wavelengths of light. The subject of colour is a rather complicated one, as it involves both the spectral characteristics of the light itself, the spectral reflectance of the illuminated surface as well as the perception of the observer.

The colour of a light source depends on the spectral composition of the light emitted by it. The apparent colour of a light reflecting surface, on the other hand, is determined by two characteristics: the spectral composition of the light by which it is illuminated, and the spectral reflectance characteristics of the surface. A coloured surface is coloured because it reflects wavelengths selectively. The spectral reflectance of red paint, for example, shows that it reflects a high percentage of the red wavelengths and little or none of the blue end of the spectrum. But an object painted red can only appear red if the light falling on it contains sufficient red radiation, so that this can be reflected. Moreover, it will appear dark when illuminated with a light source having no red radiation.

Mixing light of different colours

When coloured light beams are mixed, the result will always be brighter than the individual colours, and if the right colours are mixed in the right intensities, the result will be white light. This is known as additive colour mixing. The three basic light colours are red, green and violet-blue. These are called the primary colours and additive mixing of these colours will produce all other light colours, including white.

So:
red + green = yellow
red + violet-blue = magenta (purplish red)
green + violet-blue = cyan (sky blue)
red + green + violet-blue = white

The colours yellow, magenta and cyan are called secondary or complementary colours as they are made up of combinations of primary colours.

A colour television is an example of *additive* colour mixing in which the light emitted from the red, green and violet-blue phosphors on the television screen combines to produce all visible colours and white.

Subtractive colour mixing

Subtractive colour mixing occurs for example when coloured paints are mixed on a palette.
This always gives a result darker than the original colours and if the right colours are mixed in the right proportions, the result will be black. Subtractive colour mixing of any of the primary light colours will always produce black but subtractive colour mixing of the secondary light colours can produce all other visible colours.
So:

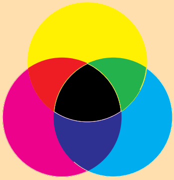
yellow + magenta = red

yellow + cyan = green

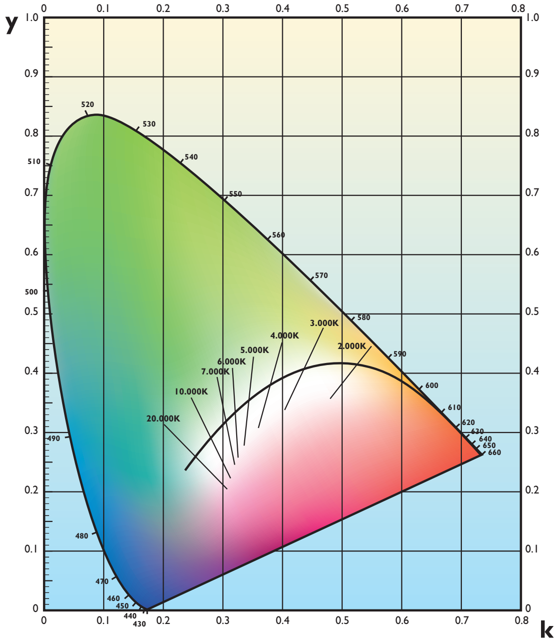
magenta + cyan = violet-blue

but

yellow + magenta + cyan = black



An example of subtractive colour mixing, for instance, is printed coloured matter that uses the secondary colours yellow, magenta and cyan (plus black) to produce the full range of printed colours. Printers, therefore, call magenta, yellow and cyan the primary colours.



* CIE = Commission Internationale de l'Eclairage

CIE chromaticity diagram

A graphic representation of the range of light colours visible to the human eye is given by the CIE* chromaticity diagram. The saturated colours red, green and violet are located at the corners of the triangle with intermediate spectral colours along the sloping sides, and magenta at the bottom. Going inwards, they become lighter and diluted at the same time. The centre of the triangle -where all colours meet- is white. The colour values are numerically plotted along the right-angled x- and y-axis. Thus, each light colour can be defined by its x- and y-values, which are called chromaticity coordinates, or colour point.

Also contained in the triangle is the so-called Black-Body-Locus represented by a curved line (see section on colour temperature onwards). It indicates the colour points of the radiation emitted by blackbody radiators at different temperatures (K). For instance, the colour point at 1000 K equals with that of red light of 610 nm.

Colour rendering

Although light sources may have the same colour appearance, this doesn't necessarily mean that coloured surfaces will look the same under them. Two lights that appear the same white, may be the result of different blends of wavelengths. And since the surface may not reflect the constituent wavelengths by the same extent, its colour appearance will change when it is exposed to one or other light. A piece of red cloth will appear 'true' red when seen illuminated by white light produced by a continuous spectrum, but in an equally white looking mixture of yellow and blue light it will look greyish brown. Because of the absence of red wavelengths, there is no red for the cloth to reflect into the eye to notice.

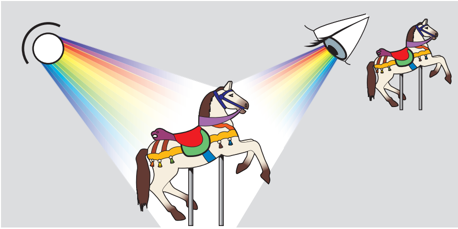
Colour rendering is an important aspect of artificial lighting. In some situations colours should be represented as naturally as possible as under daylight conditions, yet in other cases lighting should highlight individual colours or create a specific ambience. However, there are also various lighting situations where it is not so much a precise natural colour rendering that matters most, but where illumination level and efficacy are of greater importance. So, colour rendering is an important criterion when selecting light sources for lighting application solutions.

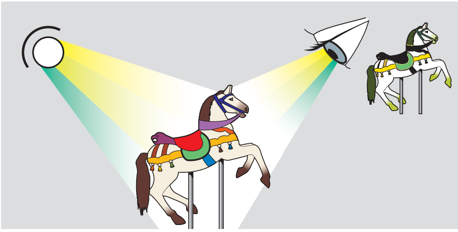
To classify light sources on their colour rendering properties the so called colour rendering index (CRI or also denoted as Ra) has been introduced. The scale of the Ra ranges from 50-100. The following table shows the meaning of the Ra values:

Ra = 90 - 100	Excellent colour rendering properties
Ra = 80 - 90	Good colour rendering properties
Ra = 60 - 80	Moderate colour rendering properties
Ra < 60	Poor colour rendering properties

Metamerism

Metamerism is the property exhibited by some coloured surfaces of showing different colour appearances under different light sources. It results from the differences in interaction between the reflective properties of the dyes, and the spectral composition of the light. One paint manufacturer, for example, might mix a particular shade of brown in a certain way. Another manufacturer trying to match it arrives at what appears to be the same colour using a different formula. These two paint colours, although apparently the same under one light source will look differently under another source owing to the difference in spectral composition of the other light used. Metamerism can be minimized by using products from the same paint or dye manufacturer. Many manufacturers also limit the number of colorants used in formulating colours to reduce the chance for metamerism.





These 2 figures illustrate the principles of the colour rendering. In the top picture a lamp, emitting light with all colours, illuminates a rocking horse. The light reflected from the rocking horse enters the eye of the observer forming in his brain an image as depicted in the top right corner. In the bottom picture the light falling on the horse has no red radiation. This means that no light will be reflected from the red parts of the rocking horse and these parts will appear dark to an observer as can be seen. Both pictures indicate that the spectrum of the light source plays an important role in the way we perceive the colour of objects.

Incandescent/halogen

Low-pressure Sodium

Metal halide

Colour temperature

Although white light is a mixture of colours, not all whites are the same since they depend on their constituent colours. So a white with a higher proportion of red will appear warmer and a white with a higher proportion of blue will appear cooler. In order to classify the different types of white light, the concept of colour temperature is applied which is described as the colour impression of a perfect black-body radiator at certain temperatures. This concept can be best explained with the help of familiar thermal radiators like the filament of an incandescent lamp or an iron bar. When these materials are heated to a temperature of 1000 K their colour appearance will be red, at 2000-3000 K they will look yellow white, at 4000 K neutral white, and at 5000-7000 K cool white. In other words: the higher the colour temperature, the cooler the impression of the white light becomes.

Colour temperature is an important aspect in lighting applications – the choice of colour temperature being determined by the following factors:

- *Ambience*: warm-white creates a cosy, inviting ambience; neutral/ cool-white creates a business-like ambience.
- *Climate*: inhabitants of cooler geographical regions generally prefer a warmer light, whilst inhabitants of (sub)-tropical areas prefer, in general, a cooler light.
- *Level of illumination* needed. Intuitively, we take daylight as a natural reference. A warm-white light is daylight at the end of the day, at a lower lighting level. Cool-white light is daylight during the middle part of day. This means that in interior lighting, low illumination levels should be achieved with warm-white light. When a very high lighting level is needed, this should be realised with a neutral or cool white light.
- *Colour scheme in an interior*. Colours like red and orange are shown to advantage with a warm-white light, cool colours like blue and green look somewhat more saturated under a cool-white light.

Examples of different colour temperatures	
Type of light	**Colour temperature (K)**
Candles	1900 – 2500
Tungsten filament lamps	2700 – 3200
Fluorescent lamps	2700 – 6500
High-pressure sodium (SON)	2000 – 2500
Metal halide	3000 – 5600
High-pressure mercury	3400 – 4000
Moonlight	4100
Sunlight	5000 - 5800
Daylight (sun + clear sky)	5800 - 6500
Overcast sky	6000 - 6900

Continuous and discontinuous spectrum

A light spectrum in which all wavelengths are present is called a continuous spectrum, ranging from red through orange, yellow, green, blue to violet. White light like daylight has such a spectrum, as well as white light from so-called thermal radiators like the flame of a candle and the filament of an incandescent light bulb. White light, however, can also be achieved by two or more selected wavelengths, and the other wavelengths being totally absent. For example by mixing red, green and blue, or merely blue and yellow. Light sources with selected wavelengths have so-called discontinuous spectra, like for example gas discharge lamps.

Daylight at noon: approx. 6000K

Daylight at sunset: approx. 2000K

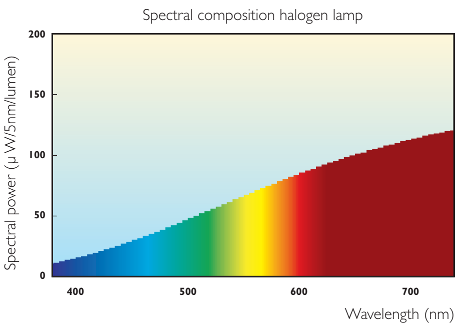
4. Sources

The development of electrical power well over a century ago revolutionised artificial lighting. It was then that the flame was replaced as the main source of artificial light in favour of electrically powered lighting. Since that time, the history of electric lighting has been one of continuous development punctuated by a series of major innovations.
When incandescent lamps first appeared by the end of the 19th century, their efficacy* was just 3 lm/W, which has improved to around 14 lm/W today. In the 1930s and 40s, the appearance of gas discharge lighting and fluorescent lighting offered efficacies of around 30 to 35 lm/W.
This was a major increase over the incandescent lamp and even today, the fluorescent lamp is still one of the most efficient white-light source available with efficacies up to 100 lm/W. A more recent innovation is lighting using light-emitting diodes (LEDs).

Incandescent lamps

In the second oldest form of electric lighting – the incandescent lamp – an electric current passes through a thin high-resistance wire, nowadays always of tungsten, to heat it to incandescence. To prevent oxidation of the wire or filament as it is known, it is contained either in an evacuated glass bulb or one containing an inert gas (usually a mixture of nitrogen and argon). Over time, evaporation of tungsten atoms from the filament blackens the inside of the bulb and makes the filament thinner until it eventually breaks at its thinnest point, ending the life of the lamp.


Examples of incandescent and halogen lamps



* Light source efficacy= total luminous flux of a light source for each watt of electrical power supplied to the source (Lumen per watt, lm/W)

The halogen incandescent lamp

Several techniques have been developed in an attempt to eliminate evaporation of the filament and so extend the life of the incandescent lamp, one of the most successful being the tungsten-halogen lamp. The filling of this incandescent lamp contains a halogen (bromine) that compound with the tungsten atoms that are 'boiled off ' the heated filament. Because the glass envelope of this lamp is much closer to the filament, the temperature of the filling does not fall below 250° Celsius which prevents the condensation of the compound. Instead of depositing on the inside of the glass, the tungsten-halogen compound circulates by convection until it hits the filament. On the filament the compound is dissociated due to the filament's temperature of 2800-3000° Celsius, leaving the tungsten atoms behind on the filament, and releasing the halogen atoms to the gas filling to start a new 'halogen cycle'. Because of the relative small volume and the sturdy quartz wall, halogen lamps can be safely operated at high pressures, thus reducing evaporation of the filament even more. It also allows higher temperatures increasing the luminous efficacy of the lamp up to 45% higher compared to incandescent.

Gas discharge lighting

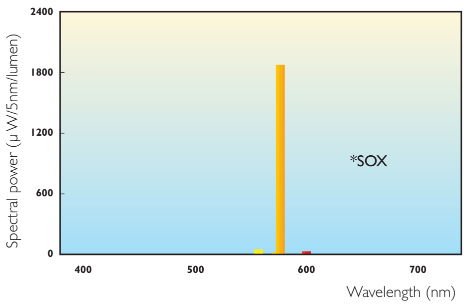
In a gas discharge lamp, an electric current passes through a gas between two electrodes at the opposite ends of a closed glass tube. Collisions between free electrons and the gas atoms excite the gas atoms into higher energy levels. These excited atoms subsequently fall back to their natural energy states, and release the corresponding energy surplus in the form of radiation.

Examples of low-pressure sodium lamps

Low-pressure sodium lamps

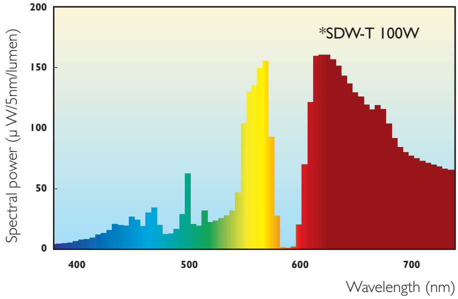
In a low-pressure sodium lamp, visible radiation is directly produced by the discharge of sodium. It emits most of its energy in the visible part of the spectrum at wavelengths of 589 and 589.6 nm (the characteristic yellow sodium light). When started, sodium lamps initially generate a red colour. This is caused by neon that is also present in the gas filling which serves to initiate the discharge process. These lamps must have a very efficient heat isolation, as they produce only very little heat by themselves. Lamp efficacy is very high.

Spectral composition low pressure sodium lamp*



Examples of high-pressure sodium lamps

Spectral composition high pressure sodium lamp*

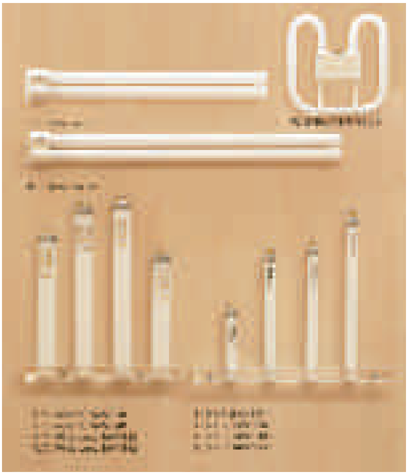


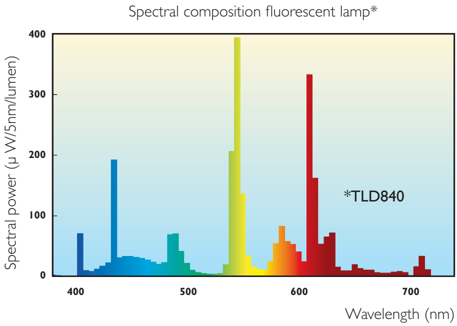
High-pressure sodium lamps

High-pressure sodium lamps operate at much higher gas pressures, resulting in more inter-atom interactions than with low-pressure lamps, leading to a broadening of the emitted radiation pattern. The White SON (SDW-T) lamp is a very high-pressure sodium lamp. The characteristic yellow radiation is completely absorbed, leaving a very warm-white light, with strong rendering of red colours.

Fluorescent lamps

The (compact) fluorescent lamp is basically a low-pressure mercury gas discharge lamp with the inner surface of the discharge tube coated with a mixture of fluorescent compounds — called phosphors — that convert the invisible ultraviolet radiation emitted by the mercury discharge into visible radiation. With a broad range of phosphors available, the lamps are available in a wide range of colours and colour renderings, and are mostly used for general lighting.





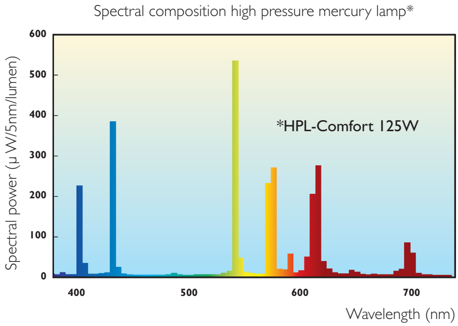
Examples of fluorescent lamps

Examples of compact fluorescent lamps

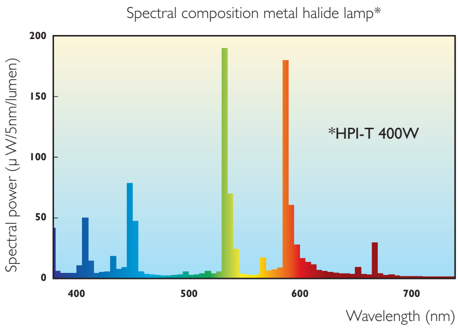
Phosphor coatings

Fluorescent lamps are low-pressure mercury gas discharge lamps with the inner surface of the discharge tube coated with phosphors.When ultraviolet radiation generated by the mercury discharge within the lamp strikes the phosphor, the electrons in the phosphor atoms jump to a higher energy level.The electrons subsequently fall back to their normal level, emitting radiation with longer wavelengths, within the visible range, than that of the original ultra violet radiation. The most important factor determining the light characteristics of a fluorescent lamp is the type and mixture of the phosphors used.This determines the colour temperature, colour rendering and luminous efficacy of the lamp. Some phosphors show an emission band covering almost the whole visible spectrum and therefore produce white light when used alone. Mostly, however, a combination of phosphors with different, complementary colour characteristics is used. In this way either a combination of good colour characteristics with a very high luminous efficacy can be obtained, or even excellent colour character istics, be it at the at the cost of luminous efficacy.

Examples of high-pressure Mercury lamps



Examples of metal halide lamps

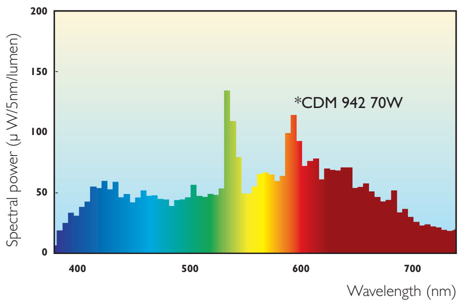


High-pressure mercury lamps

High-pressure mercury lamps contain mercury vapour confined in a quartz discharge tube (called: burner) that operate at a pressure between 200 and 1500 kPa, at which pressure the discharge process is found to emit a large proportion of its energy in the visible part of the spectrum (in contrast to the low-pressure mercury lamp which emits predominantly invisible ultraviolet). The discharge tube, which emits a bluish-white light, is housed within an outer glass bulb. The inner surface of this outer bulb can be coated with fluorescent powder that emits mainly red to improve the colour rendering, with about 10% increase of the luminous flux.

Examples of ceramic metal halide lamps

Spectral composition ceramic metal halide lamp*

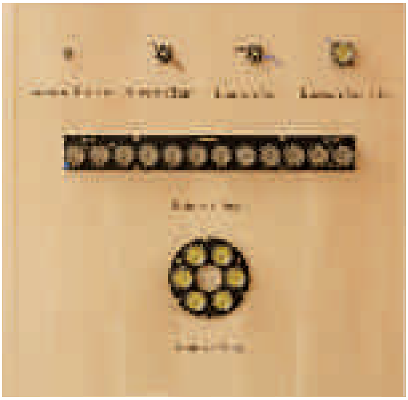


Metal halide lamps

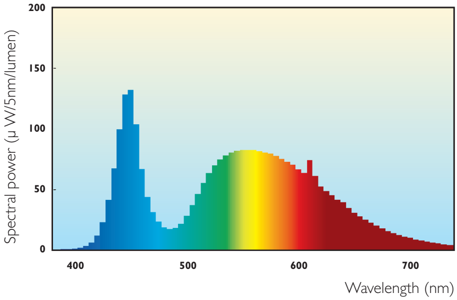
Metal halide lamps have been developed from high-pressure mercury lamps by adding other metals in the form of halide salt to the discharge. With each metal having its own characteristic radiation pattern, the result is a substantial improvement of efficacy and colour quality.

Ceramic metal halide lamps

A more recent development is the ceramic metal halide lamp that features a discharge tube made of ceramic material instead of quartz glass. By applying ceramic, the lamp can be operated at a higher discharge temperature, and it also enables an optimal geometry of the burner. Both innovations have resulted in substantially improved colour characteristics.



Examples of solid state light sources



Solid-state lighting

The most recent evolution in lighting is solid-state lighting based on light emitting diode (LED) technology. The light generation principle is similar to what happens in gas discharge lamps, but now the discharge happens in a solid state material: orbit changing electrons cause atoms to get 'excited' that subsequently fall back to their natural state thereby releasing its surplus energy in the form of radiation.

LED technology has been around since many years but due to its modest luminous flux and monochromatic light quality few applications existed for many years and LEDs were primarily used for signal lighting in control panels and in traffic lights. Recent technological breakthroughs, however, have lead to significant advances in performance including the generation of white light which has opened a whole new future for accent and general lighting applications. It's key features are: long life, robust, small size and low maintenance.

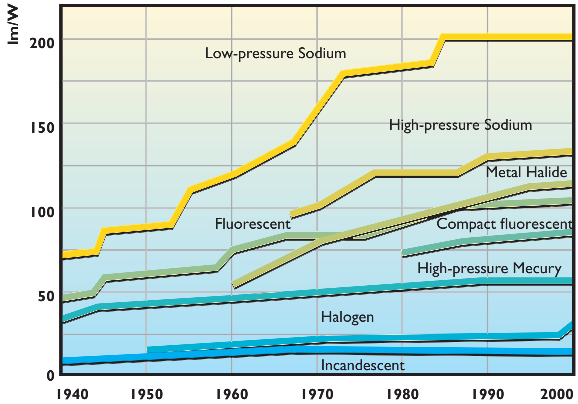
White light generation with LEDs

By its very nature, LEDs can only generate monochromatic colours. So in order to create white light, two or more colours need to be combined. One solution for white LED light is by mixing red, green and blue semiconductor chips into one single LED, or, by placing separate red, green and blue LEDs very close together, and optically mixing the emitted radiation.

A more common approach, is to use LEDs that emit blue light and cover them with a phosphor coating that converts a part of the blue light to yellow light, together creating white light. These white LEDs have colour temperatures ranging from 4500 to 8000K. By applying multiple phosphor coatings, the blue light is converted into more colours, which improves the colour rendering index to a level of >80 which is good to excellent.

Overview of some typical lighting sources

Lamp type	Luminous flux (lm)	Luminous (lm) efficacy (lm/W)	Colour temperature (K)	Colour rendering index (R_a)	Power (W)
Incandescent/halogen	60 – 48400	5 – 27	2700 – 3200	100	5 – 2000
Low-pressure sodium	1800 – 32500	100 – 203	1700		18 – 180
High-pressure sodium	1300 – 90000	50 – 130	2000, 2200, 2500	10 – 80	35 – 1000
High-pressure mercury	1700 – 59000	35 – 60	3400, 4000, 4200	40 – 60	50 – 1000
Fluorescent	200 – 8000	60 – 105	2700, 3000, 4000, 6500	60 – 95	5 - 80
Compact fluorescent	200 – 12000	50 – 85	2700, 3000, 4000, 6500	80	5 – 165
Metal halide	5300 – 220000	75 – 140	3000, 4000, 5600	65 – 95	70 – 2000
Ceramic metal halide	1500 – 23000	68 – 95	3000 – 4200	80 – 95	20, 35, 70, 150, 250
LED	10 – 170	Up to 50	3000 – 8000	up to 90	0,1 – (x)3W

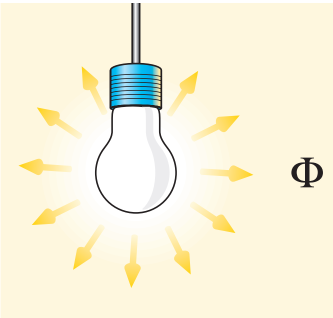


Development of luminous efficacy from 1970 onwards

$$\text{Efficacy (lm/W)} = \frac{\text{Luminous flux (lm)}}{\text{Power input (W)}}$$

5. Photometrics

There are four basic photometric units that lighting practitioners use for the quantitative measurement of light:

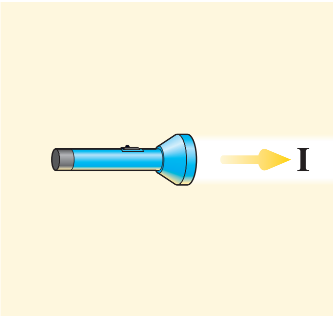


Luminous flux Φ

This expresses the total quantity of light radiated per 1 second by a light source. The unit of luminous flux is the *lumen (lm)*

Examples:

• 75W incandescent lamp:	900 lm
• 39W fluorescent lamp:	3.500 lm
• 250W high pressure sodium lamp:	30.000 lm
• 2000W metal halide lamp:	200.000 lm



Luminous intensity I

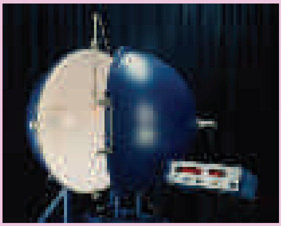
This is defined as the flux of light emitted in a certain direction. The unit of luminous intensity is the *candela (cd)*

Examples (centre of beam):

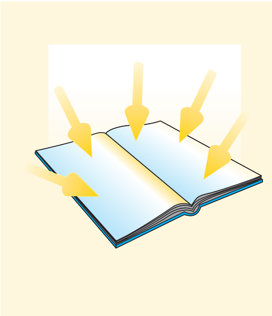
• 5W bicycle lamp without reflector:	2,5 cd
• 5W bicycle lamp with reflector:	250 cd
• 120W incandescent reflector lamp:	10.000 cd
• Lighthouse:	2.000.000 cd

Luminous flux measuring technique

In laboratories, this is usually measured using an instrument known as an 'Ulbricht sphere' – a hollow sphere painted matt white on the inside to make it perfectly diffusing with the light source located at its centre. The illuminance on any part of the sphere's inside is proportional to the luminous flux and a small window in the sphere allows this illuminance to be measured.



Courtesy: YFU

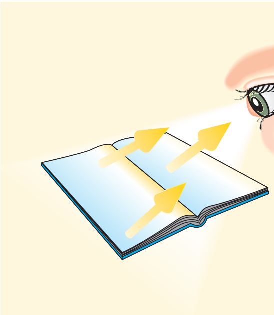


Illuminance **E**

This is the quantity of light falling on a unit area of a surface. The unit of illuminance is lumen/m^2, or *lux (lx)*

Examples:

• Summer, at noon, under a clear sky (equator):	100.000 lux
• In the open under a heavily-overcast sky:	5.000 lux
• Artificial light, in a well-lit office:	800 lux
• Full moon, on a clear night:	0,25 lux



Luminance **L**

This describes the light emitted from a unit area in a specific direction. The unit of luminance is expressed in *cd/m*^{2} (apparent surface)

Examples:

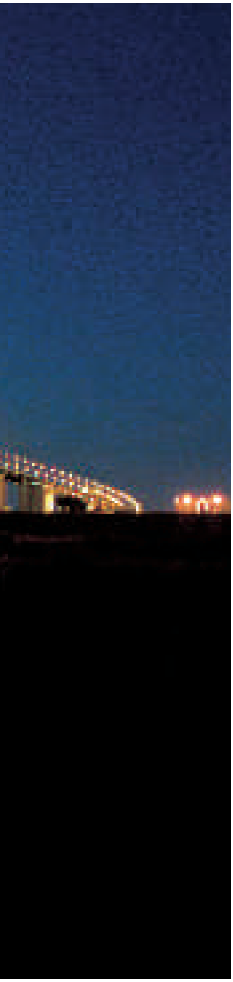
• Surface of the sun:	1.650.000.000 cd/m^2
• Filament of a clear incandescent lamp:	7.000.000 cd/m^2
• Fluorescent lamp:	5000-15.000 cd/m^2
• Road surface under artificial lighting:	0,5-2 cd/m^2

Illuminance measuring technique

Various instruments known as visual photometers have been in existence for several hundred years for measuring illuminance usually involving a visual comparison of the luminance created by two light sources on a screen. All these have now largely been replaced by what are known as physical photometers that use electrical techniques to measure the electric current or voltage generated when light falls on a light-sensitive cell (photoemissive, photovoltaic or photoconductive).

Courtesy: OPAL

Part Two: Lighting



The human eye has evolved to respond to wavelengths between 380 and 780nm of the electromagnetic spectrum. This range of wavelengths is what we perceive as light. Within this narrow waveband we experience all the visible aspects of our world. Sight, therefore, is the most vital sense mankind possesses and understanding of how the eye works and how the brain responds to the visual stimuli they receive is crucial to an understanding of the way light impacts on our lives.

1. Vision

The human eye is a spherical organ capable of swivelling under muscular control within the eye socket in the skull. It functions in roughly the same way as a traditional camera with a lens that projects an inverted image of a scene onto a light sensitive inner back surface. This surface, called the retina, consists of more than a hundred million light-sensitive nerve endings. These transmit signals to the brain that it interprets as visual information.

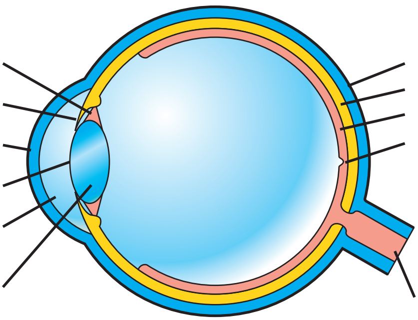
To focus an image on the retina, the lens of the eye can be made to contract under muscular control, making it more convex to increase its power. This is known as accommodation. In front of the lens is the iris that, just like the diaphragm of a camera, can open or close to regulate the amount of light entering the eye through the hole in the centre of the iris called the pupil.

The structure of the retina: rods, cones and light sensitive ganglion cells

The light-sensitive nerve endings that make up the retina are of two types called rods and cones. The rods are far more numerous than the cones and are spread fairly evenly over the rear of the eye except for the area on the axis of the eye called the fovea. The rods are connected to the brain in groups of about 100 and are highly sensitive to light and to movement. It's therefore the rods that provide the eye with its high sensitivity, but they are not capable of distinguishing colour.

The cones are also distributed over the rear of the eye but they are much denser in the fovea. Unlike the rods, the cones are individually connected to the brain so they are less sensitive

Cross section of the human eye



to light intensity. There are three types of cones, sensitive respectively to red, green and blue radiation, which are responsible for giving us our perception of colour. People missing one of the groups of cones or where the cones do not function properly may exhibit partial colour blindness. If they are missing two sets of cones, they are completely colour blind and can see only in shades of grey.

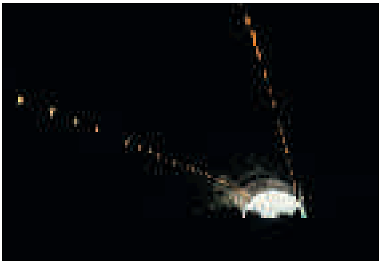
Beside cones and rods, the retina also contains light sensitive ganglion cells. They influence our biological clock that in turn regulates the daily and seasonal rhythms of a large variety of physiological processes, including the body's hormonal system. Light of the early hours of the day, in particular, synchronizes the internal body clock to environmental time or the Earth's 24 hour light-dark rotational cycle. Without light, the internal clock would be free-running with a period of about 24 hrs and 15 minutes and would consequently deviate day after day ever increasingly from the environmental clock time. This would result in symptoms similar to those of jetlag after travelling over several time-zones.

Adaptation

Adaptation is the mechanism by which the eye changes its sensitivity to light. This is done in three ways: adjustment of the iris to alter the pupil size, adjustment of the sensitivity of the nerve endings in the retina, and adjustment of the chemical composition of the photosensitive pigments in the rods and cones. Adaptation from dark to light takes less than a minute but adaptation from light to dark takes somewhere between 10 and 30 minutes.

Contrast

Contrast expresses the difference in luminance between closely spaced areas of a scene. Contrast takes two forms which mostly occur together: colour contrast and luminance contrast, the latter usually being expressed in terms of the contrast ratio which is the ratio of the higher to the lower luminance in the scene. The ability of the eye to detect luminance contrast depends on the state of adaptation of the eye, which is governed by the overall luminance of a scene. So, for example, a white surface against a black background will appear whiter, and a tunnel



Luminance contrast in tunnels: the exit may look 'whiter' than it really is due to the dark surrounding area in the field of view. This may cause dangerous adaptation difficulties for drivers. For this reason, exits (and entrances) of tunnels often have special lighting solutions to prevent abrupt contrast transitions.

Glare from e.g. traffic headlights can lead to discomfort, eye strain, headaches and even veiling.

Reduced accommodation capacity due to ageing

which may not be very dark may appear so when seen from outside on a bright day. The cause of these contrast effects lies in the inability of the eye to adapt simultaneously to strongly different luminances. Glare is the sensation produced by luminance levels within the field of view that are considerably higher than the brightness to which the eyes are adapted. This can lead to discomfort and in extreme cases to eyestrain and headaches.

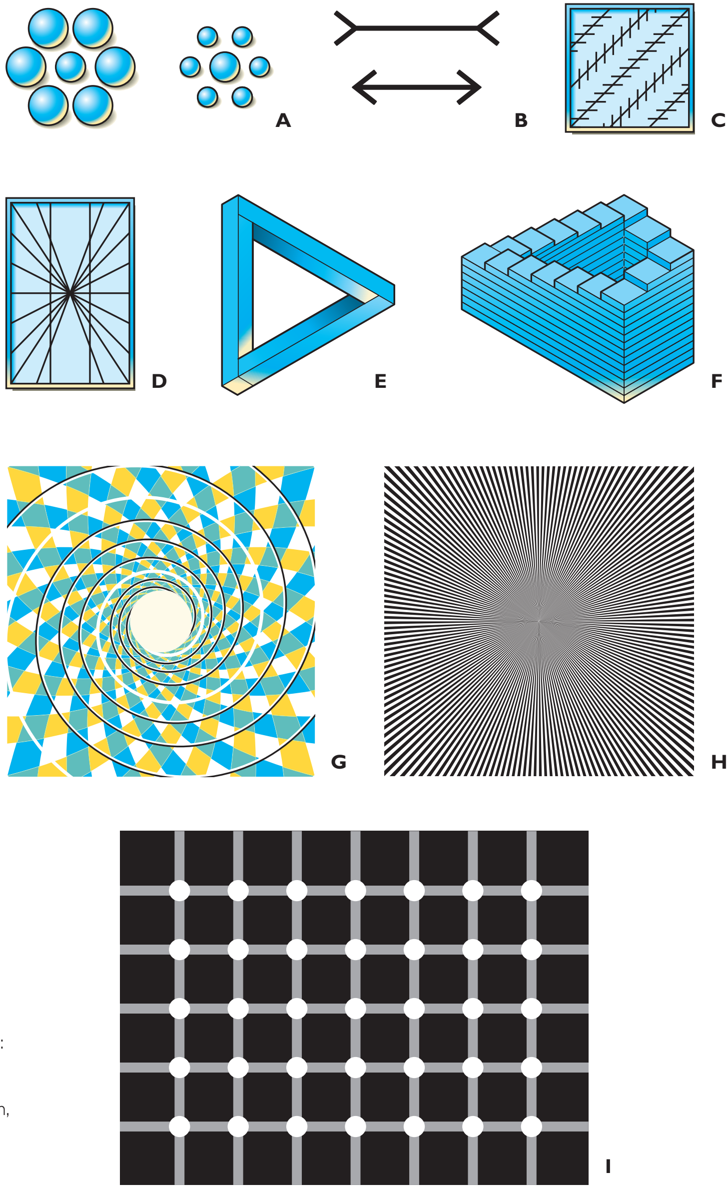
Contrasting colours also have a mutual influence on each other. The general effect is that under the influence of a surface of strongly saturated colour, other surfaces will take on a hue of the complement of that colour. For example, yellow flowers against a blue background appear livelier than when seen against a grey background.
A red surface will look more saturated in contrast with a green surface, which effect butchers take advantage of by displaying their meat on a bed of lettuce leaves to give it a fresh, red appearance. The phenomena of colour contrast are of particular interest to the interior decorator and lighting designer as it determines to a large extent in how far colour effects enhance or just spoil the overall result.

Age defects in the eye

Eyesight deteriorates with age – first slowly then more rapidly due ageing of the tissue that form the optical pathway. These include loss of transparency of the eye liquid as well as hardening and yellowing of the lens. Hardening of the lens results in reduced accommodation ability which means that nearby objects (printed text for example) becomes more difficult to see, necessitating the use of reading glasses with convex lenses. In addition, yellowing of the lens reduces overall sensitivity, visual acuity and contrast sensitivity. The sum of all these conditions affects the eye to such an extent that a 60 year old person may need up to 15 times more light than say a 10 year old person to perform the same visual task (e.g. reading) with the same degree of comfort and effectiveness.

The eye deceived

Our brain has learned to interpret the visual stimuli the eyes receive as a representation of the world around us. The brain can also correct the picture offered. Like at sunset with its distinct red-coloured daylight - the world is nevertheless perceived in its 'normal' colours, unless deliberately observed. A grey surface in full sunshine may have a higher luminance than a white surface in the shadow, but the brain will have no problems in distinguishing between the two shades, as it takes the brightness impression from the overall visual scene into account. On the other hand, under exceptional conditions, the visual image can play tricks with the brain as the examples of optical illusions below illustrate.



Examples of optical illusions: A. and B. illusions of size, C. and D. illusions of parallelism, E. and F. illusions of perspective, G. illusion of depth (apparent spiral), H. illusion of movement and I illusion of brightness perception (white dots appear to contain dark spots).

2. Lighting quality

Good quality lighting is a crucial factor affecting our ability to perform tasks at work and at home. It also has a profound effect on our mood and (as recent research confirms) on our health and well being. It embodies a combination of several criteria including lighting level, luminance contrast, glare and spatial distribution of the light, colour and colour rendering.

a. Lighting level

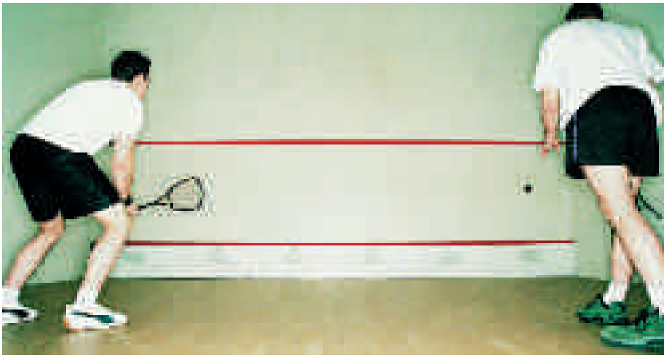
The lighting level should always be high enough to guarantee sufficient visual performance for the tasks at hand. Research has shown that improvement of the lighting level from a low or moderate level to a high lighting level increases the speed and accuracy with which objects can be detected and recognised. In an office or factory, a person's visual performance depends upon the quality of the lighting and of his or her own "seeing abilities". Here, age is an important criterion since lighting requirements increase with age - a sixty year old requiring an average of 15 times more light to perform a specific visual task than a ten year old. Moreover, in general, the amount of light required increases with the speed with which the visual information is presented and decreases with the size of object being viewed. A tennis-ball, for example, is smaller than a soccer ball and moves faster. Consequently, the lighting levels required to play well are higher for tennis than for soccer. And a production process involving the detection of small object details calls for higher illuminances than one where visual requirements are less demanding.

b. Luminance contrast

Luminance contrast, or, luminance distribution within the field of view, is an extremely important criterion of lighting quality. If luminance contrasts are too low, the result will be a dull and flat visual scene with no point(s) of interest. Too high contrasts, are distracting and give rise to adaptation problems for the eye when changing from one visual target to the other. Well-balanced contrasts give a harmonious visual scene, which gives satisfaction and comfort.

As a general rule in interior situations, it can be taken that for satisfactory results the luminance contrast ratio (= ratio between highest and lowest luminance) in the field of view should not be larger than 3 and not smaller than 1/3.

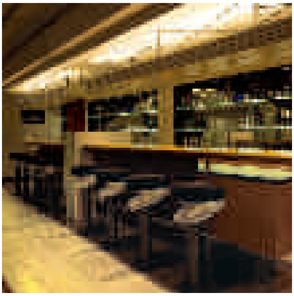
Squash requires a high lighting level



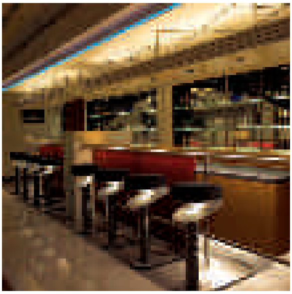
c. Glare restriction

Glare is the sensation produced by brightness levels within the visual field that are considerably greater than the brightness to which the eyes are adapted. This can lead to reduced visual performance and to discomfort. Too much glare can even lead to complaints such as veiling, eye strain and headache. It's therefore important to limit glare to avoid errors, fatigue and accidents. The degree of glare restriction attained depends very much on the optical quality of the luminaires used in combination with the type of lamp used. Thanks to their larger dimensions, fluorescent lamps have lower luminances than high intensity gas discharge lamps and it is therefore easier to limit glare with these lamps.

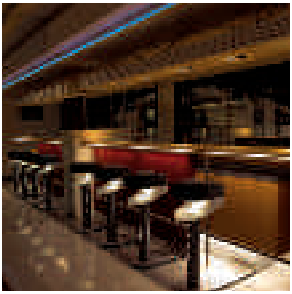
For chess, a high lighting level is not necessary



Too low luminance contrasts cause a dull ambience



Too much luminance contrasts give adaptation problems



Well balanced luminance contrasts create the right ambience

d. Spatial distribution of the light

An important criterion of lighting quality is the way in which the light is spatially distributed since it is this that determines the pattern of illuminances that will be created. The illuminance recommendations applicable to indoor lighting can be implemented in a number of ways. The light sources can be spread fairly evenly using a system of so-called diffuse general lighting, it can be concentrated in certain areas using directional lighting, or it can be distributed throughout the space but with local accents where needed using a combination of the two systems just mentioned.

e. Colour and colour rendering

An object is seen as being coloured by virtue of the fact that it reflects only part of the waveband of the light incident on it. The way in which the colours around us are rendered therefore depends strongly on the colour composition of the lighting. Proper colour rendering is of importance when objects must be seen in their 'true' colour appearance. Generally speaking, the lighting employed in a interior must be so chosen that familiar objects (e.g. foods, drinks, people) appear pleasant and natural. A proper choice of light source (colour rendering of at least Ra 80), easily avoids this problem. Having said that, there are also situations where colour rendering is of little or no importance. Road lighting is an example, the purpose here being to make the road and objects on it clearly discernable to the motorist, and surface colours play practically no part in this.

Lighting and economics

Lighting quality in any situation is inevitably related to economics since there is often a temptation in new office and industrial building projects and in renovations to leave lighting considerations to the very last. This can result in the installation of a cheaper lighting system to meet budgetary constraints, resulting in inferior lighting, dissatisfied personnel and reduced productivity.

Looking for a low-cost lighting solution can also be false economy. Over the life of a typical lighting installation, the costs of the electricity it consumes will be greater by far than the initial cost of the installation or the cost of maintenance. So choosing a lighting system on installation costs alone may not provide the most economical system to operate in the long run. Using the most efficient light sources, which may not necessarily be the cheapest, will usually result in the lowest overall system cost.

A well designed lighting installation will also provide optimum lighting where it's needed with due regard to the tasks that need to be performed and, where appropriate, with accent on architectural features. At the same time, it will be cost-effective by not providing more than is needed. For example, in industries where good colour rendering is not essential, choosing lamps with a colour-rendering index of 90 would be an unnecessary expense, and lamps with an index of 80 may be adequate. The ideal lighting solution, therefore, is one tailored specifically to a customer's requirements taking all factors into account.

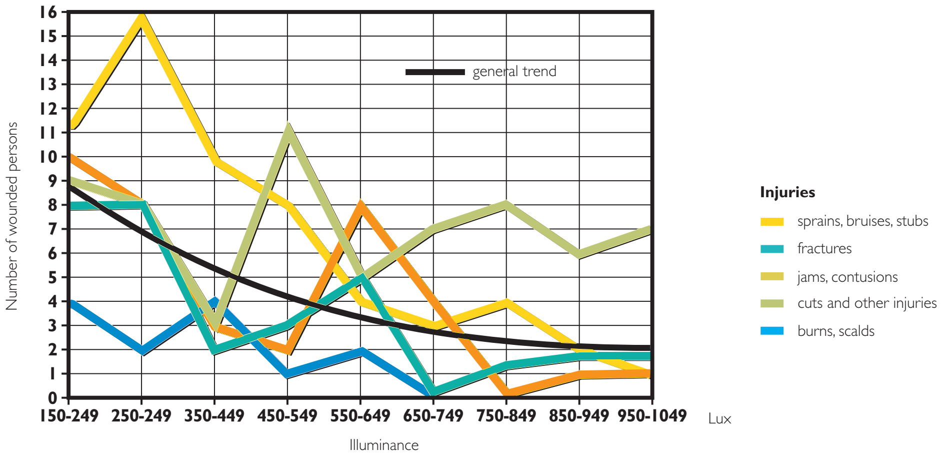
Flicker

A quality criterion not often mentioned in standards is the frequency of lamp operation. Some people experience headaches because of the flicker of fluorescent lamps operated on conventional ballasts (50 Hz). Fluorescent lamps running on modern high-frequency electronic ballasts (around 30 kHz), however, do not exhibit this flicker phenomenon and incidents of headache are found to be significantly lower when electronic ballasts are used. Of course, electronic high-frequency ballasts are also recommended because they're more efficient and result in longer economic lamp life than lamps operating with conventional ballasts.

Lighting in the workplace

Good lighting on a task and in the workplace is also essential for optimal (visual) task performance, especially with a progressively ageing population. Research on the quantity and quality of lighting over the past decades has shown that improvement of lighting quality from a low or moderate level increases the speed and accuracy with which objects can be detected and recognised.

Accident risk in the workplace is also reduced when there is greater awareness of potentially dangerous situations and when the mood, alertness and health of industrial workers are promoted by good-quality lighting. This effect can't be overemphasised as poor levels of worker concentration and high levels of fatigue cause a considerable number of accidents. Besides its effect on visual performance and accidents, lighting also has a powerful influence on the creation of a stimulating working environment. Today, a lot of emphasis is given to layout and interior design of the workplace, but lighting too plays an important role. Whilst it can emphasise positive elements of a design, lighting can also detract from these elements, for example by poor colour rendering or glare effects.



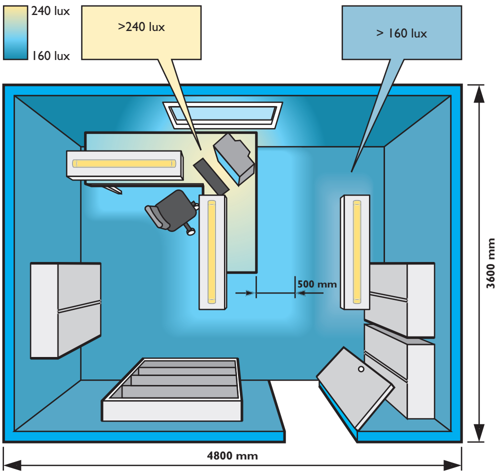
Number of accidents for different industrial tasks as a function of the lighting level (347 accidents investigated in total). [Völker, S., Rüschenschmidt, H., und Gall, D., "Beleuchtung und Unfallgeschehen am Arbeitsplatz", Zeitschrift für die Berufsgenossenschaften, (1995).]

Lighting regulations

Lighting requirements for rooms and activities for indoor work places are specified in the AS/NZS 1680.2.1:2008: interior and workplace lighting-secific applications-circulation spaces and other general areas and AS/NZS 1680.2.2: interior and workplace lighting-specific applications-office and screen-based tasks. The standard specifies requirements for lighting systems for almost all indoor work places and their associated areas in terms of quantity and quality of illumination. In addition recommendations are given for good lighting practice.

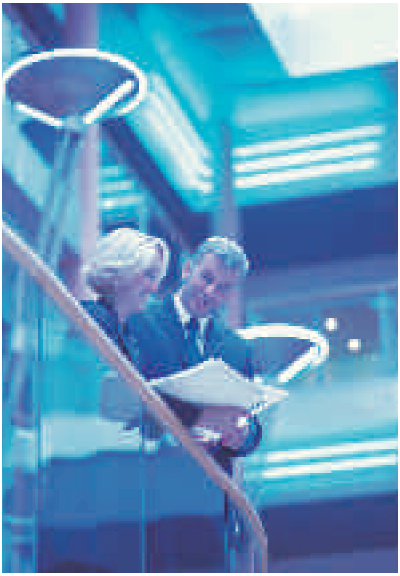
The office segment lists four basic quality parameters for indoor tasks and activities: maintained illuminance level (Eav), uniformity (Emin/Eav), glare restriction (UGR) and colour rendering (Ra) or colour rendering group. The figures below give a brief extract of the lighting requirements for the office building segment.

Offices		
Type of interior, task or activity	**Illuminance**	**Glare restrictions**
Filing, copying,etc.	240	19
Writing, typing, reading, data processing	320	19
Technical drawing	600	19
CAD work stations	160(240)	19
Conference and meeting rooms	240	19
Reception desk	320	19



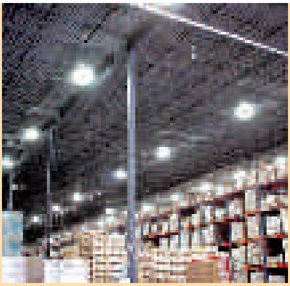
The variety of industry applications is enormous. Merely as an example, the table below gives an idea of the lighting requirements according to AS/NZS 1680.2.4:1997: Interior lighting-industrial tasks and processes (Amdt 1 September 1998) for the *electrical industry*. Norm tables are available for all relevant industry segments.

Electrical industry			
Type of interior, task or activity	**Illuminance**	**Glare restriction**	**Colour rendering group**
Cable and wire manufacture	240	25	2
Winding:			
- large coils	240	25	2
- medium-sized coils	400	22	2
- fine gauge wires	800	19	1B/2
Coil impregenting	240	25	2
Galvanising	160	28	2
Assembly work:			
- rough e.g. large transformers	240	25	2
- medium e.g. switchboards	400	22	2
- fine e.g. compents insection, soldering	600	19	1B/2
- precision e.g. inspection of small pots	1200	n/a	1A/1B
Electronic workshops, testing, adjusting	800	n/a	1A/1B



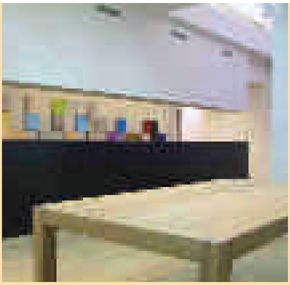
3. Lighting systems

A lighting installation system does more than reveal to us our surroundings so that we are able to work efficiently and in safety. Nowadays lighting is seen also as a way of creating a pleasant atmosphere in the interior as a whole and as a means of providing comfortable conditions in which to live and work. The lighting accentuates the functional and decorative qualities of the space, and its proportions. It is not there just to improve visual perception, but also to determine the emotional atmosphere: cool or warm, businesslike or pleasant, happy or solemn. This is the lighting designer's task, which is achieved by creating comfortable and stimulating lighting systems.



General lighting

General lighting provides a uniform level of illumination over a large area. In some rooms, for example closets, storage rooms, utility rooms and garages, one luminaire or a group of luminaires can provide all necessary illumination. These indoor areas tend to be where the style and appearance of the room itself is secondary to the objects to be lighted, and cost is a deciding factor. The requirement is for good general lighting distribution, primarily horizontal illumination and no shadows.

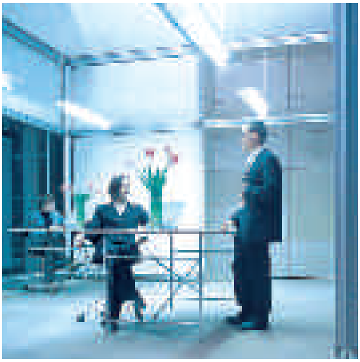


Architectural lighting

Architectural lighting aims to accentuate the features and specific elements of the space itself, like walls, ceilings, floors, etc, instead of the objects present. Luminaires for architectural lighting usually produce only modest amounts of illumination and are often chosen for their appearance as well, with complementary luminaires providing the room's general or the task lighting.

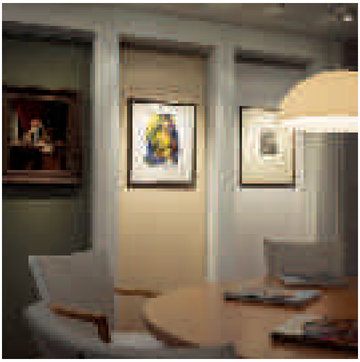
Task lighting

As its name suggest, task lighting illuminates specific work areas like desk- and counter-tops. Task lighting reduces the reliance on general overhead lighting and provides better quality lighting for specific tasks with lighting pointed directly at the work area. Most task lights are directional and local.



Accent Lighting

Accent lighting is used to highlight specific features within a room such as art objects in museums and special offers in shops. This type of lighting should not create too much brightness contrast.



Ambient lighting

Ambient lighting is used to set the mood or ambience within a living or working space.
It is commonly a combination of general-, architectural-, task- and accent lighting to create a highly specific atmosphere in a room.

4. Luminaires

While the lamp is the primary source of light, reflectors and lamellae are required to help spread the light and direct it where it's needed. The luminaire is the apparatus that performs these functions. The luminaire can also act as a screen for glare and protects the lamp. It contains elements for distributing, filtering and transforming the light emitted by a lamp and includes all items necessary for fixing and protecting the lamp(s) and for connecting it (them) to the power supply.

Where the luminaire is designed for gas discharge lamps, it also contains the electrical ballast system or gear for driving the lamp and maintaining electrical safety. This may be an electro-magnetic or, more common nowadays, electronic ballast that are compact, weigh less and offers significant benefits in control, energy saving, light quality and lamp starting. The broad scope of luminaires can be sub-divided into various categories, each of which has specific applications. These are summarised below.

Luminaire types:

- Recessed-mounted luminaires
- Spots/projectors
- Surface-mounted luminaires
- Decorative luminaires
- Pendant luminaries
- Free-floor-standing luminaires
- Up lights
- Trunking lighting systems
- Down lights

Examples of a recessed-mounted (top) and pendant luminaire

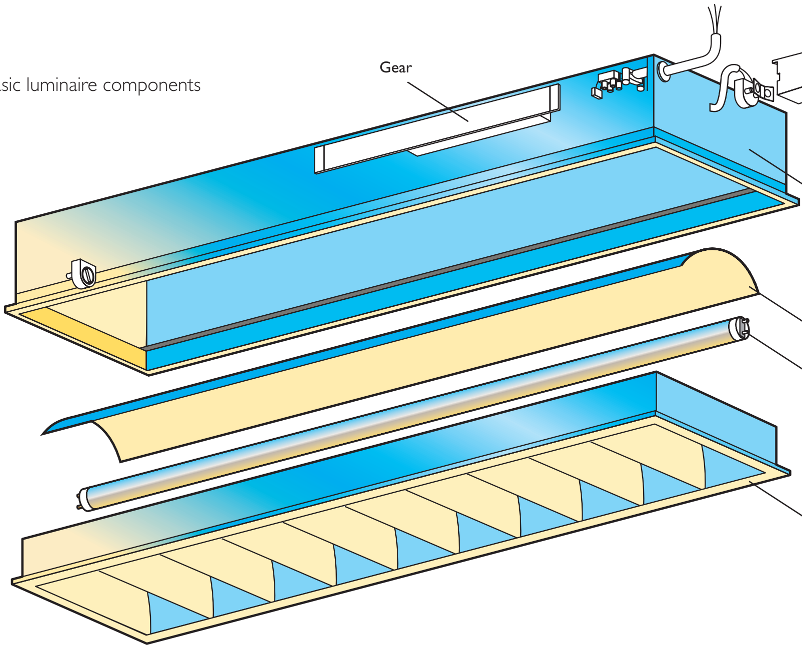
The style and construction of the luminaire housing reflects the function it has been designed to do and can range from utility for industrial lighting right through to stylish designs for top-of-the-range shops and architectural lighting.

Safety

Luminaires (as well as lamps, gear and controls by the way) have to comply with international and Australian safety regulations developed by official governmental bodies. These include for each class of luminaire stringent norms and standards concerning electrical safety, electromagnetic interference, impact and ingress protection, flammability, UV radiation, etc.

An authorised member of the manufacturer or his authorised representative must issue a so-called Declaration of Conformity which, among others requirements, must include the specification to which the product complies. If the manufacturer has the facilities to carry out full testing of the product to the relevant specifications, it has the right to do so. Testing of a product at a third party laboratory is not mandatory, but may be more prudent to verify its compliance. The manufacturer carries full legal liability for all damages resulting from non-compliance of his products.

Basic luminaire components



5. Lighting & the environment

The environmental relevance of lighting is receiving more attention. Around the world Legislation sets targets for the reduction of greenhouse gases, reduction or elimination in the use of hazardous substances such as mercury and lead and mandatory recycling of used lamps. The cost of electricity is going to increase due to the need of investments in renewable energy supply and shortage of crude oil. In addition, large end-users have identified sustainability as part of their company strategy and environmental management systems.
The good news is that Philips has developed products that comply with present and future legislation and that this also leads to a reduction in ownership costs. In fact, everybody benefits from buying "green" products. You from better margins, the end-user from lower cost for lighting and the society for less environmental pollution.

Sustainability – the key to all our futures
Sustainability demonstrates our commitment to the future. All our lighting solutions are a balance between social (safety, well-being), economical (lowest cost of ownership) and environmental (CO_2-reduction, minimal hazardous substances) requirements. Our aim is to sustain the world's resources, so that our children's children can still have the lifestyle we enjoy today.

Dow Jones Sustainability Indexes
Member 2006/07

Philips is Leader in sector leisure goods at the Dow Jones Sustainability Index in 2004, 2005, 2006 and 2007

MASTER – full compliance with current and future environmental legislation
The choice of the best type of lamp from our product portfolio will depend on the needs of the individual customer, and whether he is looking for cost-saving benefits in the short term or the long term.

If a customer is looking for the lowest possible cost of ownership in the long term, combined with superior technical and environmental performance in terms of light quality, lifetime reliability and full compliance with current and future environmental legislation, our MASTER lamps are always the best possible choice.

Defining good environmental performance
We define the environmental performance of our products in six key areas to make it more tangible:
- Energy efficiency to reduce CO_2 emissions from power stations
- Long, reliable lives to reduce waste
- Reduction or elimination of hazardous substances exceeding legislation
- Lightweight, simple and recyclable packaging to reduce waste and transport
- Possibility for upwards recycling of reclaimed components into similar products
- Miniaturisation leading to low product weight, saving on materials

Green Products

MASTER products with outstanding performance in one or more of these areas that define good environmental performance are designated Green products.

Green Products are your guarantee that your customers will select the best environmental product in that product range in the market.

Green products can be recognised by the symbol and the green areas in which they outperform.

We cut mercury to industry leading low

This is how we have responded to the forthcoming legislation on the "Restriction of the use of certain Hazardous Substances" (RoHS, 2002/95/EC, effective by 1-7-2006).

The following hazardous substances are set to be banned by this directive of the European Union.

- Lead
- Mercury
- Cadmium
- Hexavalent Chromium
- Polybrominated Biphenyls (PBB)
- Polybrominated Diphenyl Ethers (PBDE)

All Lighting products are included in this directive but some applications are exempt.

Hazardous Substance	Applications	Value
Mercury		
	Energy Savers	< 5 mg
	Straight fluorescent lamps for general lighting	
	• Standard colors	< 10 mg
	• 80-colors normal life	< 5 mg
	• 80-colors long life	< 8 mg
	Fluorescent lamps for special purposes	Exempted
	High Intensity Discharge lamps	Exempted
Lead		
	Glass in electronic components (e.g. starters)	Exempted
	Glass in fluorescent tubes	Exempted
	High melting temperature solder (Pb>85%)	Exempted
	Electronic Ceramic parts (e.g. drivers)	Exempted

Philips has always set the pace in reducing mercury content. Our fluorescent lamps consistently will meet, and all fluorescent MASTER lamps exceed, the values defined in the RoHS. We have used our knowledge on mercury consumption and dosing to push the limit further. From September 2005 we have brought products to the market with considerably reduced mercury content - to a record level. Also substances such as lead in glass and radioactive materials in starters and glow switches are eliminated even when they are exempted in the RoHS.

You can recognise these best in class products by the following:

On product:

Green product

On packaging:

Minimum mercury

Minimum mercury

Lead-free

Radioactive-free

Appendix - About Philips

Royal Philips Electronics of the Netherlands is one of the world's biggest electronics companies and Europe's largest. It is a global leader in colour television sets, lighting, electric shavers, medical diagnostic imaging and patient monitoring, and one-chip TV products. Its 164,500 employees in more than 60 countries are active in the areas of lighting, consumer electronics, domestic appliances and medical systems. Philips is quoted on the NYSE (symbol: PHG), Amsterdam and other stock exchanges.

Philips Lighting, a division of Philips Electronics and number one in the global lighting market, strives to improve people's lives with effective and appealing lighting solutions based on a thorough understanding of people's needs, desires and aspirations.

The company wants to be recognised by all stakeholders as setting the pace in the lighting industry, as the best partner to do business with, and as a responsible corporate citizen contributing to the sustainability of society at large.

The division's products are found all around the world: not only everywhere in the home, but also in a multitude of professional applications, for example 30 per cent of offices, 65 per cent of the world's top airports, 30 per cent of hospitals, 35 per cent of cars and 55 per cent of major football stadiums (for example, eight of the twelve at the 2006 football World Cup in Germany).

Products include a full range of incandescent and halogen lamps, compact and normal fluorescent lamps, high-intensity gas discharge and special lamps, lighting based on light emitting diodes (LEDs), fixtures, ballasts, lighting electronics and automotive lamps.

Notes: