Fundamentals of Light and Colour

Radiation

Radiation is emission or transfer of energy in the form of electromagnetic waves.
These electromagnetic waves travel through a vacuum with a velocity close to 300 000 km/s.
Interactions between matter and radiation are explained with the quantum theory of radiation.
It states that energy is emitted and absorbed in discrete quanta (photons). Examples of these interactions are photoelectric, chemical, and biological effects of radiation.

Optical Radiation (UV Light IR)
Light may be defined as any radiation capable of causing a visual sensation directly.
Light waves occupy only a very small part of the spectrum of electromagnetic waves. The limits of visible radiation are not well defined and vary according to the individual – the lower limit is generally taken as being 380 nm and the upper limit 780 nm (1 nanometre (nm) $\lambda = 10^{-9}$ m).
The visible spectrum can be divided into a number of approximate wavelength ranges, each of which makes a certain colour impression on the human eye:

380 - 435 nm violet
435 - 500 nm blue
500 - 566 nm green
565 - 600 nm yellow
600 - 630 nm orange
630 - 780 nm red

Ultraviolet and Infrared Radiation
Electromagnetic radiation with wavelengths just beyond the violet and red ends of the visible spectrum are known as ultraviolet and infrared radiation respectively.

Ultraviolet radiation
A study of the effects obtained with ultraviolet radiation of different wavelengths has led to the following classification by the CIE into three wavebands:

UV-A (long-wave)	315-400 nm
UV-B (medium-wave)	280-315 nm
UV-C (short-wave)	100-280 nm

This classification is based upon a small number of well-investigated processes - principally the effects on the human skin - and by no means implies that all practical applications of UV are confined to a distinct waveband. Some processes respond to a wide ultraviolet spectrum and others overlap into the visible spectrum as well.

Infrared radiation
As with ultraviolet radiation, infrared radiation occupies three wavebands:

IR-A (short-wave)	800 - 1400 nm
IR-B (medium-wave)	1400 - 3000 nm
IR-C (long-wave)	3000 - 10000 nm

Vision

The eye has a lens, which focuses an image on a light-sensitive surface, the retina.
The retina consists of a delicate layer of nerve tissue in which there are two types of nerve fibre endings in the form of light-sensitive cells, called cones and rods. The concentration of cones and rods varies over the retinal area. On the optical axis the centre of the retina(the fovea) only contains cones. Outside the fovea area, the rods and cones are mixed, the proportion of cones decreasing towards the periphery of the retina.

Central vision
The cones in the fovea produce a very sharp image showing the greatest detail of which the eye is capable.

Peripheral vision
The periphery of the retina, which is composed chiefly of rods, does not produce sharp vision, and objects seen by this area appear as fuzzy silhouettes. The periphery is, however, highly sensitive to movement and flicker.

Adaptation
Adaptation, the process whereby the eye is able to function over a wide range of illuminance levels, involves (amongst other things) a change in the pupillary opening along with photochemical changes in the retina.

Colour Vision

The cones enable us to distinguish colours. This is possible because there are in fact three types of cones, with pigments sensitive to the red, green and blue parts of the spectrum, respectively.
The brain interprets the relative stimulation of the three colour receptors as the colour impression. Persons who miss one type of cone are partially colour blind.

Spectral Sensitivity of the Eye

Within the visible range of the electromagnetic spectrum the eye sensitivity varies strongly with different wavelengths of the same energy content.
For example, under conditions of photopic vision the eye is about twenty times more sensitive to light with a wavelength of 555 nm (yellow-green) than it is to wavelengths of 700 nm (deep red) or 450 nm (violet-blue).
The peak sensitivity for scotopic vision lies about 50 nm nearer to the blue end of the spectrum than the maximum sensitivity for photopic vision.
As early as 1924, the Commission Internationale de LEclairage (CIE) laid down a standard spectral eye sensitivity curve for photopic vision, The curves give the relative photopic eye sensitivity (V) as a function of the wavelength (l), and are therefore generally called V(l) curve having its maximum at 555 nm.

Black body radiator

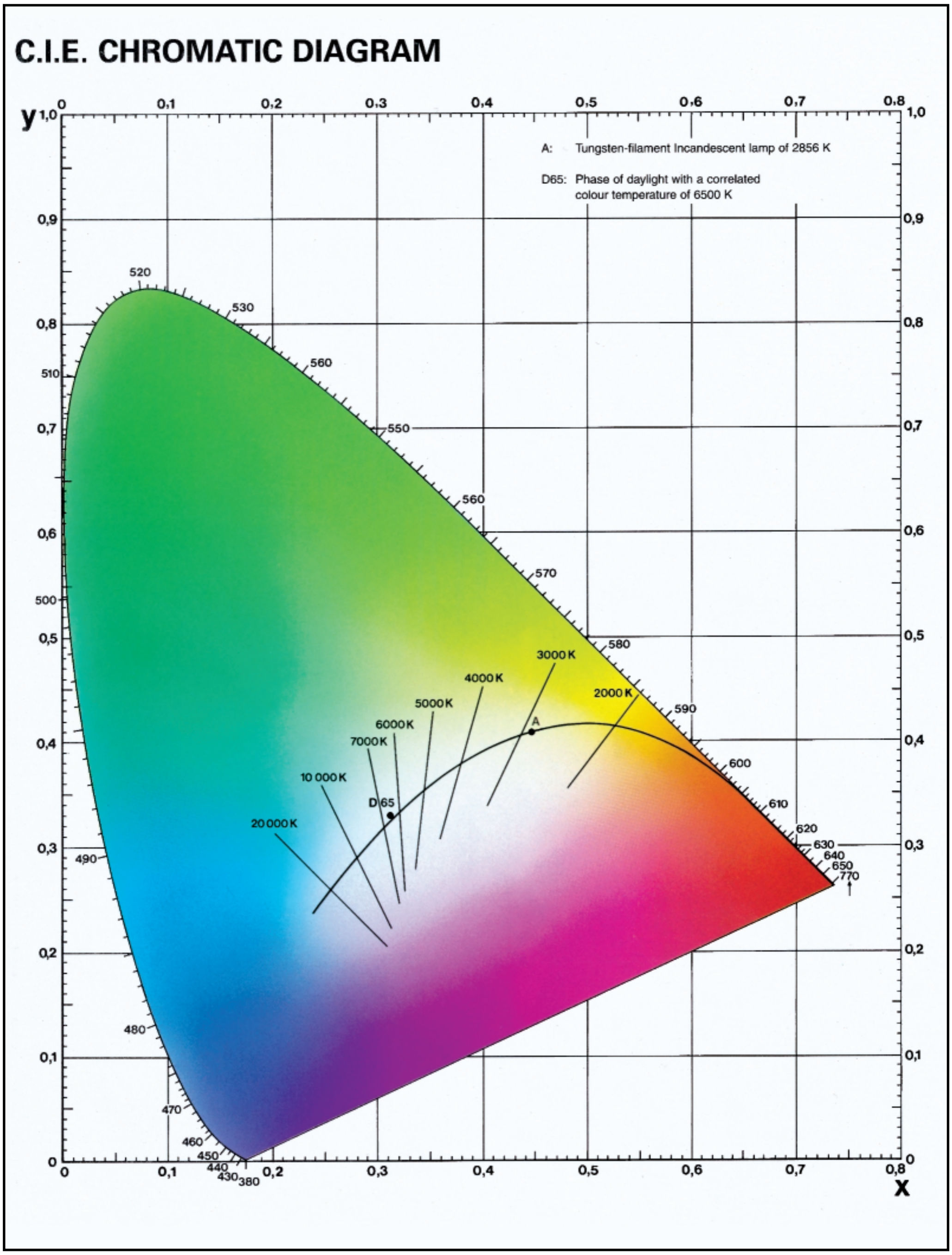
The black body, or full radiator, is a body that absorbs all radiation falling upon it, transmitting none and reflecting none. The radiation characteristics of such bodies are accurately known and can be very precisely calculated at all wavelengths and temperatures.
The spectral energy distribution of a black body is, according to Planck's law, a function of wavelength and absolute temperature. Not only does the radiant energy increase rapidly with operating temperature, but the wavelength at which the maximum occurs becomes shorter.
Radiation of this form is called thermal radiation, or black-body radiation. And because all wavelengths are present in the spectrum of a thermal radiator, such a spectrum is called a continuous spectrum. The black-body radiator is often used as a primary reference standard when describing the light from practical light sources.

Systems of Colour Specification

CIE System

The chromaticity diagram

The chromaticity diagram, or colour triangle, adopted by the CIE in 1931 permits the mathematically exact specification of any colour of light in terms of two chromaticity co-ordinates, x and y. These co-ordinates are calculated from a knowledge of the lamp's spectral energy distribution and the response of a CIE standard colorimetric observer related to the three types of light sensitive cones in the human eye. The most saturated light colours are found along the sides of the triangle, these gradually diluting into 'white light' toward the centre. In this diagram the boundaries are formed by the spectral locus which is composed of the colour points of monochromatic radiation ranging from blue in the left corner towards green in the top and finally red in the bottom right corner.



Colour Temperature

Colour temperature is a term used to describe the colour of a light source by comparing it with the colour of a black body radiator, or full radiator. The temperature of the black body, in Kelvin, at which a colour match is obtained, is said to be the colour temperature of the source.

The curve formed on the CIE chromaticity diagram by plotting the chromaticities of a black body radiator at various temperatures, is known as the Planckian locus. Any source that has a chromaticity on this locus may be specified by a colour temperature. A source not on the Planckian focus can be described by means of its correlated colour temperature, that is, the temperature of the black body at which its colour resembles most closely that of the source; provided, that is, that it is not too far from the Planckian focus.

Colour Rendering

The CIE General Colour Rendering Index R_a

In order to be able to compare the colour characteristics of various types of light source, the concept of a colour rendering index, based on the appearance of a number of test colours under different illuminants, was introduced by the CIE.

The average of the chromaticity shifts occurring when the test colours are alternately illuminated, first by the lamp under test and then by a reference source of the same colour temperature, provides a good measure of the colour rendering properties of the test source.

The reference light source used for sources with a correlated colour temperature of 5000 K and below is a full (or black-body) radiator of the nearest colour temperature. Above 5000 K, the reference source used provides simulated or 'reconstituted' daylight of the appropriate colour temperature. In the CIE test colour method recommended for international use in 1965, eight Munsell test colours of medium saturation were used for measuring and specifying these colour rendering properties. Nowadays, fourteen test colours are often employed, saturated red, yellow, green and blue, and colours approximating the human skin and green foliage having been added.
The general colour rendering index, or R_a, of a source has a maximum value of 100, which occurs when the spectral distributions of the test source and the reference source are identical. Incandescent lamps have a spectral energy distribution almost identical to that of the standard source, and therefore give excellent colour rendering. The efficacy of these lamps, however, is rather low.
In discharge lamps which have a much higher efficacy a large variety in spectral composition hence colour rendition is found, ranging from light sources like Fluorescent super 80 and 90 lamps and CDM metal Halide lamps with good or excellent colour rendition while still having a high efficacy on one hand and ultra high efficacy lamps like SOX with a very moderate colour rendition.

Limitations of the R_a System
Two serious limitations of the R_a system should be mentioned. In the first place, it should be remembered that the R_a of a lamp is an average value based on the examination of only eight test colours. Secondly, a low value for a particular colour can mean either that the colour will be poorly (weakly) - rendered, or that it will be exaggerated, perhaps even with a flattering effect as will be explained in the new CRV system
Thus, a source may be found to have a seemingly acceptable R_a value, despite the fact that it is incapable of faithfully reproducing a particular test colour.

The New CRV system: precise definition of colour quality

The right light
Colour rendering is an important aspect of artificial lighting. In some situations colours should be represented as naturally as possible under daylight conditions yet in other cases lighting should highlight individual colours or create a specific atmosphere. However, there are various lighting situations where it is not so much a precise natural colour rendering that matters most but where light level and efficiency are of greater importance. Whether your requirement is for medium quality colour rendering, natural colour rendering or highlighting of special colours, there is the right kind of lamp for each and every application.
In the past, finding the right quality colour rendering and tailoring it to your precise requirement was a complex task. It called for special skills acuired through long – and often costly – experience.
Now, however, the new CRV diagram (Colour Rendering Vector) means you can get the results you need – without first going through a costly learning curve!

The Colour Rendering Vectors (CRV) system provides a completely new and more sophisticated way of defining colour quality, making it a valuable tool for lighting professionals involved in the specification of light sources and the design of lighting installations.

Up to 215 measuring points
Instead of being limited to just the eight colours of the colour rendering index (CRI) method, CRV uses a much larger number of colours as fixed measured points. In fact, 215 colours have been selected from a multitude of practical situations, and include colours which are widely used in textiles, paints and many other products, as well as those which are most commonly found in nature. The colour rendering ability of the light source under investigation is tested at each point of these 215 colour points, and compared with that of a reference light source.

Separate analysis of deviations
Another important improvement is that the colour deviations are analysed separately for each of the 215 colours. There is no averaging, so the rendering of each individual colour is assessed and registered separately.

The CRV diagram
These deviations are represented by a CRV diagram – a circle showing all the, colours of the spectrum around its circumference, and containing two axes serving as references to show the deviation in the rendering of each colour.
The deviations are indicated by a vector pointing from the natural colour (viewed, under a reference or full-spectrum light source) to the perceived colour (viewed under the test light).

Three aspects of colour quality
Each one of the up to 215 vectors is an arrow which shows three aspects of colour quality:
- The director of the vector shows the direction of the colour deviation. A shift towards the circumference of the circle indicates an increase in colour saturation (more intense), while a shift towards the centre means a decrease in saturation (less intense).
- The start and end points of the vector show the true colour (under the reference light source) and the perceived colour (under the test light source), respectively.
- The length of the vector shows the magnitude of the colour deviation.

Two main parameters
Thanks to its accurate representation of colour quality for up to 215 measuring points the CRV method gives a very precise impression of the colour rendering characteristics of a light source. In describing colour quality, two parameters are particularly important:

Hue: the direction and magnitude of the shift in colour.

Chroma: the direction and magnitude of the shift in saturation.

A third parameter, the colour value or 'lightness', refers to the amount of light reflected from a coloured surface, and can vary for colours of the same hue and chroma. In practise, colour shifts are almost always a combination of shifts in hue and chroma, and the lightness will not be considered further here.

Selection of lighting on colour quality
Key factors in the selection of lighting for specific application include the type of activity carried out in the area, the general environment, the desired ambience and the products being sold. Three basic levels colour quality can be defined: high, good and average.

High colour quality
An incandescent lamp, with its low efficacy of 12 lumen per watt, possesses a well balanced colour spectrum. Application of the CRV method therefore shows no deviation at all.
The discharge lamps with the best colour rendering properties are the fluorescent 'TL' lamps of the /90 series.
The diagram for these lamps (see next column) indicates hardly any deviation, thereby demonstrating the excellent colour rendering characteristics of this light source. In the home, up-market shops and showrooms and museums, high colour quality is essential to ensure that people, products and displayed objects have a natural colour appearance.

Good colour quality
Fluorescent 'TL' lamps of the /80 series have good colour rendering characteristics. The diagram shows only a limited colour shift. These fluorescent lamps are therefore very widely used in many applications where good colour rendering is important.
In offices, department stores and light industrial premises, good colour quality is a major consideration. In these cases it is not acceptable for colours to deviate substantially from their natural appearance.

Average colour quality
Fluorescent lamps of colour /33 cause appreciable deviations in colour rendering, as the CRV diagram shows. As a result, lamps of this colour quality are suitable only for use in situations where colour rendering is of little importance. In railway stations and car parks, efficiency takes priority over colour rendering. Here, the light source will not be selected primarily for its colour quality. However, when people are working in these areas, at least average colour quality is recommended.

Philips, recycling and the environment
We are not just concerned about great product innovation. A great deal of effort has gone into making our products environmentally friendly.
The company is committed to the Environmental Management System (ISO 14001) in its European factories – this is annually audited – and has implemented eco-design programmes to make sure that, in the product creation process, environmental issues are dealt with correctly.
For customers, the Philips standard of quality is a clear indication that the products meet or surpass the declared specifications. What is more, the products are delivered as agreed upon and the service meets the customer's expectations.
During the past we years we have successfully reduced environ-mentally unfriendly substances in our lamps. For example Philips took the lead in the reduction of mercury in our TL-D Super 80 Fluorescent lamps and elimination of mercury in SON-PIA lamps.
However, Philips has also started to investigate how we can intelligently recycle our products. The first generation of recycling (also called downward recycling) focused on reusing lamp components in whatever application possible (e.g. through reuse in building materials). Most manufacturers doing so reached 100 % recycling, which although it seemed promising at first, was still based upon the use of highly valuable natural resources (e.g. fluorescent powders) in less valuable applications (e.g. road construction materials).
The second generation of recycling focused upon the re-use of those resources in the same applications as where they were initially used. This 'upward recycling' ensures we (re) use our natural resources to their fullest potential.
However, the most valuable resource consumed by light sources, is however the energy in the form of electricity it consumes. Therefore, the most energy efficient light sources are also the most environmental friendly. Philips has therefore focused its second generation recycling efforts on its Master products. Combining the most efficient use of energy and the highest possible percentage of reuse, we call this SMART ECOLOGIES. To help our customers, to identify these products easily, we have given these special ranges of Master products an easily recognisable Green Cap. A symbol of the highest quality, combined with the best environmental friendly alternative.

Philips Quality Standards
In striving for optimum quality levels, the internationally recognised ISO 9001 system for quality assurance, and the newer QS 9000 standard, have been implemented and rigidly enforced in Philips factories. Almost all phases of development and production are involved in a process of continual improvement within the framework of Total Quality Management (TQM) and achieving so-called 'world class' levels of quality.
But quality is not just a piece of paper or a set of good intentions. It is about making products with zero defects and good lifetime reliability for ease of mind. It is about supplying our customers with their goods at the right time, and it is about developing the best lighting products in the world and communicating the benefits in the most effective way. It is about handling questions and queries in the most helpful and speedy manner. In short it is about making us easy and rewarding to do business with.
And with our company wide quality improvement program BEST (Business Excellence through Speed and Teamwork) we are confident we will also in this new millennium be capable of continuously 'Making things better'.

International standards and approvals for control gear
In this publication the specification of Philips control gear satisfies the standards for safety, performance and reliability quoted in the numerous IEC publications for ballasts (electronic and electromagnetic), ignition devices, etc. As for Electro-Magnetic Interference, Philips products conform to the relevant European and/or IEC regulations.
On many occasions, formal approval will amount to supervised manufacturing test procedures or testing at the manufacturer's premises (SMT), meaning that these tests are then performed by Philips own engineers, under official supervision. As soon as approval is given, these may be shown on the product labelling (e.g. ENEC).