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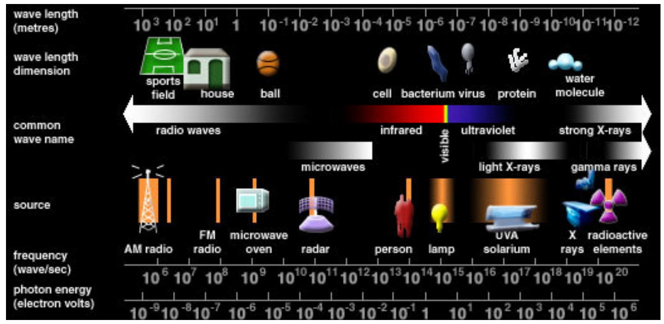
Vision

Lighting



Light is a form of energy, visible with the naked eye, that can be transmitted from one point to another at a finite speed. Visible light is a small proportion of the radiation spectrum which ranges from cosmic rays to radio waves. Two complementary theories have been proposed regarding the behaviour and propagation of light.

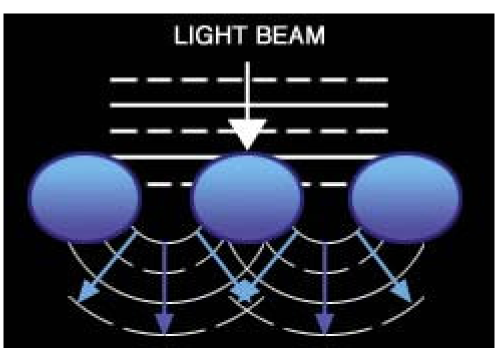
Particle theory

Wave theory

The refractive index n of a material is the ratio between the speed of light in the space c and the speed of light in the material itself v: n=c/v

All materials have an index greater than 1: air = 1.003, water = 1.33, diamonds =2.42. This extremely high index endows diamonds with their distinguishing visual qualities.

The Huyghens principle, theorized by the Dutch physicist Cristian Huygens (1629-95), states that: each point of an advancing wavefront is the centre of a new disturbance, the source of a new series of waves. This means that light, in the same way as water, after passing through a crack tends immediately to "enlarge" itself.

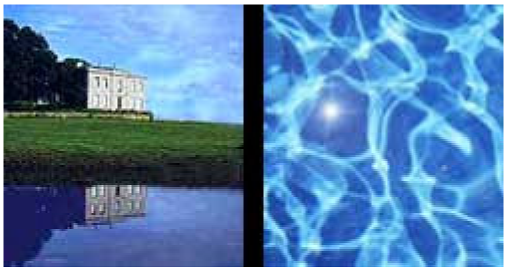


The Italian Jesuit Francesco Grimaldi (1618-1663) was among the first to note that, when the light of the sun entered into a dark room through a small hole, the images that it formed on the opposite wall were much lager than what might have been expected.
The Huyghens principle is the basis for the phenomenon of diffraction.

The Fermat principle is attributed to the French mathematician Pierre de Fermat. The exact formulation of this principle is: the path followed by a light ray to travel from one point to another through whatever medium, is such that makes its optical path approximately equal to other routes immediately adjacent to the effective one. More simply, we can say that to travel from one point to another, light takes the path that requires the minimum possible transit time.

The Mirage Phenomenon

Reflection and refraction are two physical phenomena that form the basis of how we perceive the world.



The laws of mathematics that govern these two phenomena are surprisingly simple and are the basis for geometric optics.

Diffuse reflection

Mixed reflection

Specular reflection

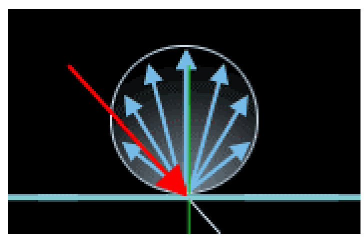
Refraction

Diffuse reflection

In diffuse reflection, contrary to that which arises out of specular reflection, each incident ray is broken up and reflected in every direction, with a spherical distribution which is independent of the direction of the incident ray. Diffuse reflection is obtained with an opaque surface.

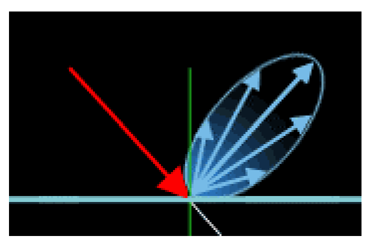
The law of diffuse reflection establishes that the luminous intensity of light reflected from a diffuse surface is at its maximum in the direction perpendicular to the surface, and varies in all directions as a function of the cosine of the angle with the perpendicular.

The law of diffuse reflection is also called the Lambertian law after the physicist Lambert who was the first to define it.



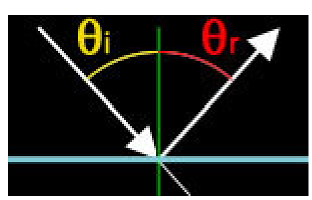
Mixed reflection

Mixed reflection occurs when a specular and a diffuse reflection component are present contemporaneously. The incident ray is broken up in every direction, with a non-spherical distribution (as with diffuse reflection) depending on the direction of the incident ray. Depending on the surface of the material, it is possible to obtain more reflective or diffuse components.



Specular reflection

With specular reflection, for every incident ray that hits a surface, there is only one corresponding reflected ray. We call this the angle of incidence θ_i the angle formed by the ray and the perpendicular to the surface; and the reflection angle θ_r that formed by the perpendicular and the reflected ray. The law of specular reflection states that:

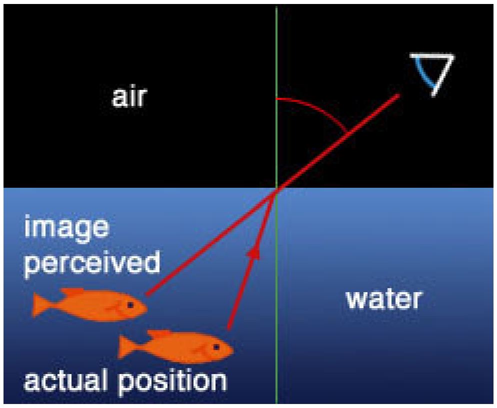


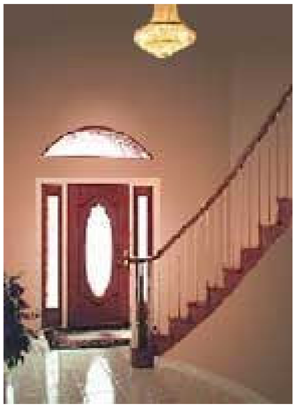
Specular reflection is obtained with smooth and polished surfaces.

1) the angle of reflection is equal to the angle of incidence
2) reflected rays, incident rays and normal rays are on the same plane

Refraction

When a light ray passes from one material to another the radiation changes propagation direction: this phenomenon is known as refraction. The extent of the deviation depends on the difference between the refraction indices of the two materials. This deviation is the reason for which when looking into water we see objects shifted with respect to their actual positions and straight lines seem to be broken. The refraction index of a material depends on the radiation wave length, and this produces the phenomenon of dispersion.

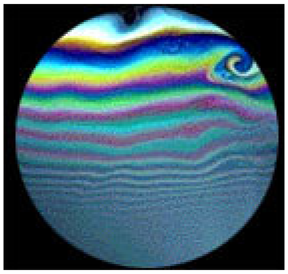




When surfaces are perfectly smooth reflection follows the traditional laws of optic geometry, according to which the angle of incidence is equal to the angle of refraction. However, an irregular surface becomes even more reflective when the angle that it forms with the direction of the source rays is very small.

This type of pleasant lighting effect is often found on walls or floors near to doors or windows. When we find ourselves in front of these surfaces, as with a mosaic, the knowledge of the microscopic structure of the surface lit by the light rays assumes a great importance because the irregularities of the surface itself are often comparable with the wave length of incident radiation and generate lighting effects that can not simply be predicted by the law of specular reflection.

When, under particular conditions, two light rays arrive at the same point the result of their sum may be darkness. This strange behaviour, proves the wave nature of light, and is called inference. This phenomenon is also dependent on the length of the radiation wave. For this reason in a white light beam, only a few colours can be eliminated: this is what happens in a fine layer of oil and soap, or in the reflection of a CD.

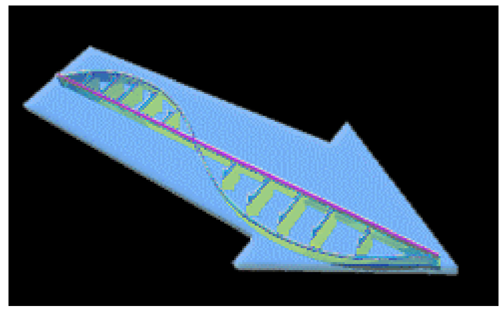


When radiation passes through a material its intensity diminishes and such a reduction becomes more relevant when the material in question is denser. This phenomenon is known as absorption. When light hits molecules, as may occur in the atmosphere, radiation is redirected in all directions. This phenomenon is called scattering and is more evident in shorter wave lengths (like blue) than for colours like red.

The colours of the sky

Light wave vibrations always occur on one plane.

The plane on which this occurs is called the plane of polarisation. If this plane is constant light is polarised linearly. In general, however, natural light changes its polarisation direction continually

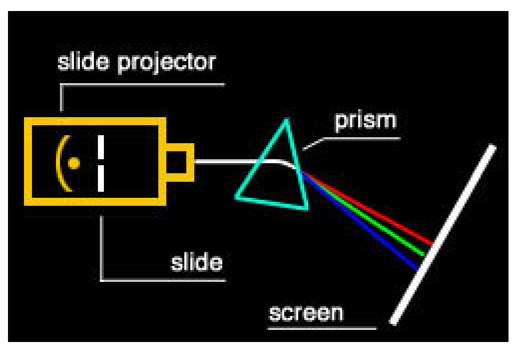


IIn many phenomena, like interference and diffraction, light behaves as if it was made up of waves, while in other cases (almost all the geometric optics) it appears to be made up of particles which are called photons. In reality light behaves at times like a wave and at others like a particle, and this amazing duality, also present in other components of materials like protons, neutrons and electrons, is the basis of quantum mechanics.

Many laws of physics can be verified by means of a few simple experiments. Let's look at how to produce a continuous spectrum.

Equipment necessary:
A slide projector
A slide frame into which a black cardboard crack of 1mm is inserted.
A glass prism, or a triangular glass basin full of water.
A white screen

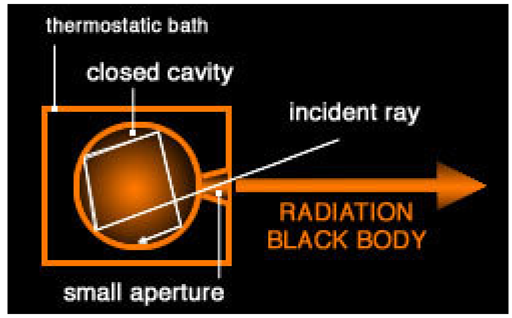
Description:
The image of the crack must be projected on the prism which will produce the spectrum on the screen a few metres away.



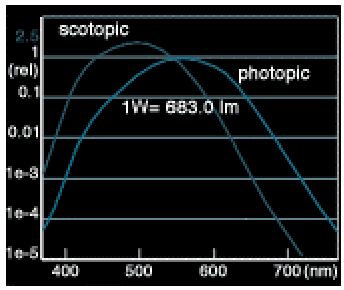
Observing the spectrum with a basin of water

Creating a rainbow

Radiometry measures the energy associated with radiation. Light radiation transports energy, it is in fact able to warm the bodies with which it comes into contact, producing an increase in kinetic energy of the atoms. In order to measure the energy transported by a beam of radiation, we direct it onto a "blackbody" i.e. a body able to absorb all the radiation it receives. If it is possible to measure the temperature of the body in question, from the variance of this quantity it is possible to ascertain the energy absorbed by the body.



Photometry measures light from the point of view of our visual system. It must therefore take into account that our eyes are not equally sensitive to all wavelengths, given that we see yellow-green far better than red and blue.

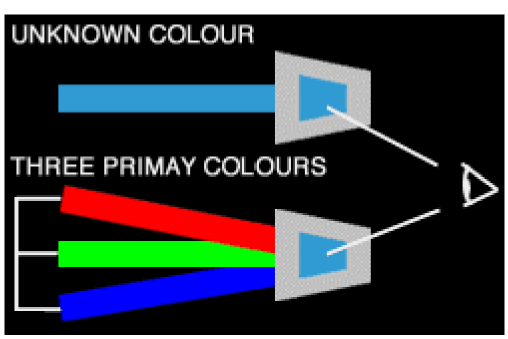


The following are the principle photometric measurements:

Measurements	Symbol	Unit of measurement	Abbreviation
Luminous flux	Φ	lumen	lm
Illuminance	E	lux	lx
Luminous intensity	I	candela	cd
Luminance	L	candela per mq.	cd/mq

When we want to change the emission spectrum of a lamp we do this by placing a filter in front of the source, that is an object which is able to eliminate certain wave lengths. Filters may be based on light absorption (absorbents) or on the physical principle of interference (interferentials). Their usefulness is obvious, given that they may be used to eliminate UV radiation emitted from a lamp or to change the colour temperature of a source, in order to emphasise certain colours or details.

Measuring colour is not a simple issue, given that it is not possible to find a physical instrument able to match the capacity of the eye.
The first colorimetric measurements were in fact carried out using our eyes as "zero



detectors": an instrument, that is able to indicate when two colours are equal.

Additive synthesis

Subtractive synthesis

It is important to observe the historical development that colour and light have undergone in the course of the centuries in the artistic arena. Knowledge of materials and techniques used by artists throughout the years allows us to increase our understanding regarding the best ways of preventing damage from occurring to museum pieces.

The understanding of colour and light can help to present a work of art in a manner which is more responsive to the desires of the artist, without the need for excess philology or the risk of being anachronistic.

The colour of ancient

Colour in the Middle A

Oil painting

Synthetic pigments

1800s: study of colour

Today

The colour of ancient Greece and Rome

Often, the idea that we have of ancient art does not correspond to the facts. A glaring example is that regarding the use of colour. Our idea corresponds to a past in black and white with severe white statues. In reality colour certainly plays a fundamental part not only in wall paintings and mosaics but also in statues and reliefs. In Roman times the fresco assumed a great importance.

Vitruvio in *De Architectura* described it precisely, helping us to understand that plaster painting is a process involving the blending of fresh lime and sand which, when dry, fixes the colours.

In Roman paintings, the majority of the pigments used were of mineral origin. Yellows, reds, dark colours and certain greens were obtained by settling, and at times calcinations of natural earths containing various metal oxides. Others have vegetable origins for example some pinks; black was often obtained using bones and wood. Others were manufactured artificially, vermilion red or blue, starting from a base of minerals containing rare metals. The red vermilion which produces the hottest and brightest red is unfortunately not a stable colour and has therefore created conservation problems since Roman times.

Vitruvio says: "When vermilion is applied to the plaster of enclosed halls, it conserves its colour without alterations. But in open areas, for instance in the peristyles or exedras, when an vermilion painted area is penetrated by the sun's or moon's rays, the colour is altered and in losing its properties becomes black" (Vitruvio, De Architectura, VII, 9.2). This is the one of the first historical descriptions of what has become known as the photochemical effect. The remedy, suggested by Vitruvio, was that of plastering the colour with a layer of fused wax.

Walls painted in Roman times may seem overly vivacious and often even crude, but we must not forget that daylight was limited, with small openings and doors which opened onto interior courtyards, and that the artificial lighting of oil lamps was scarce. Light vibration was therefore particular and due to sparse furnishings, floors, walls and ceilings took on a more important role.

Colour in the Middle Ages

One of the most important sources on the composition of colour in the Middle Ages, and from which to return to the best method of protection, is certainly *Il Libro dell'Arte* by Cennino Cennini. In this book the principle techniques used for frescos and tempera are described.

The colours available to artists of the era were those obtainable with the mix of the available pigments. The preparation of pigment could be based on many natural or artificial substances. Some colours were easily available and economical, but others were extremely rare and very expensive. A costly example would certainly be the famous ultramarine blue - so called as it was found only in Afghanistan - which was extracted from lapis lazuli and at the time more expensive than gold.

In the late Middle Ages such colours were reserved for the Virgin Mary's mantle, and their use was described separately in the contract signed by the painter. Red could often be obtained with vermilion or with red lacquer which, however, is extremely sensitive to light and can change colour completely if erroneously exposed to light.

In the *Incoronazione della Vergine* by Lorenzo Monaco, the altar piece executed by the artist for the church of the Santa Maria degli Angeli convent in Florence, the Virgin's mantle was originally a deep mauve which now appears to be white.

It is important to note that the medieval painters were also extremely knowledgeable with regard to the pigments which they used and were always on the lookout for new substances. The altar piece of the church of Santa Croce in Florence, by Ugolino di Nerio, would be an apt example as the artist chose to make use of azurite instead of ultramarine, because of its particular greenish tone.

Cennini also speaks of *cangiantismo*, the choice of colours possessing properties which change in appearance according to the amount of light with which they come into contact. It is clear that the aspect of lighting was anything but secondary for medieval painters.
Another text of definite interest for those wanting to know more on the use of pigments utilised in tempera, is *Della Pittura* by Leon Battista Alberti which studies in depth and develops many of Cennini's themes.

Oil painting

The introduction of oil painting, in the first half of the 1400s, was an significant event for painting itself as well as for the protection of works of art. This innovation was immediately disseminated throughout Northern Europe, even though recent analysis has confirmed that the Dutch painters of 1420, Van Eyck and Campin, continued to use a tempera background turning to oils only for the final part of the painting.

Oil painting gradually began to establish itself in Italy. For those studying the protection of art works, compositions arising out of the Venetian school of the 16th century certainly have a prominent place of importance. Venice was in fact the principle commercial point of the era, which in turn enabled its artists to procure all the known pigments of that time.
Incredulità di San Tommaso, painted by Cima di Conegliano in 1500, contains practically all the known pigments of the day. The artist succeeded in using only one colour more than once in this work.

The expert in the use of colour was probably Tiziano. In *Bacco and Arianna* the Venetian master made use of the purest ultramarine blue of all the paintings examined by the National Gallery in London.

Synthetic pigments

From the point of view of an art historian and the protection of museum pieces, a year of definite importance would be 1704, in which the first synthetic pigment, Prussian blue, was created. Prussian blue soon substituted many natural pigments and by 1720 Canaletto had already used such colours for his paintings.

It was however the first thirty years of the 1800s that brought about a real growth in the creation of synthetic pigments thanks to the discovery of cobalt, chrome, cadmium and the synthesis of an artificial ultramarine blue. The creation of these colours, and the ability to preserve them in tubes, allowed for an ease of painting outdoors thus contributing to a decisive change in the history of art.

The Impressionists were among the principle innovators of painting. Up until this point, most painted works had been created in the studio, now the light of open spaces began to take on a prominent importance and it was not by chance that the Impressionists were among the first to communicate a concern for the lighting utilised in exhibiting their work.

1800s: study of colour and illumination

During the 1800s artists began to understand the importance of accurate lighting studies as well as human perception of colour, and that only an in-depth understanding of this topic could allow for the display of painted works in manner which would make for their best possible fulfilment.

One of the foremost scholars in this area was the French Chemist Michel Eugene Chevreul, director of the dyeworks at Gobelins upholsterer in Paris and author of numerous studies on colour, such as his paper on successive and simultaneous contrasting colours. Chevreul also dedicated time to the study of frames which, up to that point had never been considered important. Chevreul also recommended the careful analysis of lighting conditions in which paintings are exhibited, because the relationship between light tones and dark tones, like tones of white, may vary according to lighting changes.

It was the Impressionists in particular that understood the importance of the exhibiting environment for the full of appreciation of an art work, and who revolutionised the traditional way of presenting paintings. At the first Impressionist exhibition in 1874 evening opening hours allowed for a comparison of the effect of the works lit artificially with that observed in during daylight opening hours. Degas and Van Gogh also dedicated attention to the theme of artificial lighting.

The analysis of environments and light continued into the post-Impressionist period. Seurat in particular, established a technique which has become known as Pointillism - Divisionismo in Italy - dedicating a large amount of attention to colour. Colour in his paintings is not created by mixing diverse substances, but instead obtained with a combination of pure colour points, using a technique which makes use of the additive synthesis of colours in a similar manner to that of a monitor, instead of turning to the traditional subtractive synthesis. According to Seurat this technique allowed for the creation of richer, brighter paintings.

Today

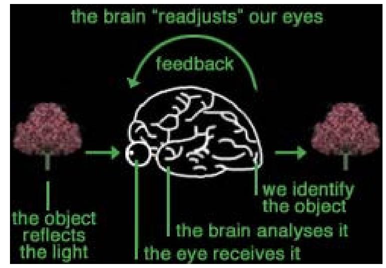
The current abundant availability of new light sources has made the theme of museum lighting even more interesting and it is therefore not easy to choose the most suitable lamp for each artwork. The modern era has also introduced new and extremely problematic issues with regard to the conservation of art works, not only in the use and choice of painting materials but above all in the creation of new and innovative restoration tools.

An issue of extreme importance is in fact represented by the yellowing of certain resins, which in past years had been largely used for the restoration of various paintings. In these cases lighting, rather than being concerned for the conservation of the painting, must prevent the substances being used for restoration from deteriorating, leaving the artwork illegible.

HOME

Light
Vision
The vision process
Physiology of the eye
Theory of vision
Visual acuity
The vision of colour
Distance and perspective
Constancy of shape
Adaptation to the dark
Perception of movement
The psychology of colour
Psychophysical measurements
Optical illusions
Lighting

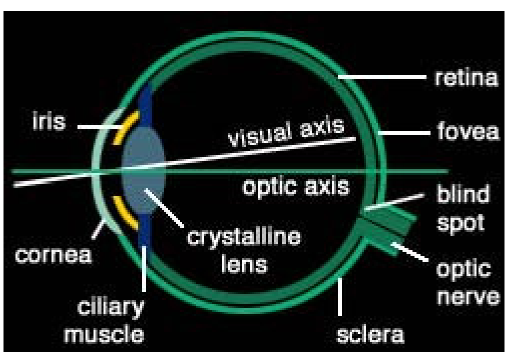
In order for us to see an object it is necessary for a source (the sun, a lamp) to direct its rays onto it, which it then directs, suitably modified, onto the eyes. Such signals are then elaborated by the brain, which subsequently makes a decision, readjusting the image with a retroactive process (feedback). It may, for example, close the pupil if the light is excessive.

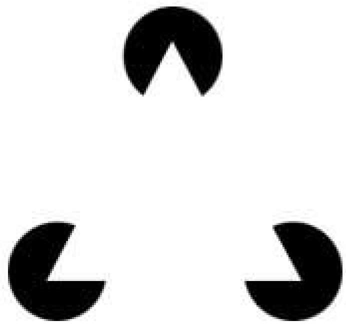


The human eye
The radiation emitted or reflected from objects around us must be received by a well crafted instrument, our eyes, which in turn must select the correct quantity of light and bring images on the retina into focus. Eyes are not simple receivers but also measure radiation according to wavelength by means of their sensitivity.

The retina

The blind spot





In 1935, the psychologist Koffka asked, "Why do things appear the way they appear?"

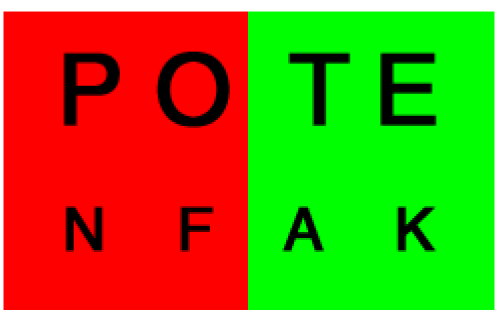
The question is far less banal than it appears to be. Much evidence exists that that which we perceive does not only depend on physical reality, but also on the operation of our brain, and every theory of vision must take this into account.

In the figure we perceive a triangle which is whiter than the background even though there is absolutely no difference.

Visual acuity is the eye's capacity to see the details of objects observed distinctly. In reality this depends on many factors, the differences in contrast between objects, the lighting, the tiredness of the eye and so on. Many people have a visual acuity lower than normal (indicated by twenty-twenty). These defects may also have influenced the work of some of the great artists.

Ametropia

Ametropia and the arts



The vision of colour is a topic that illustrates the complexity of human vision. In fact the appearance of an object's colour does not only depend on the substance that it is composed of but also, for example, on the light which illuminates it. In brief we can say that the colour of an object is given by:

The object itself

The visual system of the observer

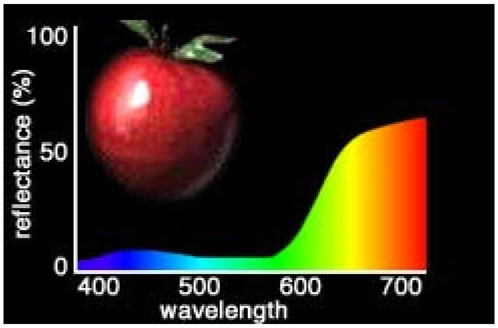
The incident light

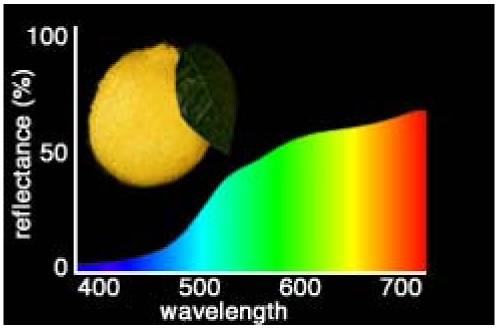
Background differences

The colour of objects

When light hits an object it can either be absorbed by the object itself, pass through and be transmitted or reflected back. For many objects the relative quantity of light absorbed and reflected depends on the length of the wave.

A red object will for example have a reflection spectrum with a peak in the zone of the long wavelength. A substance which absorbs part of the light that hits it and reflects the rest is called pigment.
If some of the visible spectrum's wavelengths are absorbed more than others the object appears coloured.





Visual and colour system

There are two types of photoreceptors in the retina of a human eye: cones, responsible for daylight vision (photopic and mesopic), and rods, used principally for night vision (scotopic).

Colour discrimination occurs in photopic and mesopic vision, indicating that it is an action performed by the cones. There are about 7 million cones and 120 million rods in the human retina although no rods are found in the central area of the retina. A 2nd visual field around the centre of the eye puts only the cones into action. Cones have three photopigment classes.

he retina is in itself a multi-layered structure the complexity of which still remains to be explored thoroughly. The brain analyses the signals that arrive, giving rise to phenomena such as constancy of colour, subjective colours, successive colour contrast.

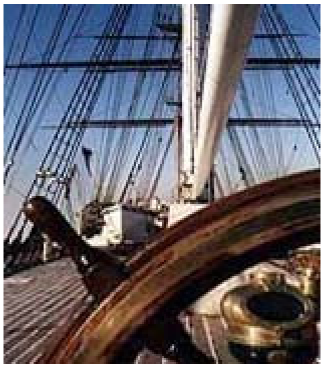
Not everyone sees colours in the same way. Certain people in particular suffer from abnormalities relating to their vision of colour which are diagnosable by testing.

Incident light

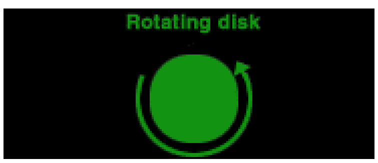
The colour of an object depends on the radiation that is directed onto it. In fact, if a magenta object (magenta is the colour obtained by combined red and blue) is hit by white radiation, which contains all the colours, it will reflect red and blue. But if the source that illuminates it does not contain blue, the object can not reflect it and will therefore assume a red appearance. In any case, it is always necessary to take into accoun constancy of colour.

The perception of distance, i.e. the capacity to understand from a scene which elements are closer and which are further away, is a situation in which the role of the brain is extremely important. The two dimensional image which arrives on the retina, would not be enough to explain if the reduced dimensions of an object correspond to an object which is near and small or far and big. Such an operation is very simple: in the photo on the side everyone understands which objects are near and which are further away.

This occurs thanks to binocular vision and parallax.



Our brains are able to constantly maintain the perception an object's shape when the retinal image changes: it is that which is called constancy of form. For example when a disk turns in front of us its image on the retina becomes elliptical. We nevertheless continue to recognise its circular shape.



When on a bright afternoon we enter into a dark movie theatre, for example, initially the only things we able to distinguish are the images on the screen. However, after a few minutes, we are able to see the person sitting next to us and after about twenty minutes we will be able to see the inside of the theatre.
This phenomenon is called adaptation to the dark and it is particularly evident with the stars.

The function of cones and rods

In order to understand the phenomenon of adaptation to the dark it is necessary to understand that rods and cones behave in completely different ways. Cones, which are found mainly in the centre of the retina, are able to collect the particulars of images and to recognise colours, but work only in conditions of strong lighting.

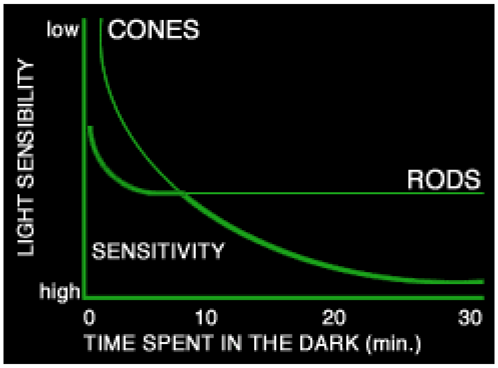
At first as we step outside under a starry sky we see very few stars and those that we do see are extremely dim. After a few minutes we start to see more and more and finally after a period of 20 or 30 minutes, in a reasonably isolated area, we are able to see millions of stars.

The function of cones and rods

Rods do not see colour but are extremely sensitive to light and movement and work under low lighting conditions. The time needed for rods to go into operation is however longer than that of the cones. This is the reason that when we consider the minimum quantity of light that we are able to perceive in relation to the time spent in the dark, an abrupt improvement occurs when we pass from cones to rods.

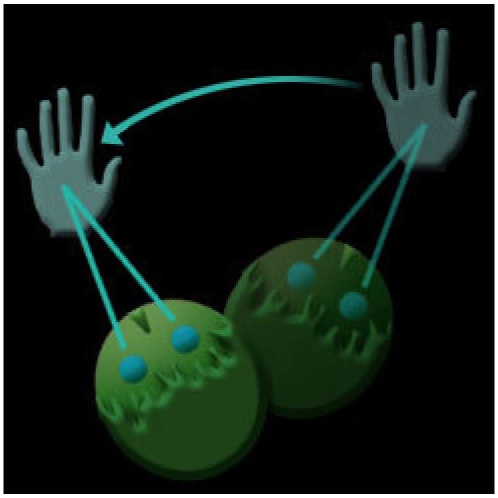
This could explain the slow appearance of the stars as described by Dante in *Paradiso*.

And as at rise of early eve begin
Along the welkin new appearances,



So that the sight seems real and unreal,

It seemed to me that new subsistences Began there to be seen, and make a circle Outside the other two circumferences. (par. XIV 70-75)



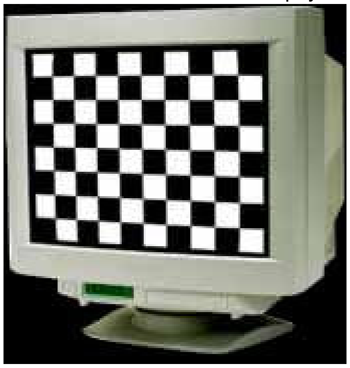
If we move a hand from right to left, keeping our heads still and moving only our eyes, the retinal image of the hand will not change and only the background will vary.
Even if we keep our eyes still and turn our heads at the same speed as the hand the retinal image of our limb will remain unchanged. Nevertheless all of us will perceive the movement.

This ability of the brain to recognise what is really moving is called "constancy of movement".

The psychological effect of colour is a theme which has been extensively debated, and which has not yet reached a definite conclusion or one accepted by everyone.
The psychologist Hermann Rorschach, inventor of the blotch method, in 1921 introduced a coloured figure in order to investigate specifically the human emotional aspect. It is of course difficult to establish which aspects of colour are inherent in the human mind and which are the results of cultural evolution.
Between different nations there are also enormous differences in use of colour: in China and Japan white is the colour of mourning even though a Japanese bride marries in white symbolising the death of the old family unit.

In order to evaluate the behaviour of a light source it is not sufficient to analyse technical characteristics measurable with instruments. It is in fact very important to evaluate the effect that such a source has on human vision. This can be observed only by implementing psychophysical measurements, i.e. measurements which use human patients and take into consideration their answers to various visual stimuli and the light source considered.

It has recently become increasingly more apparent that the computer monitor is used as a generator of psychophysical stimuli.



The complexity of our visual system leads to a series of strange problems that are not always easily explainable: let's take a look at some optical effects which often have interesting scientific implications. To start with observe the diagram on the right: you should be able to identify two different

forms.

Impossible shapes

Reversible perspective

Shadow

The term "light source" usually refers to a device able to emit energy radiations of a wavelength within the visible region (380-780 nm) of the electromagnetic spectrum. Attached to this expression we often find another adjective, essentially referring to the essence of the emission: we often hear talk of "natural" sources - or rather those present in nature, mainly the sun - or "artificial" sources, those - from candles to fluorescent tubes - which exist due to the actions of man.
A wide range of artificial sources are available which are the basic instruments of the science of lighting. The importance and significance of their selection has become one of the pivotal issues surrounding lighting design. Making use of an artistic analogy, we can say that a light source is to a lighting design project what colours are to a painting: varying in type, nature, technique, design, virtuosity, and assembly, but their linguistic content remains intact.

The evolution of the light source

For a long time man's relationship with darkness was largely defined by the use of fire, in the form of lanterns, oil lamps, torches and candles.

Over the centuries, its use was connected to the available resources of the time; the flame was generally powered by fat - animal or vegetable - or bee's wax, available in a solid or liquid form.
Up until the first half of the 19th century, oil lamps were most widely used, their main combustive agent being rape or whale oil.
In the second part of the century, studies, discoveries and inventions contributed to the widespread use of gas and subsequently electricity.

The use of gas put forward a series of problems mainly connected to the safety and quality of lighting limited by the shape and properties of the fixtures.
The application of such systems allows for lighting in many cities, forever changing the way of life of their inhabitants by making the night a supplementary part of their day.

source, characterised by its improved performance in relation to life span, quantity and quality of radiation.

In 1910, different types of sources appeared on the market which were no longer based on the traditional functional methods, but on the basis of high voltage discharge through gas. Initially, they were mainly used for luminous signs and subsequently for street and industrial use (low pressure sodium vapour lamps, 1932; mercury vapour lamps, 1935; high pressure sodium vapour lamps, 1965). This technology was subject to further studies and applications, which substantially increased performance characteristics and above all the chromatic quality culminating in the white light high pressure sodium vapour lamp (1993).

The diffusion of the tubular fluorescent lamp, which began in 1936, due to its efficacy and chromatic variety, noted a marked increase after the second world war. The technology was in time integrated with improvements relating to the composition of the fluorescent mix and the methodology of the operative system.

In the 1980s, as a contribution to the energy crisis, fluorescent compact lamps were introduced onto the market, initially conceived as alternatives to the traditional sources for interior lighting.

In the 1960s, a new type of discharge source was developed, metal halide lamps, based on the introduction in the discharge tube of small quantities of metal halide vapour. Initially used for lighting of sports complexes, these sources have also been modified over time improving qualitative and quantitative performance.

Finally, in the 1990s induction lamps made their appearance on the market, based on the principles of electromagnetic induction and characterised by exceptionally long life spans.

Types of light sources

Artificial sources can largely be divided into two groups, according to their functional principles.

Filament lamps, which correspond to the most ancient practical applications of electricity. The current passes through a spiral tungsten filament placed inside a glass bulb, which contains inert gas or a vacuum; the filament heats up quickly and becomes incandescent, emitting an optimal luminous flux of around 2500-2700℃.

In discharge lamps, luminous flux is produced by exciting a gas; this process is stimulated by a strong electric discharge and must be operated with auxiliary devices. The current is applied to two electrodes placed in a transparent body containing gas; at certain critical value, the electrical arc is triggered between them inducing the ionisation of the gas atoms which, in the course of the process, discharge the energy in the form of visible, ultraviolet and infrared radiation.

The possibility of having a wide range of lamps requires the knowledge of some practical aspects, able to "guide" the identification, the choice and the more desirable characteristics of the different types.

No one specific source exists which is adapted absolutely and unambiguously to a determined use. Lamps are the language with which light expresses itself in each individual case and for each specific need. Their use, together with the choice of the fixture and its location, determines and defines the outcome of a lighting project in a substantial way. This also is due to light's great capacity to engage emotionally and psychologically.

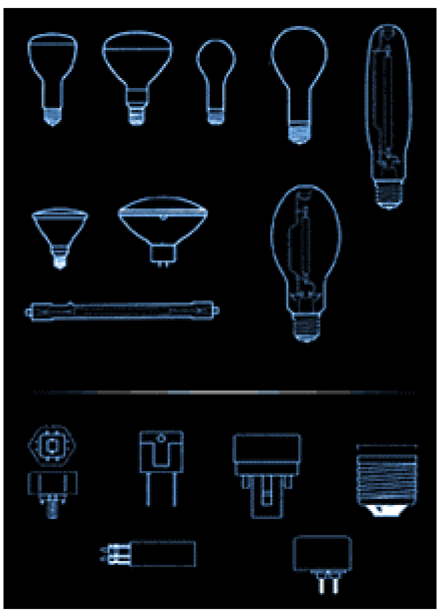
Geometric characteristics: shape, dimensions and base

Electrical characteristics: voltage and power

General characteristics: lamp life, operating characteristics and auxiliary devices

Geometric characteristics: shape, dimensions and base

Light sources are generally made up of emission devices - which vary widely in terms of shape, dimension and coating depending on the type - and a base system, which - by means of the lamp holder present on every fixture - assures entrance and transmission of electrical current inside the lamp. On-going studies and research have contributed to an ever growing movement towards more compact and smaller sources, increasing ease of use, control and resistance



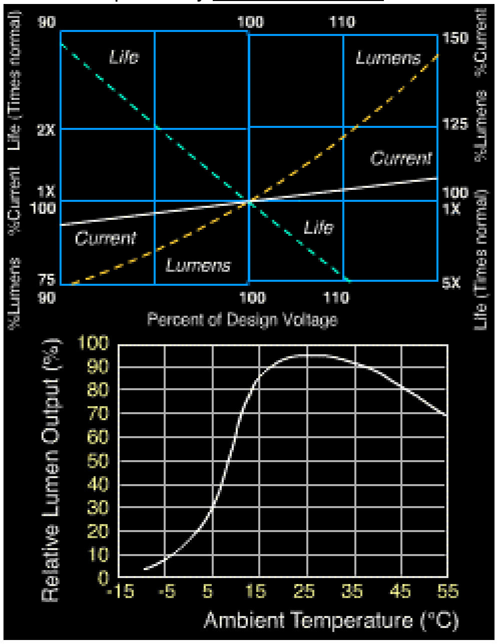
noticeable effects on the chromatic coordinates of the emission modifying the spectral power distribution.

The power of a lamp, expressed in Watt, represents the quantity of electrical energy absorbed by the source itself in operating conditions.
The Lamps currently present on the market vary widely in terms of energy consumption.

General characteristics: lamp life, operating characteristics and auxiliary devices

The life of a lamp, expressed in hours, is determined by a series of parameters, in part connected to the intrinsic characteristics of the source and in part to external forces and the type of use to which it is subjected to. Operating characteristics are largely connected to lamp starting (activation and reactivation), lamp operating position and ambient temperature.

The term "auxiliary device" usually refers to a piece of equipment necessary to the functioning of a source.
In the same way as a very low voltage lamp, for example, can not function without the aid of a transformer, the use of all electric discharge lamps must be accompanied by electronic ballasts.



Quantitative characteristics: luminous flux and efficacy

The luminous flux of a lamp defines the effective quantity of light produced by the source itself per second and is expressed in lumen.
The evaluation of the flux is controlled by well defined norms - according to the strength and the type - and varies within a wide scale of values.

The efficacy of a lamp indicates the luminous flux emitted by a source in relation to the electrical power used and is expressed in lumen per watt.
If you consider the luminous spectral efficiency curve - which plots the eye's sensitivity to individual wavelengths of light - the maximum possible

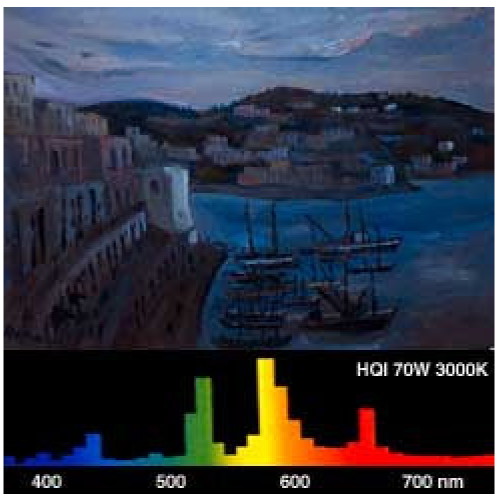
luminous efficacy which occurs at 550 nm is 683 lumen per watt (LPW). This is a theoretical value: in reality light sources actually reach much more contained values (filament sources, between 10 and 35 lumen/watt; discharge sources from 19 to 183 lumen/watt).

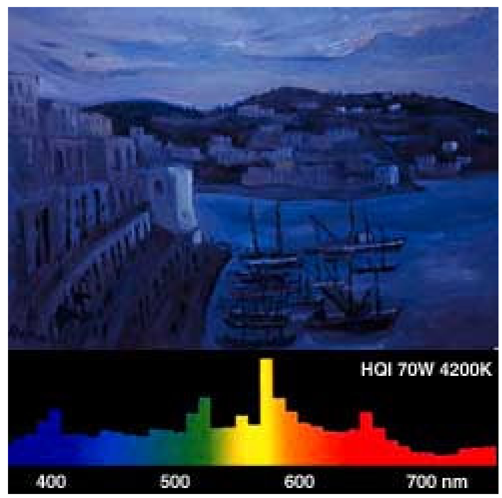
Qualitative characteristics:
colour temperature, colour rendering index and spectral power distribution

The quality and colour of a lamp are generally defined by the chromatic appearance and colour rendering.
Chromatic appearance refers to the colour of the source itself and it is quantified by the chromatic coordinates and the colour temperature.
Colour rendering indicates the way in which pigments appear to the human eye when they are lit by a specific type of lamp, and it is quantified by the colour rendering index.

Other than these parameters, it is opportune to consider the spectral power distribution which describes and quantifies the radiations in relation to a single band of colour.

Sources with similar colour temperatures and good colour rendering can in fact be characterised by very diverse spectral distribution, varying in a manner evident in the perception of colour in any object.



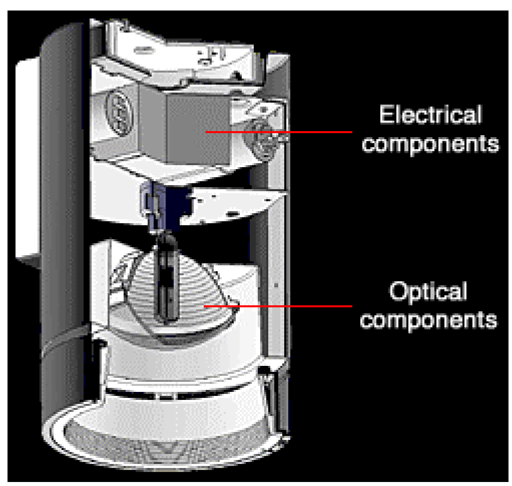


A lighting fixture is a "machine" who's role it is to direct the light emitted from one or more lamps and to distribute it in the most appropriate way for a certain function. In a lighting fixture it is always possible to identify:

- **electrical components**, necessary to power the lamp and thereby "produce" the light
- **optical components**, designed to deviate, filter, reflect, screen or diffuse the light emitted from the lamp.

The optical components can be classified in the following way:

- Reflectors
- Refractors and Lenses
- Diffusers
- Screens



Technical and decorative luminaires

Technical and decorative luminaires

A lighting fixture may be conceived to resolve a mere decorative function or to respond to precise technical lighting requirements. The former are predominately objects of aesthetics and design rather than those which produce light. The luminous emission of such a fixture is usually able to create a comfortable and pleasing luminous effect but not to respond to precise requirements. Technical fixtures, however, are conceived to resolve specific technical lighting needs, relative to a particular type of ambient and activity. In this case the luminaire's output characteristics take on particular importance.

The distinction between technical and decorative fixtures is often very subtle: in the current industrial production technical fixtures very often have considerable aesthetic content, and decorative fixtures are designed to serve specific functions.

The output characteristics of luminaires describe the way in which a lighting fixture performs its main function, that of distributing luminous flux emitted from the lamp in a space. Among the most important parameters for evaluation a lighting fixture, is the way in which it distributes luminous intensity in a space. Usually, the distribution of luminous intensity in a space is represented graphically by means of a photometric curve or three dimensionally with a photometric solid. The photometric curve represents the principle identity card of a fixture: through its careful analysis it is possible to evaluate whether a fixture responds adequately to the role for which it was designed.

It is possible to classify the fixtures according to light distribution, and therefore by their photometric curve. Another parameter often used for classification of fixtures is the beam angle. Finally, evaluating the efficiency of a fixture is also very important.

Light distribution

Asymmetric distribution

Batwing lighting fixture

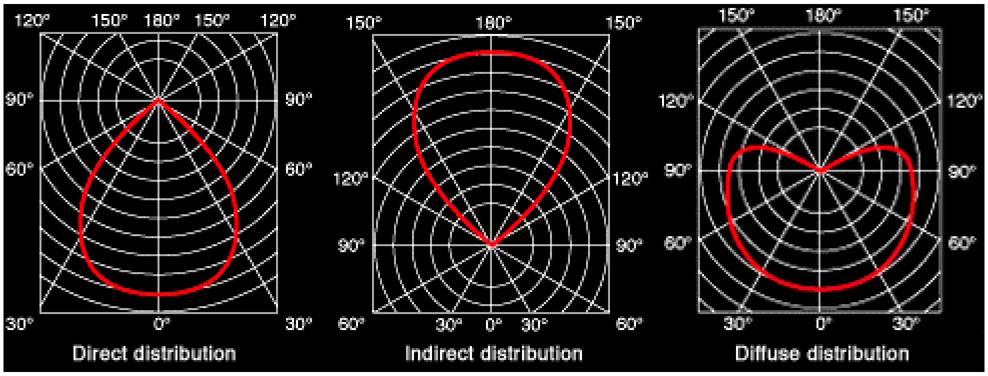
Darklight lighting fixture

BAP lighting fixture

Light distribution

It is possible to classify luminaires according to light distribution. This classification is based on the ratio of upper to lower hemispherical flux of the fitting.
Let us imagine a luminaire suspended with its axis vertical above the horizontal surface to be illuminated (the working plane). If the luminaire radiates the whole of its luminous flux in the lower hemisphere it will fall directly upon the working plane; this method of lighting is termed direct lighting and the luminaire is a direct lighting luminaire.

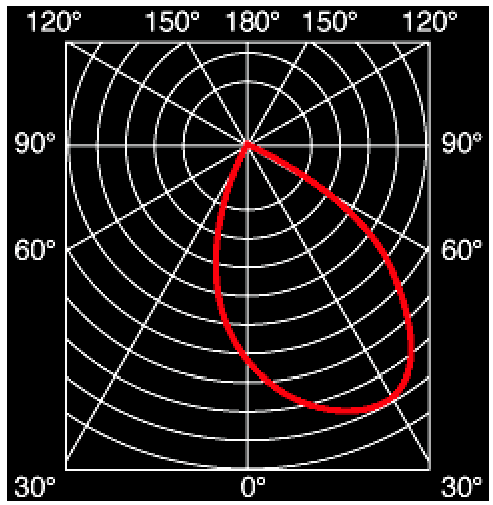
If the luminaire emits the whole of the flux in the upper hemisphere, the working plane receives only light reflected from the ceiling and walls, and none directly from the luminaries. This is called indirect lighting and the luminaire is an indirect-lighting luminaire. Between these two extremes the working plane may be lit in part directly and in part indirectly and, according to the mode of radiation either more direct or more indirect, we therefore speak of semi-direct and semi-indirect lighting and luminaries.



Direct distribution Indirect distribution Diffuse distribution

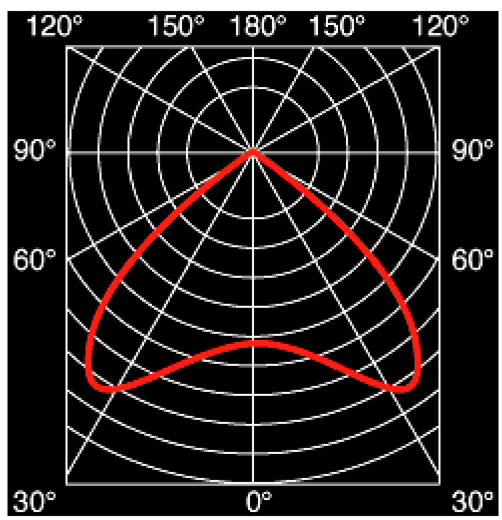
Asymmetric distribution

Asymmetric distribution is present when the luminous flux is directed in a predetermined direction asymmetric to the vertical axis of the lighting fixture. This can be the case for example with indirect-lighting fixtures mounted on walls, for which it is necessary to direct the flux mainly towards the central part of the ceiling. A particular category of asymmetric fixtures is called wall-washers which, installed on the ceiling, are designed to illuminate the vertical surface of the wall.



Batwing lighting fixture

Batwing lighting fixture takes its name from the shape typical of its photometric curve. It is widely used in working environments, schools and offices for limiting undesirable reflection. It is characterised by the fact that it projects the majority of the flux laterally rather than vertically. This allows for lateral placement of fixtures with respect to the work area instead of vertically above the area. Because specular surfaces reflect light symmetrically with respect to incident light, this behaviour means that reflected light (produced for example by a glossy paper surface) is projected laterally and doesn't come into contact with the eye of the observer.

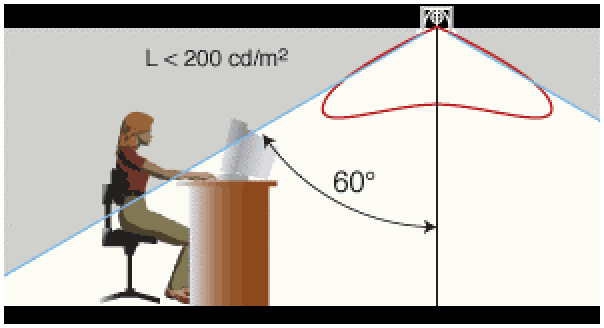


Darklight lighting fixture

Darklight lighting fixtures are characterized by a

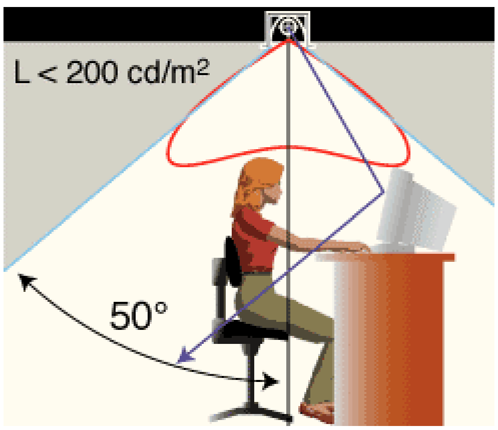
The resulting distribution of light is very relaxing as luminance less than 200 cd/m2 if we consider angles greater than 60° with respect to the vertical axis. A darklight lighting fixture, installed in a ceiling and observed from the normal visual angle of the observer, appears "dark" because the luminance relative to the observation angle is very low.

it limits glare to the maximum: the observer is in fact never directly hit by high luminance. It is also used in the working environment with video terminals, because it reduces the luminance of the reflection produced by the surface of the monitor. BAP lighting fixtures are also highly adapted to the latter role.



BAP lighting fixture

BAP lighting fixtures are characterized by a luminance less than 200 cd/m2 if we consider angles greater than 50° with respect to the vertical axis. The objective is too concentrate the emission in a narrow angle, the lateral luminance limiting to the maximum in such a way that the fixture, observed from a normal visual angle, appears "dark". The criteria is analogous to that used in darklight fixtures, but with an even narrower angle. This type of emission is particularly adapted to lighting of working environments equipped with video terminals. The surface of the video is high reflective with specular behaviour. The majority of the flux is channelled within a narrow angle and is therefore reflected downwards by the monitor and does not arrive on the eye of the observer.



Lighting design involves the conception of a lighting scenario and the identification of the type, characteristics, quantity and positioning of all the apparatus which must contribute to its creation: lighting fixtures, lamps, accessories, power supplies, filters, louvers, screens, regulation and control systems etc.

Up until fairly recently, lighting design was seen as a mere instrument necessary to guarantee the functionality of an environment. Most textbooks spoke almost exclusively of lighting connected to an activity (mainly work related) which had to be carried out in a certain environment, as if outside of strictly functional environments there was not as much need for lighting design.

A more creative dimension to lighting design has only recently been explored, in which functional needs have become integrated with architectural, expressive and creative objectives.

In other words, light is becoming increasingly more used as a material at the disposal of architects for defining a space, emphasising volume, creating atmosphere, transmitting a message and communication sensations. This has contributed to the birth of a new profession, which is no longer strictly connected to the cold application of predefined rules, but which integrates technical and creative competencies and, above all, interacts, alongside other professionals involved in the design process.

As lighting always has something to do, in one way or another, with a built environment, we could say that it is always architectural. In practise, we speak of architectural lighting when the need to "display" architecture or to contribute to creating it becomes dominant compared to that of a mere functional guarantee of the execution of an activity.

In modern architecture, the lighting designer works in strict collaboration with the architect, and together they identify solutions coherent with the total impact which the structure will have. In this case the lighting "objects" (the fixtures) are of great importance for their aesthetic value as well as the lighting effects which they produce.

On the contrary, projects involving historical structures require careful, harmonious interventions so as to avoid interpretations which contrast with the spirit of the original architecture. In this case we tend to make lighting objects disappear, hiding them as much as possible allowing the light to speak alone.

In the lighting of a working environment, functional and performance aspects are of great importance. It is above all necessary to guarantee adequate illuminance according to the requirements connected to the type of activity which must be carried out in the environment.
It is also necessary to guarantee the correct luminance's and reduction of glare.

Illuminance recommendations

Luminance balance

Glare control

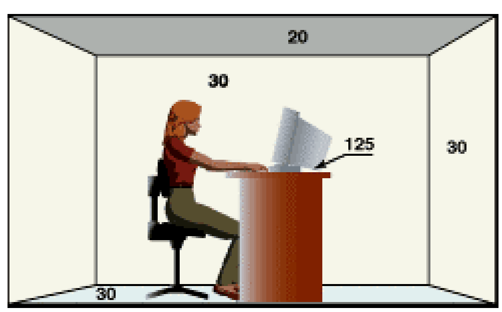
Illuminance recommendations

The tables which follow summarise the illuminance recommendations for various activities, extracted from regulations and recommendations currently in use. Normally, the values are not expressed as single figures but as a range within which one can operate according to the specific conditions.

min	med	max	Type of activity
20	30	50	External areas adjacent to entrances
50	75	100	Transit areas or for stays of brief periods
100	150	200	Occasional work; deposit areas; atria, corridors, stairs, coat checks
150	200	300	Occasional work in automated industry
200	300	500	Work with basic visual needs; roughly done machine work; auditoriums
300	500	750	Work with medium visual needs; machine tools, check points, offices
500	750	1000	Work with high visual needs; sewing, inspection and material testing; design halls
750	1000	1500	Visual tasks with fine details: work with delicate machinery; colour examination
1000	1500	2000	Visual tasks with special requirements: hand engraving; very precise work verification
	> 2000		Visual tasks of exceptional difficulty: assembling of miniature electronic components; surgical interventions

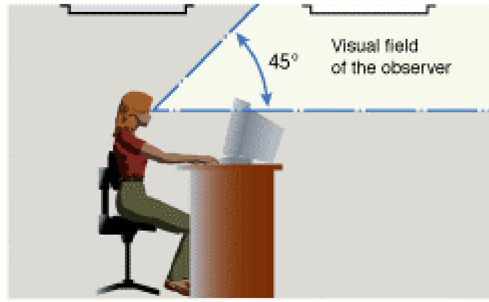
Luminance balance

In working environment is necessary to obtain the appropriate level of luminance contrast between the total visual field of the observer and the visual task so that, when he looks up he is not continuously constrained to adapt his eyes. Normally, the ratio between luminance of the visual task and the total visual field should not be less than 1/3 or more than 3.



Glare control

A important parameter for the lighting of working environments is the reduction of indirect and direct glare. Direct glare is that caused directly by the lighting fixture itself: in order to reduce it is necessary to assure that the fixtures luminance directed towards the observer is reduced as much as possible as with darklight and BAP lighting fixtures.
Indirect glare is that caused by light reflected from specular or partially specular surfaces. To limit glare it is necessary to control veiling reflections.



In commercial lighting, the principle objective is to present merchandise in a way which makes it appealing and thereby promoting its sale. Our Western society, largely based on consumerism, has developed extremely sophisticated techniques for presenting merchandise and the communication of their correlating messages: lighting plays a part in this. The lighting must always be coherent with the type of merchandise and with the image that it wants to transmit. For example, a casual clothing store aimed at a young market, would adopt high illuminance with very cold colour temperatures, generally associated with dynamism, and could even search for moderate glaring effects. All this would be perfectly coherent with a furnishings based on the use of high-tech materials, metal, plastic materials and resolute colours.

On the contrary, a shop selling classic clothing, presumably furnished with warm, traditional materials, would tend to create a more cosy, reassuring atmosphere, using warmer colour temperatures and different luminances - between areas of interest and passage ways or rest areas - and lower levels of lighting.

Lighting of works of art with different lamps can result in noticeable differences from the point of view of colour rendering and protection of the artworks themselves.
For this reason the museum environment is one to which we must pay an enormous amount of attention.

Colour rendering and works of art

Light damage to museum pieces

Colour rendering and works of art

The colour rendering of the lamps used for lighting of museum objects is a factor which determines the perception of the artworks themselves.

We must not forget that the colour rendering index is a quantity which arises from an average of results taken from a limited number of samples and this parameter therefore expresses the overall themselves.

High colour rendering would be used in cases where the paintings contain many colours, while it would be of less importance in the case of monochromatic objects and where the colours do not have particular relevance. Even in these situations though, it is advisable to make use of a light source with good colour rendering in order to obtain acceptable identification of the natural colours of the object.

aptitude of a source to produce natural colours of an object and not the correspondence to some particulars by which the art work could be strongly characterised.

The colour rendering requirements, reported in the glossary, provide a useful reference.

Light damage to museum pieces

We speak of "damage" to museum pieces every time something causes a change in the chemical composition or the physical state of the object itself. The role of conservation is that of slowing this effect as well as all the natural processes which change the organic substance. There are many factors which influence the deterioration of museum pieces.
Among them are the nature of the material which constitutes the object, the nature of the incident radiation, lighting levels, the exhibition period, ambient temperature, humidity of the environment and chemical pollution in the air.

Light is an agent of these changes in the same way as humidity and pollution. But while the latter two can be eradicated, we can not even think about eliminating light as it is necessary for us to study the object.
This situation has paradoxically resulted in the assertion that for many materials the ideal environment for conservation is complete darkness. Correct lighting therefore results in a continuous compromise between the conservation of the object and its value from the point of a view of a museum piece, as well as a compromise between lighting designers and conservationists.

In exterior lighting the luminance returned from a surface takes on more importance than the light which is directed onto it.
Normally activities carried out in exterior environments require lower lighting levels than those of interiors. In addition we must take into account that externally, any surface that is illuminated is observed by the eye against the background of the sky and dark surroundings. Under these circumstances good results can be obtained with low levels i.e. few lux. The luminance returned from the surface is of particular importance which, coming from the lighting, varies according to the reflectance of the material.

We must however take into account that exterior lighting is usually more critical than interior lighting: every error is clearly evident as it lacks the contribution of interferences which in the interior environment usually compensate for a project which is not completely perfect.

There are numerous regulations and recommendations, at national and international level, which contain provisions for strictly technical lighting aspects as well as the electrical safety of lighting fixtures.

The CIE (Commission Internationale Eclairage) is one of the principle international bodies which provides recommendations regarding technical lighting. The recommendations of the CIE are often adopted on a national level and take on regulatory status.

In Italy, the organisations involved in the compilation of regulations regarding lighting are the UNI (Ente Nazionale di Unificazione) and the CEI (Comitato Elettrotecnico Italiano): the former, covers recommendations for all sectors proposing regulations relative to the application of technical lighting, while the latter is involved with regulations regarding electronic aspects, the creation of fixtures and installations only.

The bibliography contains references to the more important UNI regulations relative to the application of technical lighting.