Light and ultraviolet radiation

13:00–15:30
22 September 2015

Light and ultraviolet radiation

Light and ultraviolet radiation comprise one of the ten agents of deterioration considered by conservators

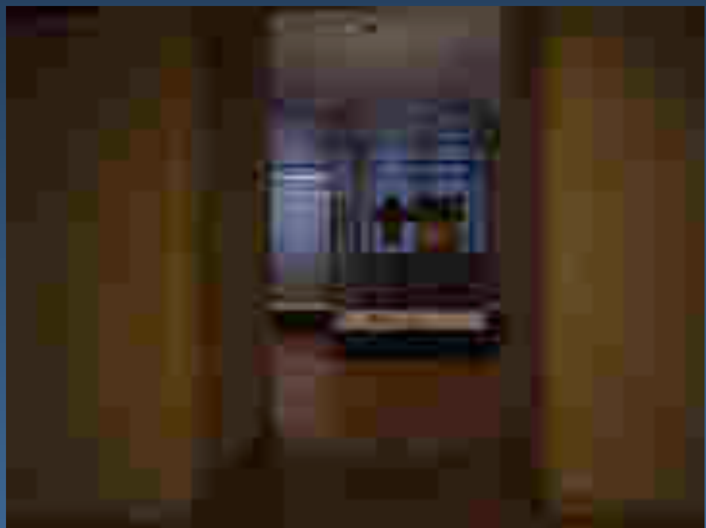
Causes of loss or damage
1. *fire* 2. *water* (e.g. ingress through roof, burst pipes) 3. *criminal action* (e.g. vandalism, stealing)
4. *physical forces* (e.g. vibration, dropping objects, building collapse) 5. *pests*
6. *Light and ultraviolet radiation* 7. *contamination* (e.g. dust, pollution) 8. *incorrect temperature* 9. *incorrect relative humidity*
10. *dissociation* (e.g. unregistered items, incorrect object location)

Light and ultraviolet radiation

However, if one excludes for the moment ultraviolet radiation, light is arguably the only factor that is necessary as well as a potential source of damage

While a museum without floods, fires, pollutants and pests is desirable, a museum without light is redundant

So the need to be able to see and appreciate objects must be balanced against the need to preserve them



Light and ultraviolet radiation

This session will look at:

- Some basic concepts of light and colour, including their measurement
- The damage caused to materials by light
- Setting and maintaining appropriate light levels
- The practicalities of lighting objects to balance display and preservation

Light, radiation and colour

What are light and ultraviolet radiation?

How do we perceive light and colour?

What factors affect colour vision?

How do we categorise colour and colour difference?

What are light and radiation?

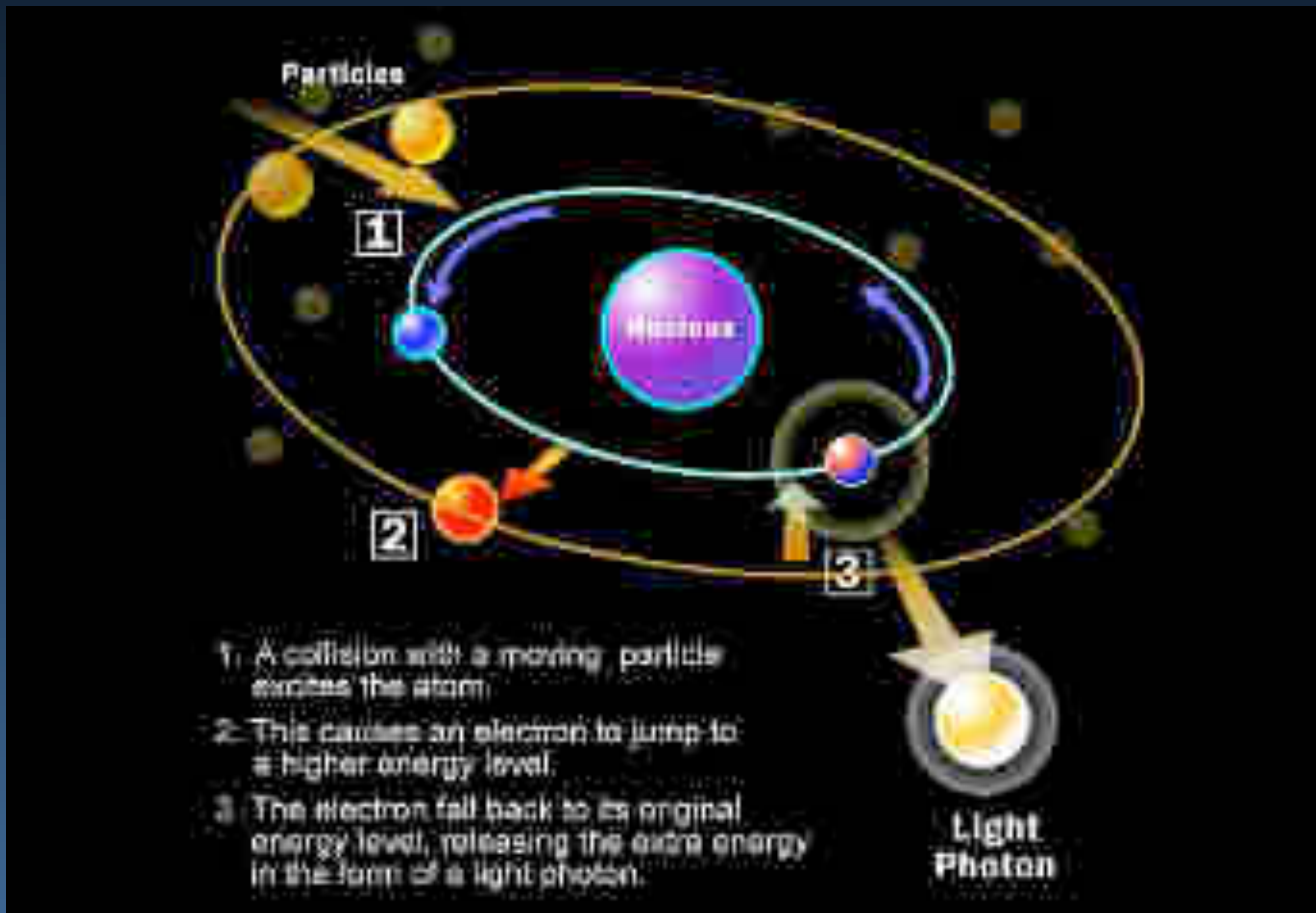
Light is a subset of radiation, characterized by the very human consideration that it is the radiation that we can see with our eyes

Radiation (and thus light) can be thought of either as a 'stream' of light particles (photons) that are emitted from a source, or as a wave propagating from that source

This dual nature of light is at the same time confusing and helpful, as various properties of light are best explained using one of the models

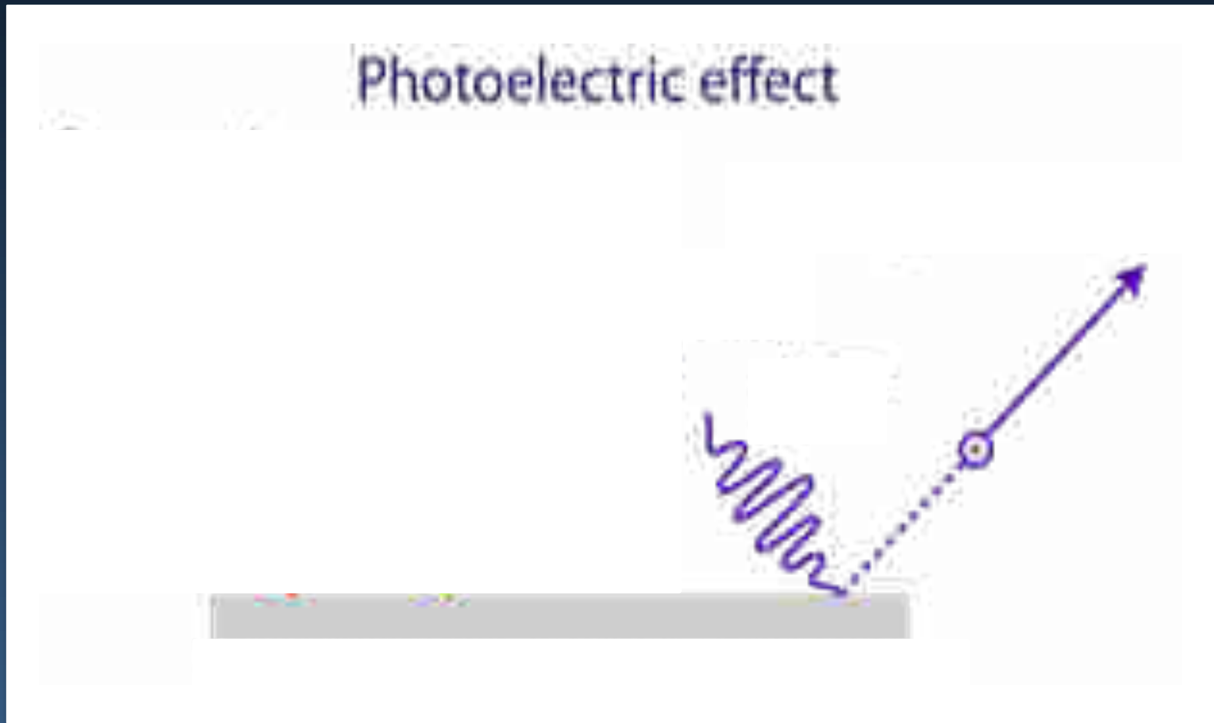
What are light and radiation?

Electrons within an atom excited by an incoming particle or by heating can lose this extra energy, emitting a photon in the process.



What are light and radiation?

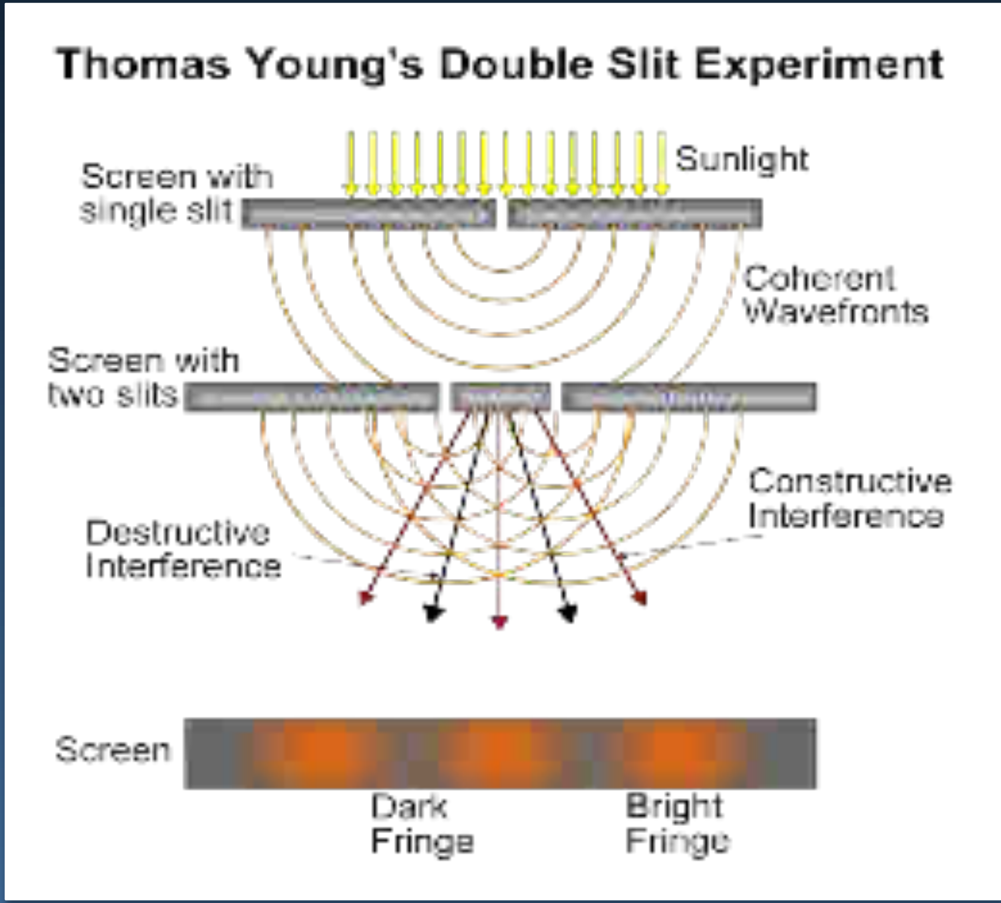
Considering light as photons can help to explain a number of phenomena, not least the photoelectric effect – the emission of an electron from a material following the impact of a photon of light



Einstein's 1905 investigation of the photoelectric effect was one of the key steps in establishing the quantum theories for which he won the 1921 Nobel Prize in physics

What are light and radiation?

The photon theory does not, however, explain other phenomena, such as the interference patterns seen when two beams of light interact – best illustrated by the 'double slit' experiment

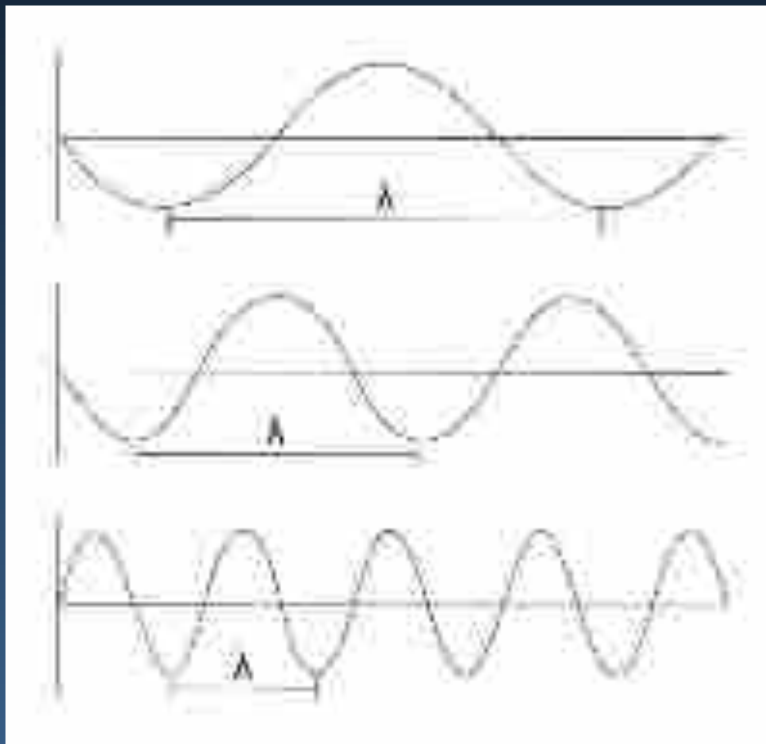


What are light and radiation?

In these circumstances light is behaving more like a wave with the interference pattern reminiscent of the interaction of wavelets or ripples on the surface of water

What are light and radiation?

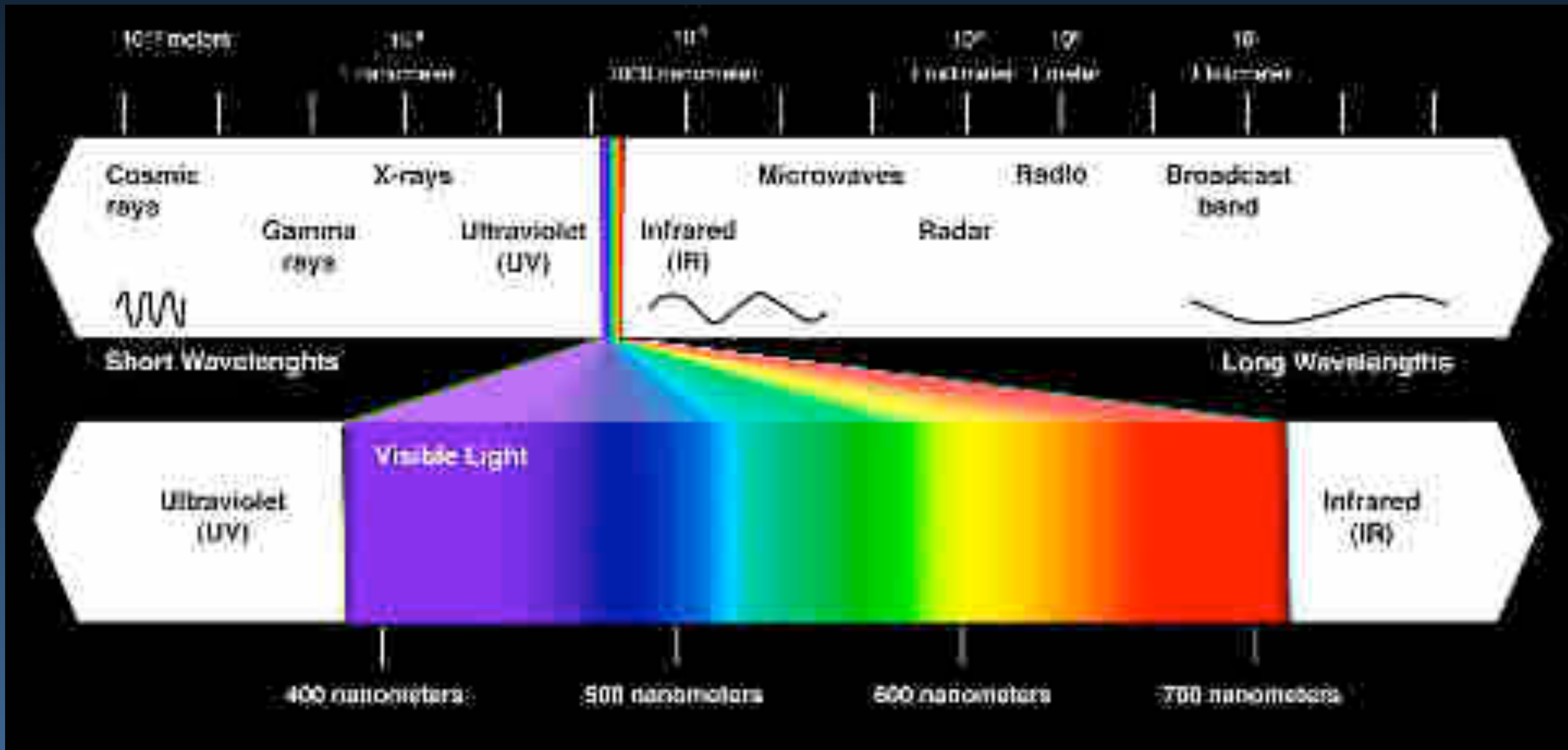
The wave model provides a more tangible representation of the properties of different types of radiation, with these defined in terms of their wavelength – denoted by the Greek character λ



The wavelength is defined as the distance between successive peaks in the waveform

What are light and radiation?

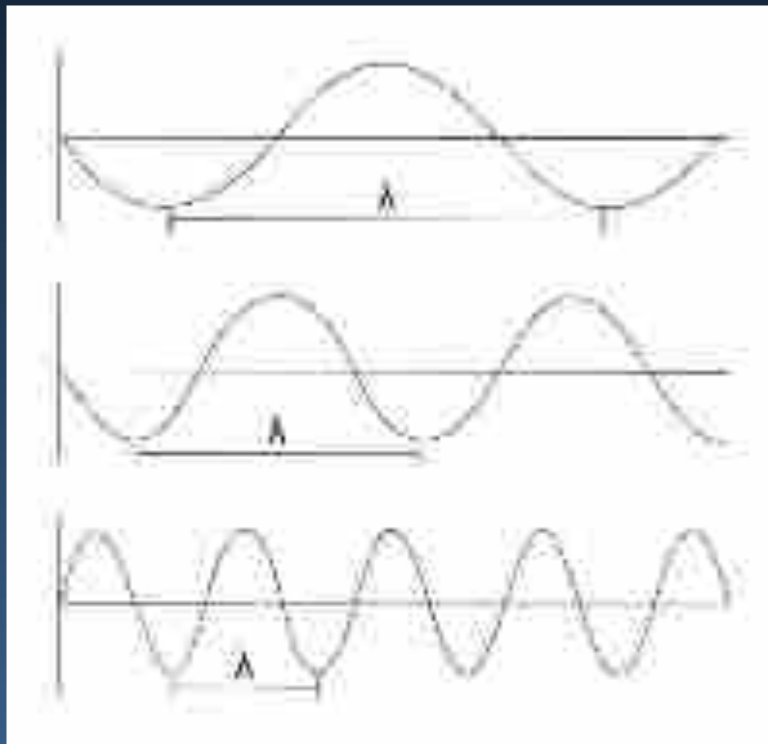
Different terms are applied to radiation with particular wavelengths
Light constitutes a small subset of this radiation



What are light and radiation?

As light, and all radiation, moves at a constant speed (commonly known as the speed of light, denoted by 'c') radiation can also be characterized by its frequency – denoted by the Greek character ν

The frequency is defined as the number of wave peaks that pass a particular point in one second



The relationship between frequency and wavelength is given as $\nu = c / \lambda$

What are light and radiation?

In addition, the energy associated with different types of radiation – denoted by ‘E’ – is determined by its frequency (ν).

$$E = h \times \nu$$

So the higher the frequency, the higher the energy

Using the relationship from the previous slide

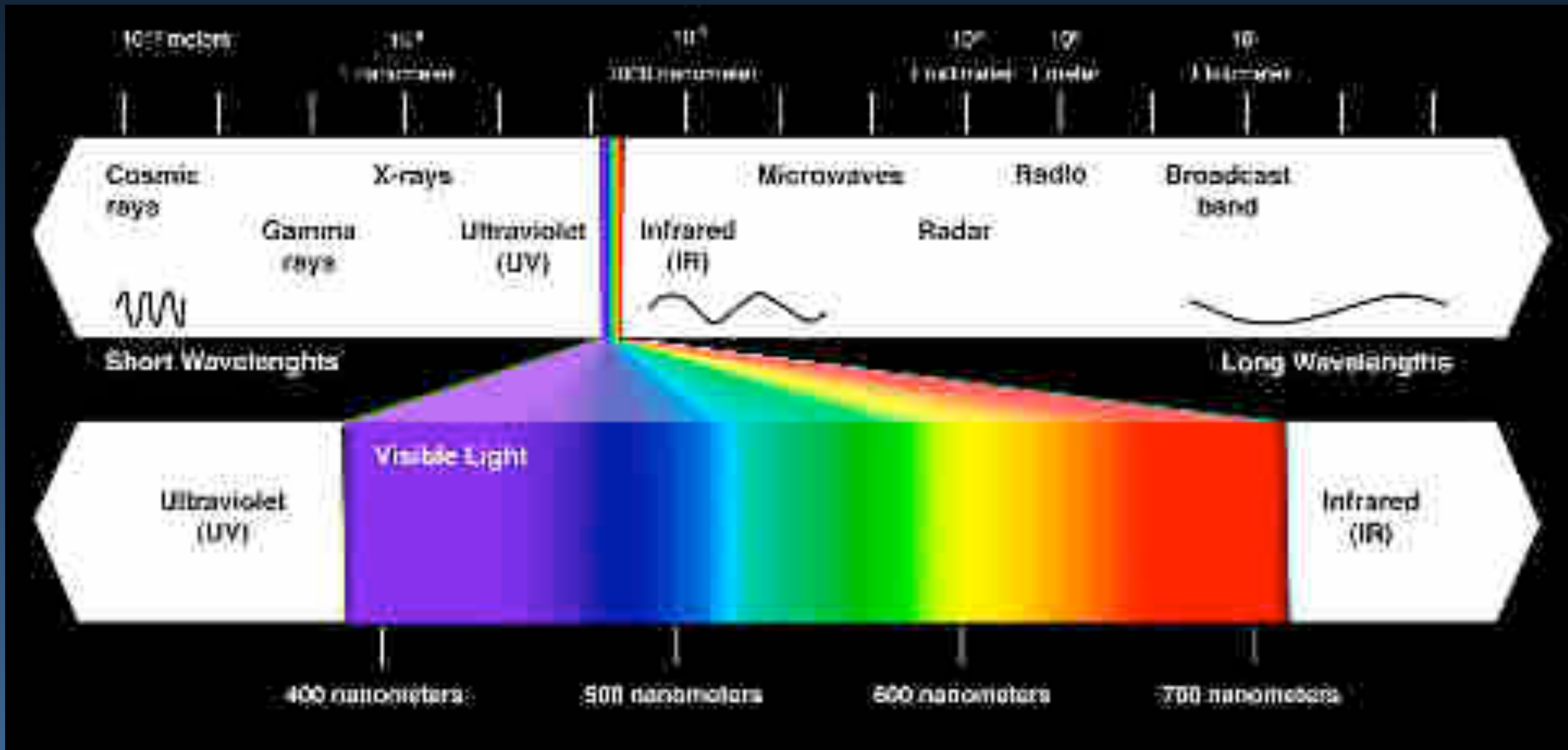
$$E = h \times \lambda / c$$

So the shorter the wavelength, the higher the energy

In the above equations, the symbol h represents Planck’s constant

What are light and radiation?

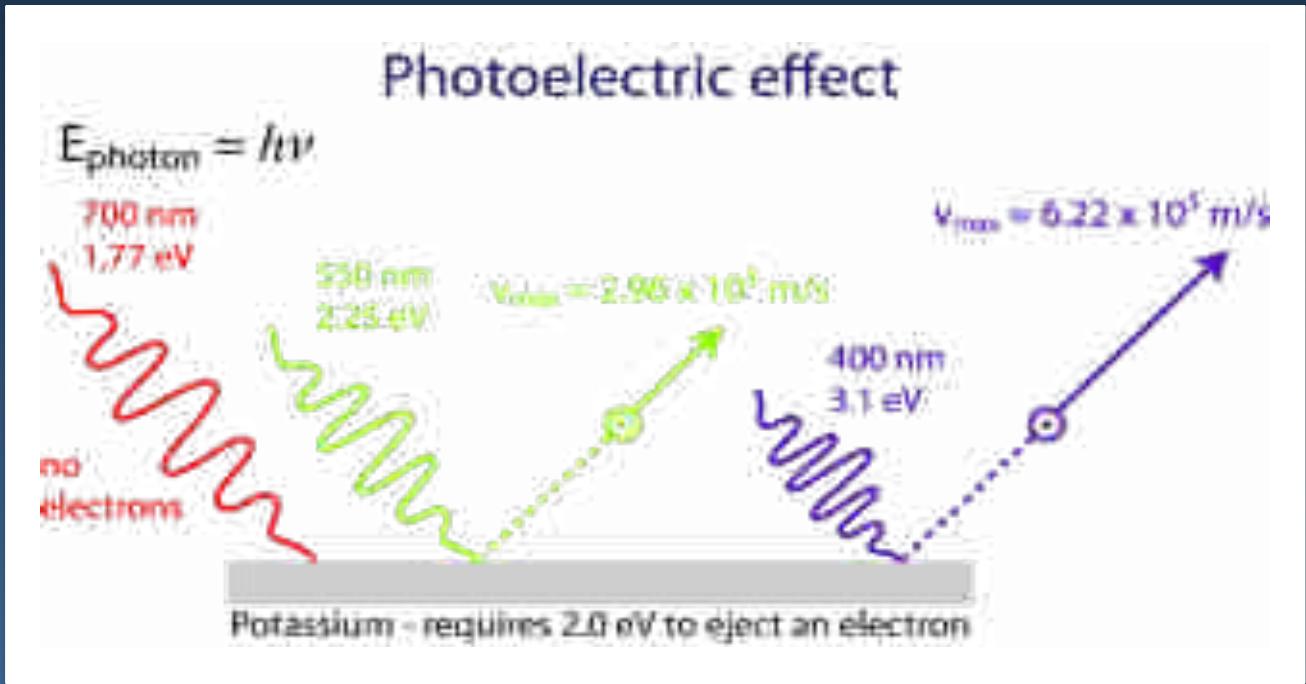
The shorter the wavelength, the higher the energy



What are light and radiation?

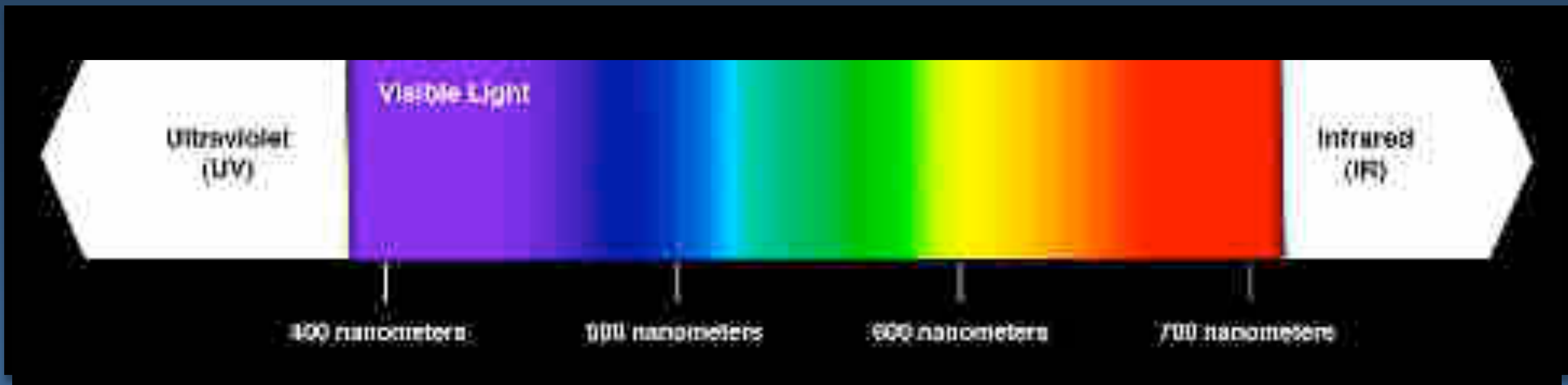
The relationship between wavelength and energy will have implications when considering the potential for damage from different types of radiation

The example below illustrates how this affects the emission of electrons in the photoelectric effect



How do we perceive light and colour?

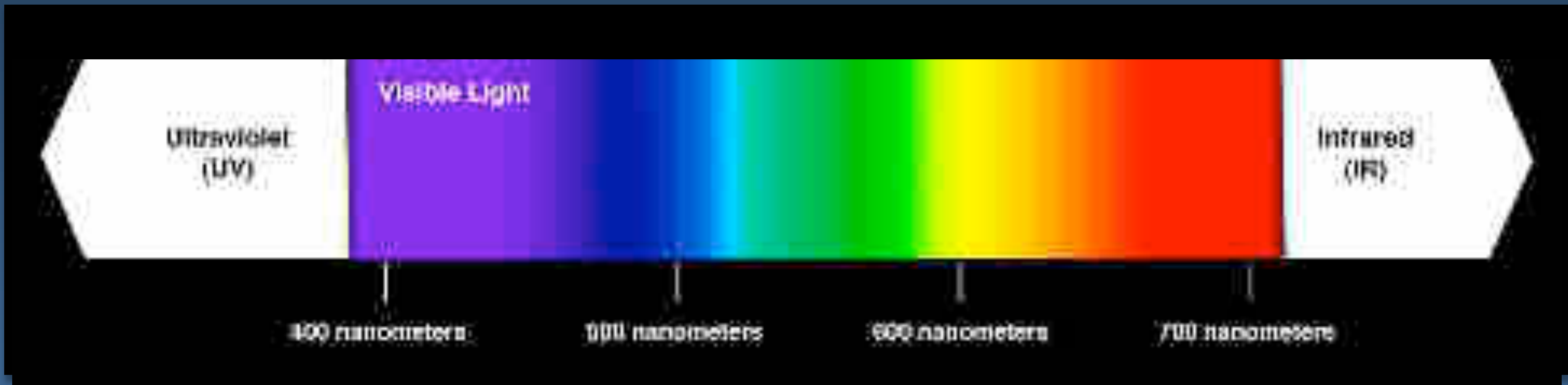
The regions of most interest in this context are the visible region – defined as that portion of the spectrum to which our eyes are sensitive – and the regions immediately bounding it, the infrared and ultraviolet



How do we perceive light and colour?

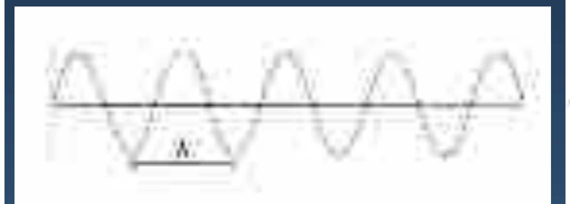
Although the different wavelengths below are shown in particular colours, these relate to the names we give to the sensations produced in the eye when it detects light rays of these wavelengths

One of the most eminent colour scientists of the twentieth century, David Wright, captured this in the title of his book
"The rays are not coloured"



How do we perceive light and colour?

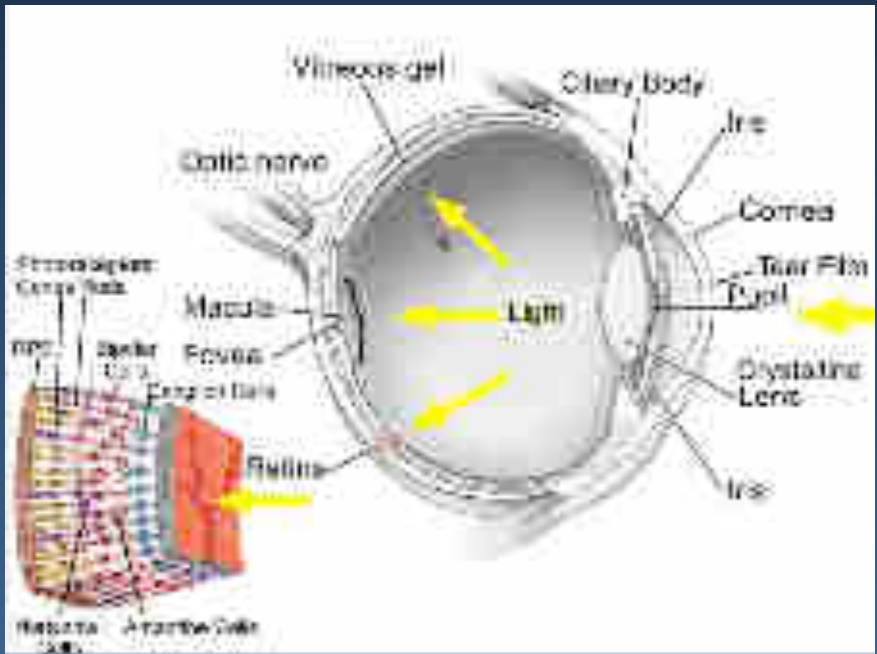
How do the eye and brain produce the sensation of colours from uncoloured radiation of different wavelengths?

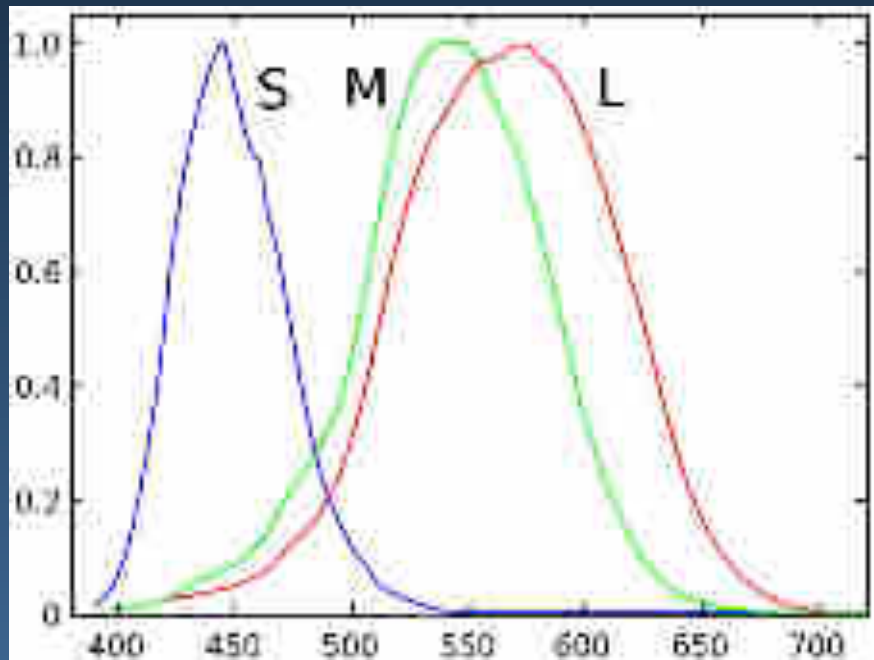



How do we perceive light and colour?

The rear surface of the eye contains photoreceptor cells that are sensitive to light

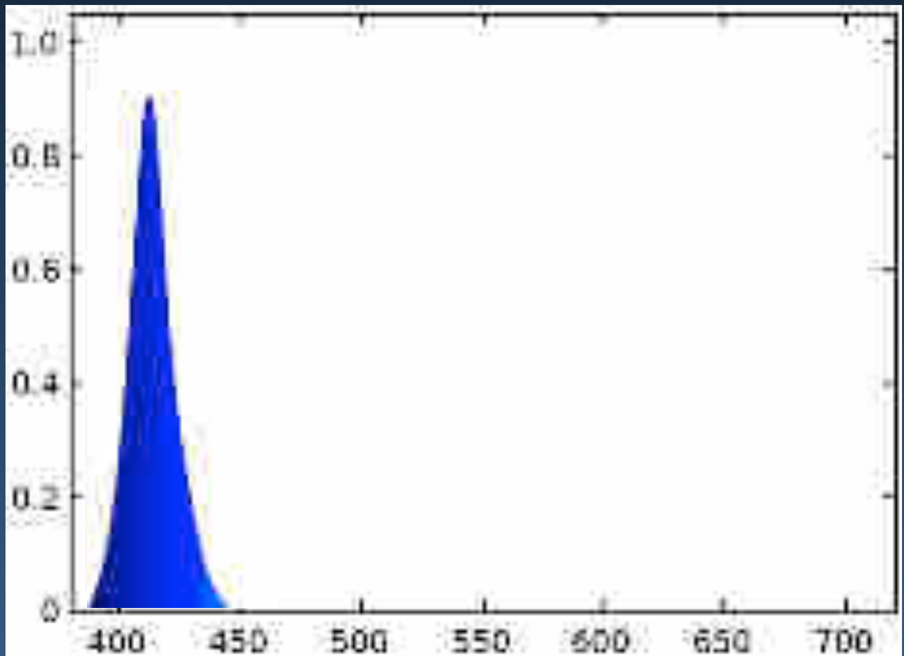
There are three types of so-called cone cells that are sensitive to different wavelengths of light. The graph shows the average sensitivities of these cones to different wavelengths, based on experiments with 1000s of subjects with 'normal' colour vision

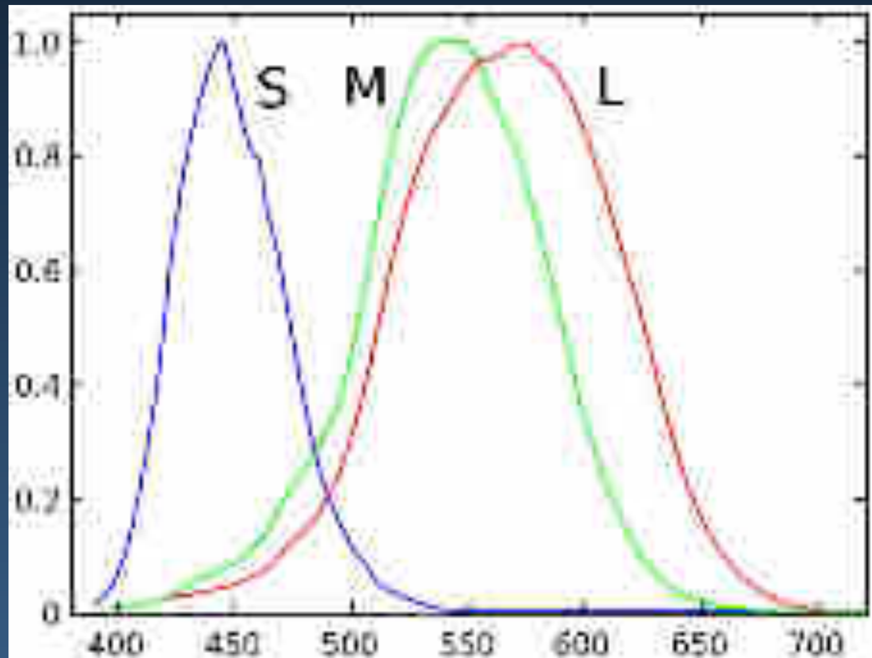




How do we perceive light and colour?

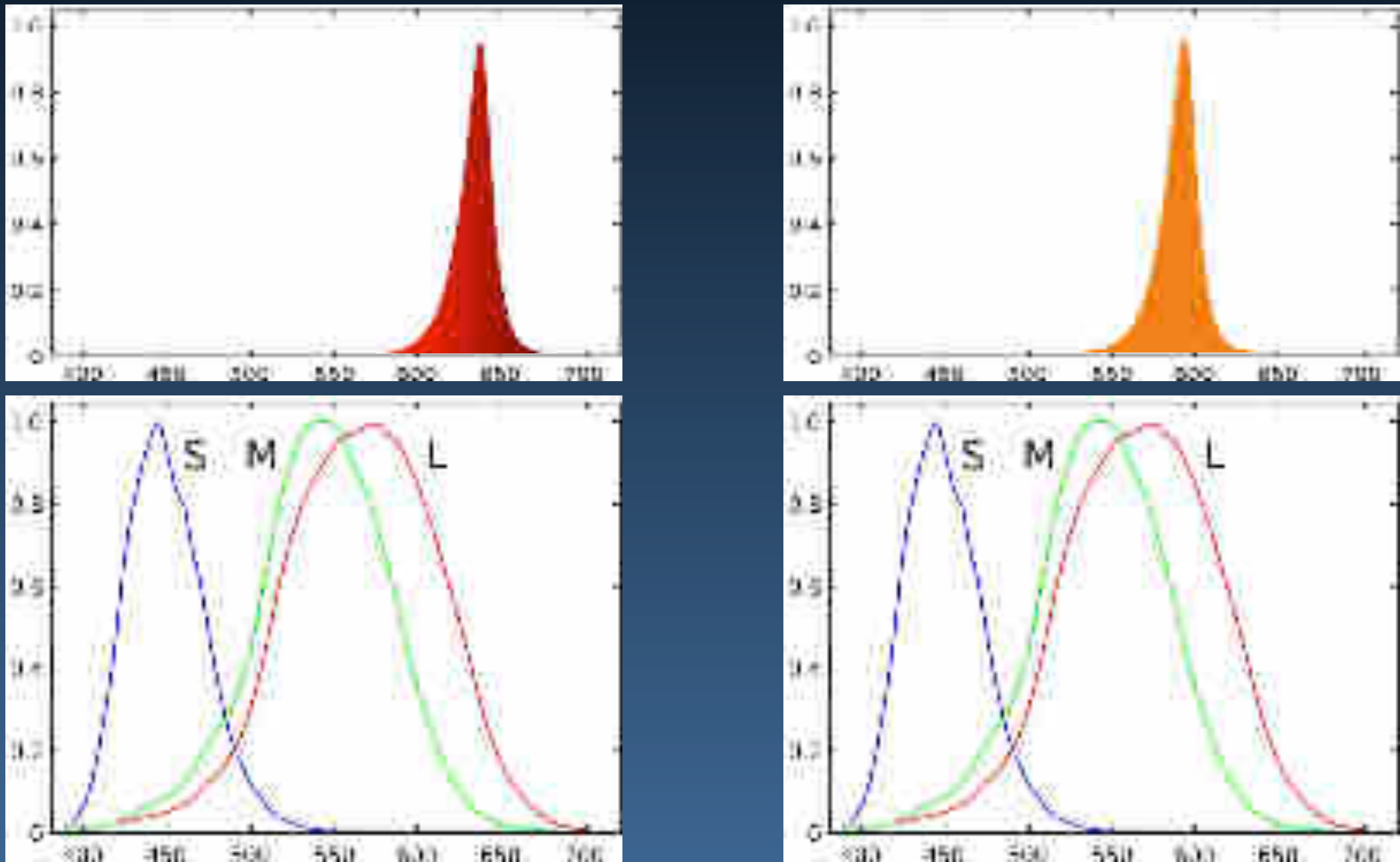
When light with a wavelength in the 400-500 nm range enters the eye it principally stimulates the short wavelength (S, or blue) cone.





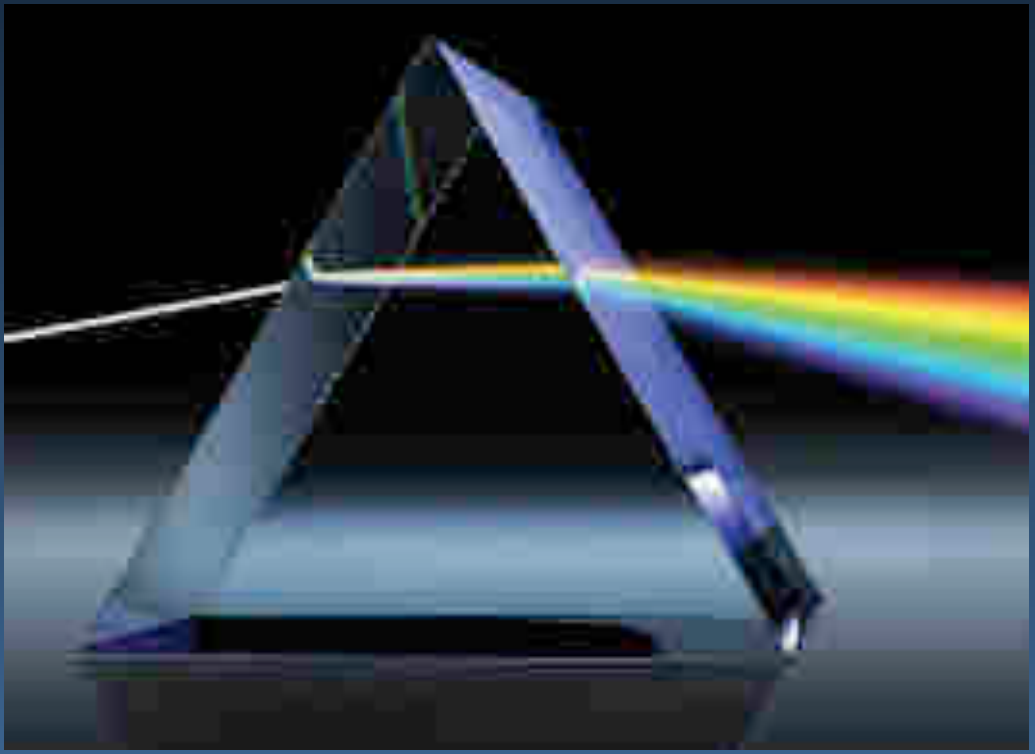
How do we perceive light and colour?

When more than one receptor is stimulated it becomes a question of the ratio of stimulation of the the different photoreceptors



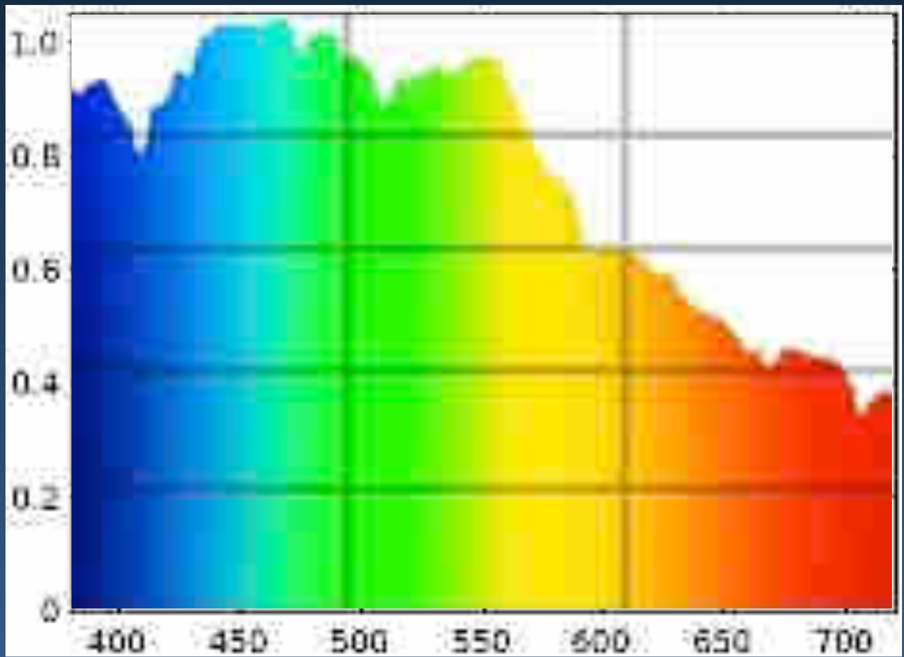
How do we perceive light and colour?

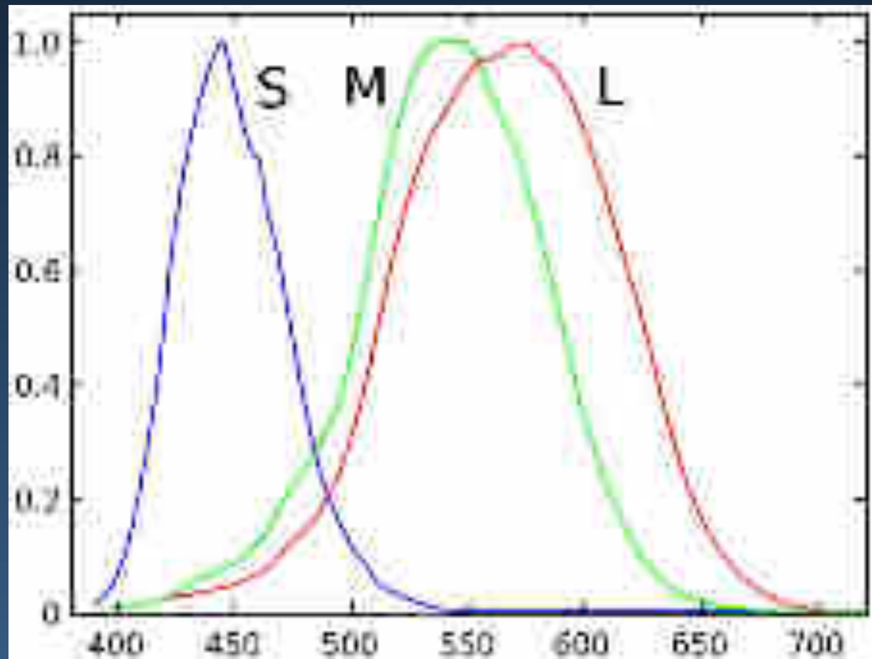
However, most light sources do not emit at a single wavelength. The experiment with a prism shows that ‘white’ light comprises a range of wavelengths (colours) of light



How do we perceive light and colour?

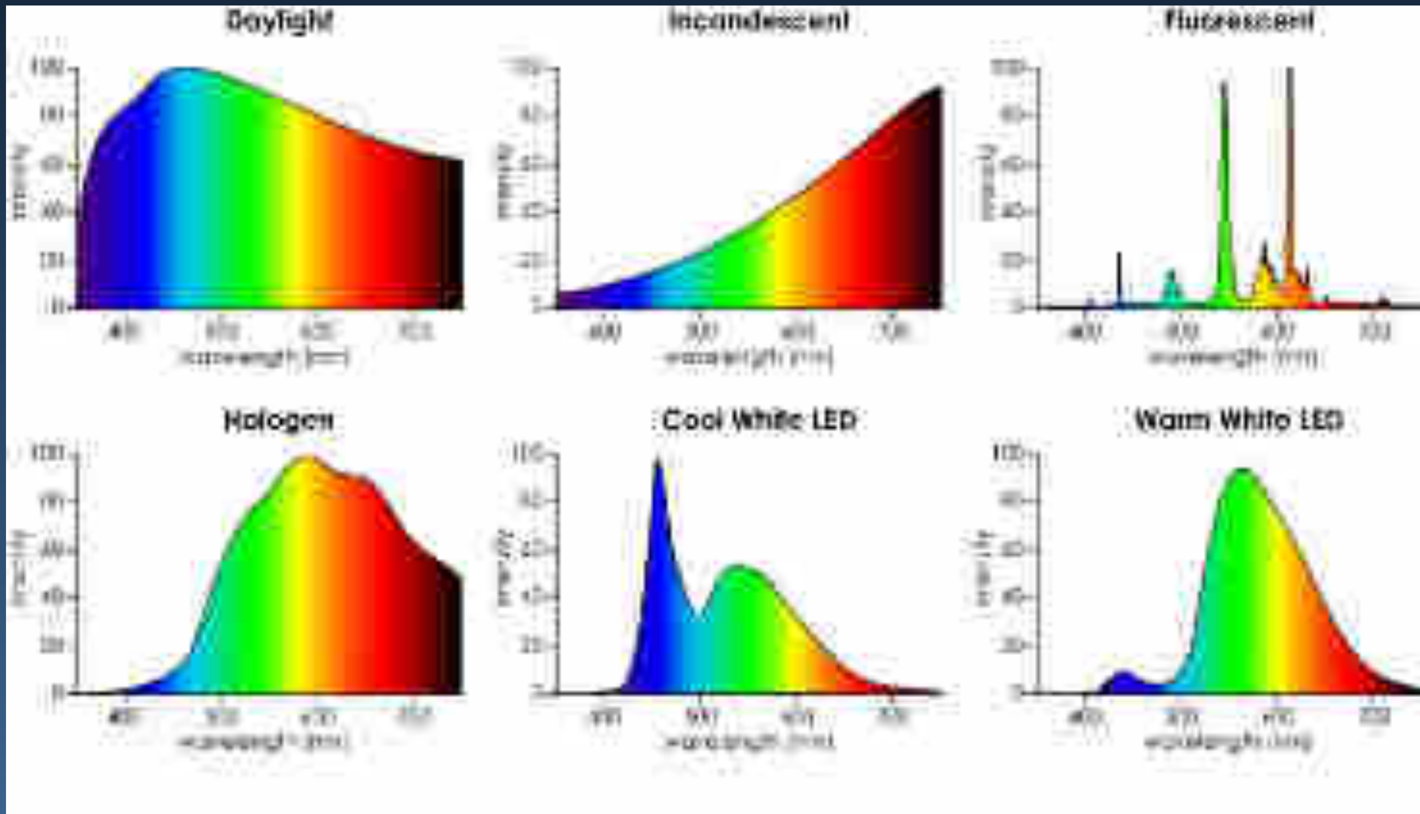
White light (daylight in this example) contains radiation over a range of wavelengths in the visible that stimulates all three sensors





How do we perceive light and colour?

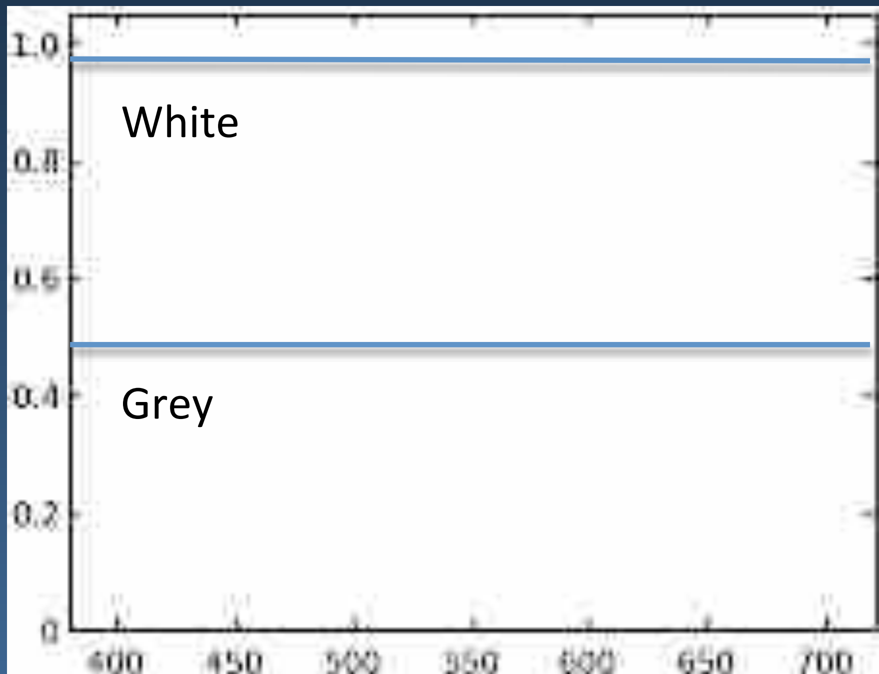
Different types of light source emit different proportions of radiation across the spectrum, altering the ratio of the three cone responses (more of this later) but all stimulate the three sensors



How do we perceive light and colour?

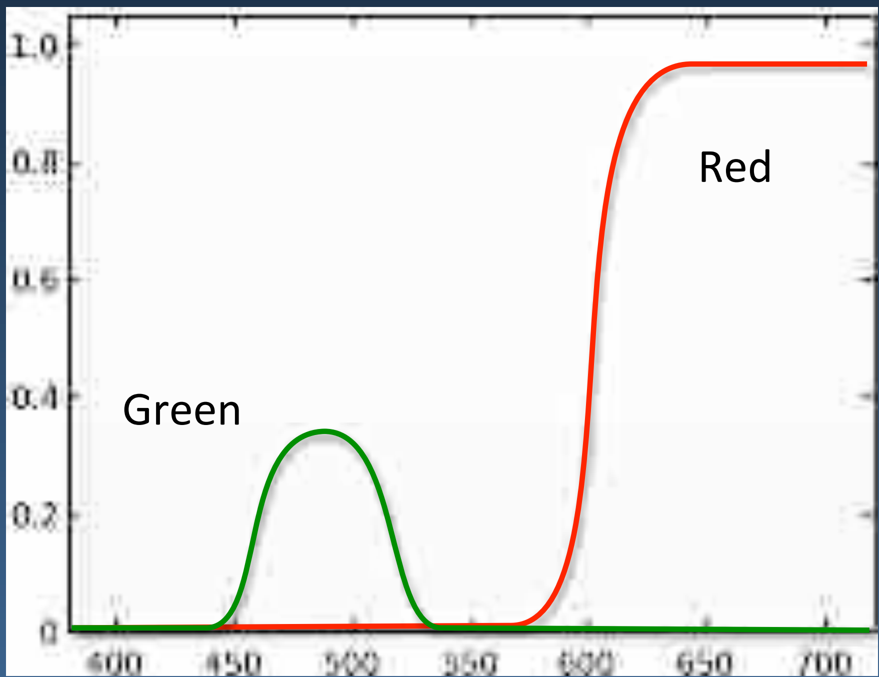
At this point we have only considered the colour of light rather than the colour of objects. Objects can modify the colour of the light that is incident upon them by reflection, absorption or transmission

If we focus on reflection, a white or grey object will not change the ratio of stimulation of the three cones as they reflect all wavelengths more or less equally – we can graph their reflection thus



How do we perceive light and colour?

Surfaces that differentially reflect certain wavelengths of light change the ratio of stimulation of the three cones, producing sensations of colour by – for example – reflecting mostly light in the red or green regions in these examples



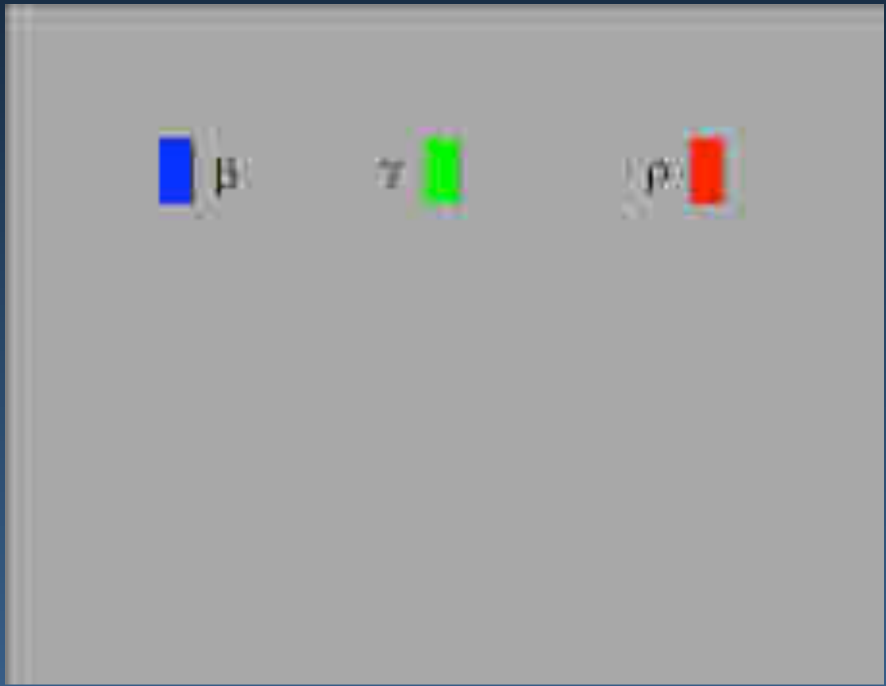
How do we perceive light and colour?

So the colour identified by the brain is the result of light from a source, reflected from an object and detected by the eye

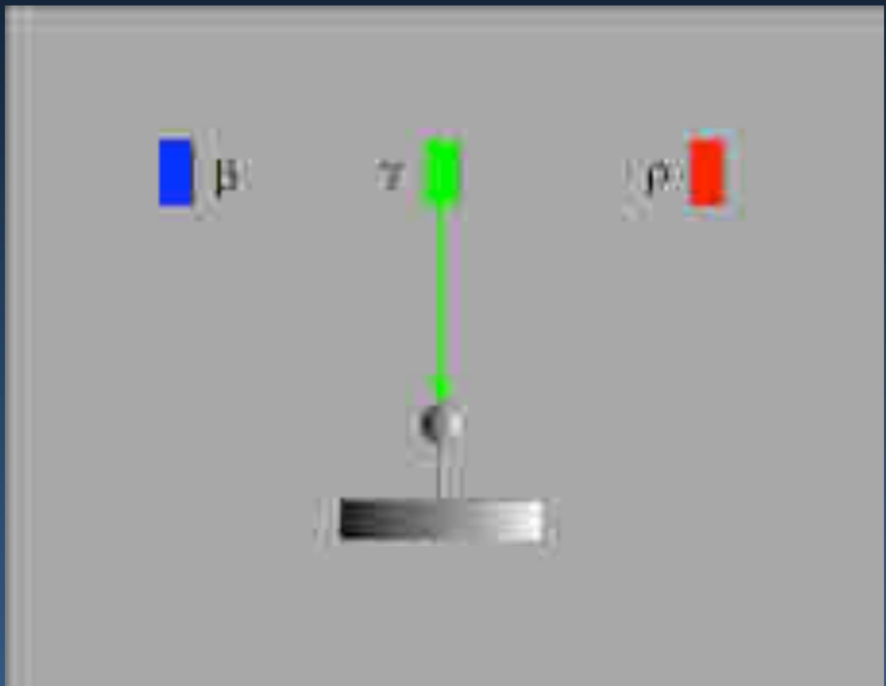
But how does the brain process the signals from the eye and what factors affect how we perceive rather than simply detect colour?

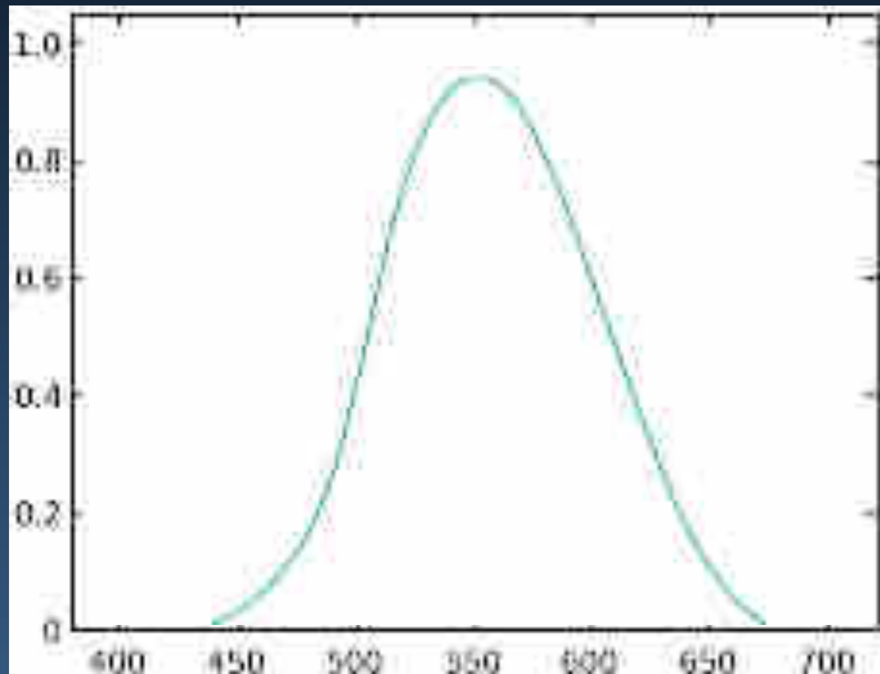
How do we perceive light and colour?

Research has indicated the way in which the signals from the three sensor are processed to provide information to the brain

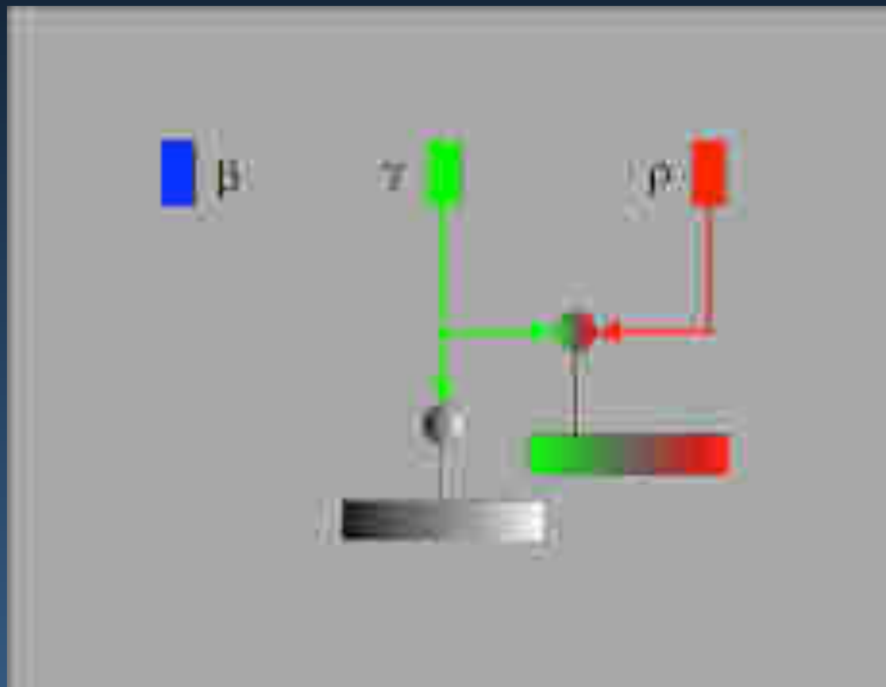


How do we perceive light and colour?

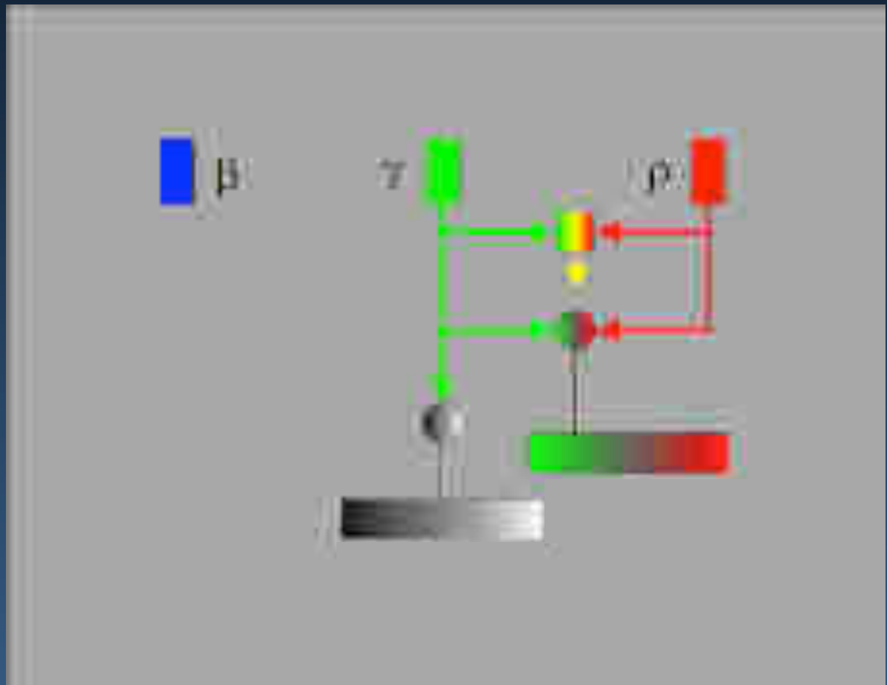


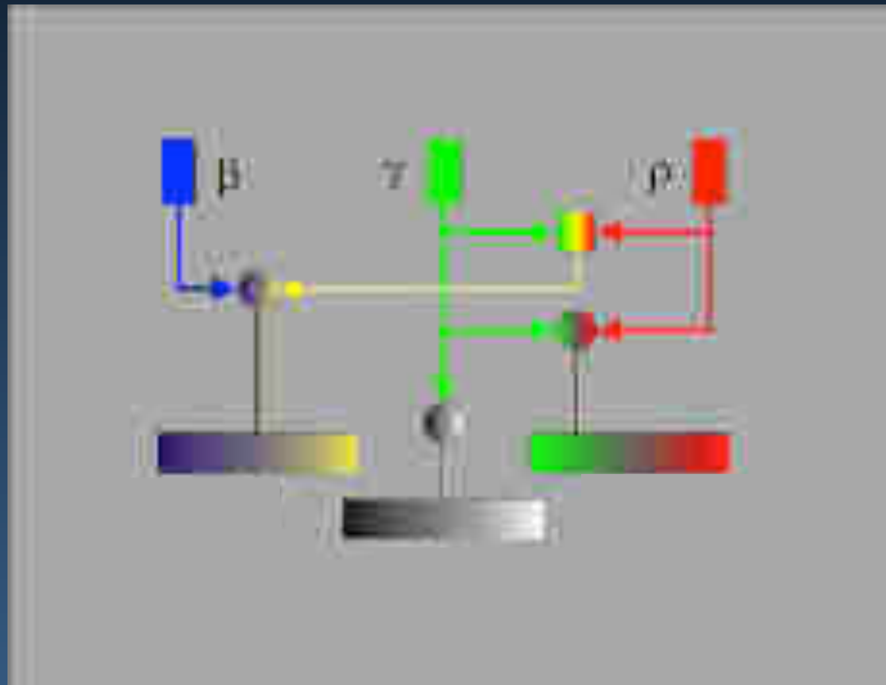


How do we perceive light and colour?



How do we perceive light and colour?



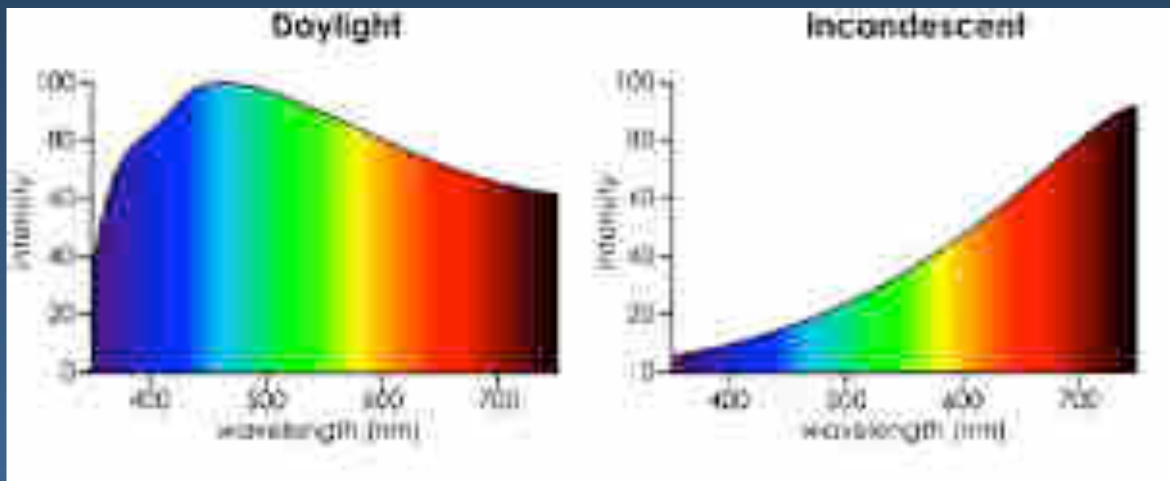


What factors affect colour vision?

Colour constancy

We see a piece of white paper as white whether we are viewing it under daylight or incandescent light – which have very different spectra (below)

This adaption is carried out by the brain, which detects a white – or light, neutral are in a scene and uses it to balance the signals from the three cones to maintain a neutral colour on the white area

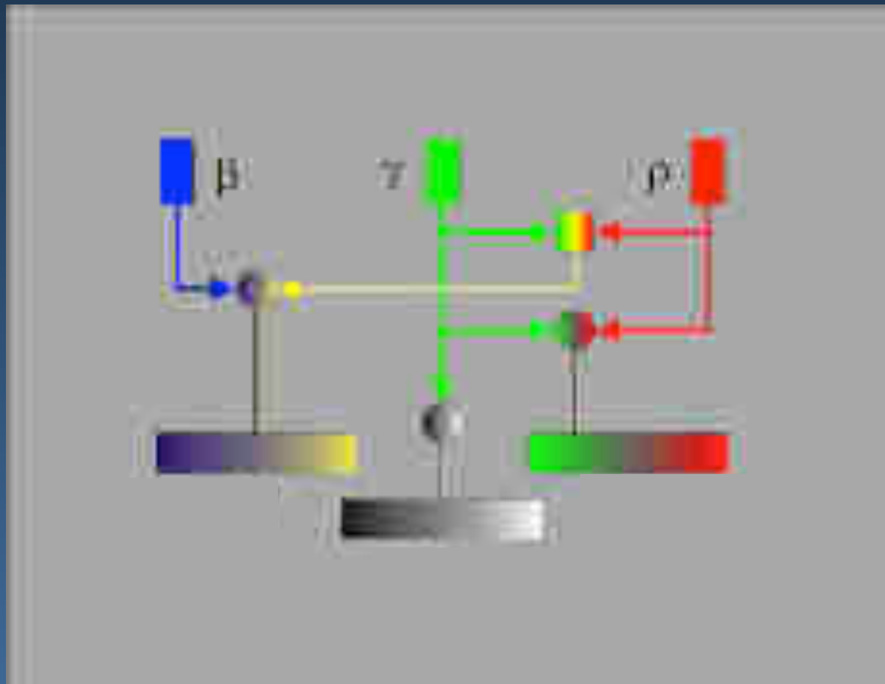


What factors affect colour vision?

Colour constancy

We see a piece of white paper as white whether we are viewing it under daylight or incandescent light, which have very different spectra (below)

This adaption is carried out by the brain, which detects a white, or neutral, area in a scene and uses it to balance the signals from the three cones to maintain a neutral colour in this area – affecting the way the other colours are perceived as a result



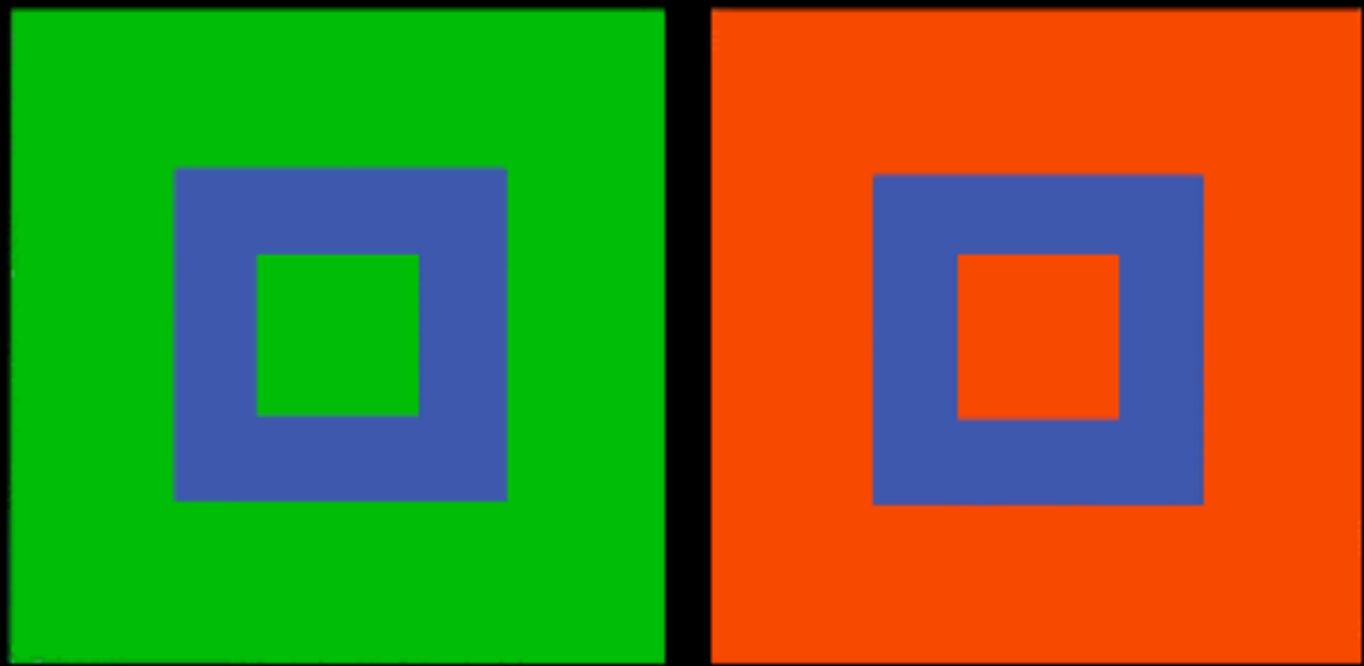
What factors affect colour vision?

Colour constancy

What factors affect colour vision?

Simultaneous contrast

Perception of colour is also affected by the surroundings

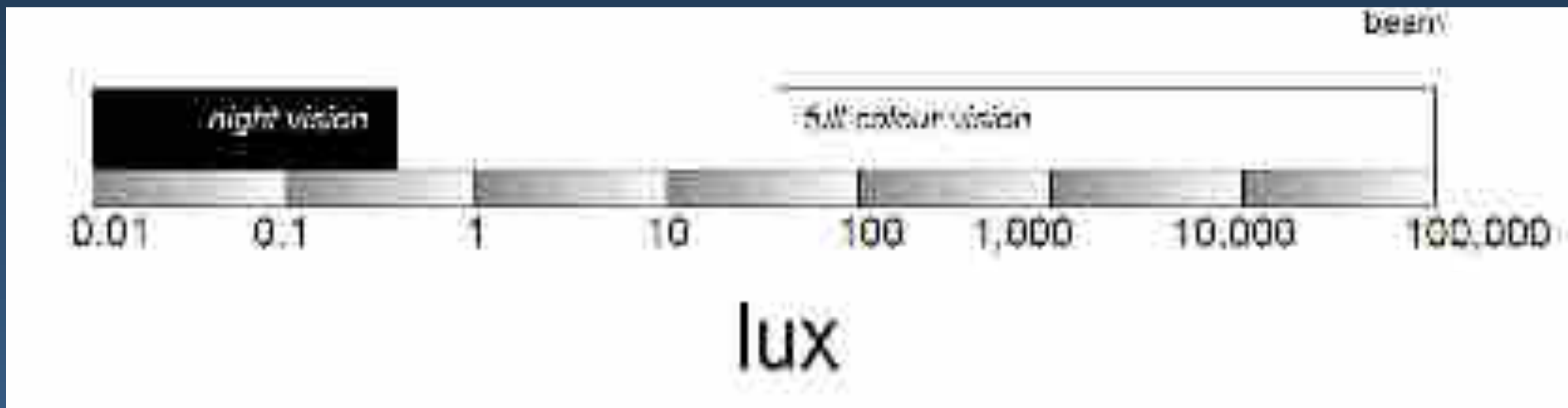


What factors affect colour vision?

Light level

At very low levels the cones do not function and vision relies on another type of sensor in the eye: the rods. The rods all have same spectral sensitivity, so vision is monochromatic – i.e. no colours are differentiated

At intermediate levels, colour vision does not function fully and we may have difficulty discerning subtle colour differences



It can take some time for the eye to switch from colour to low light vision, which is why we need a few minutes in a darkened room before we can begin to see again

How do we categorise colour?

Colour order systems

These have existed since antiquity and properties were often associated to particular colours

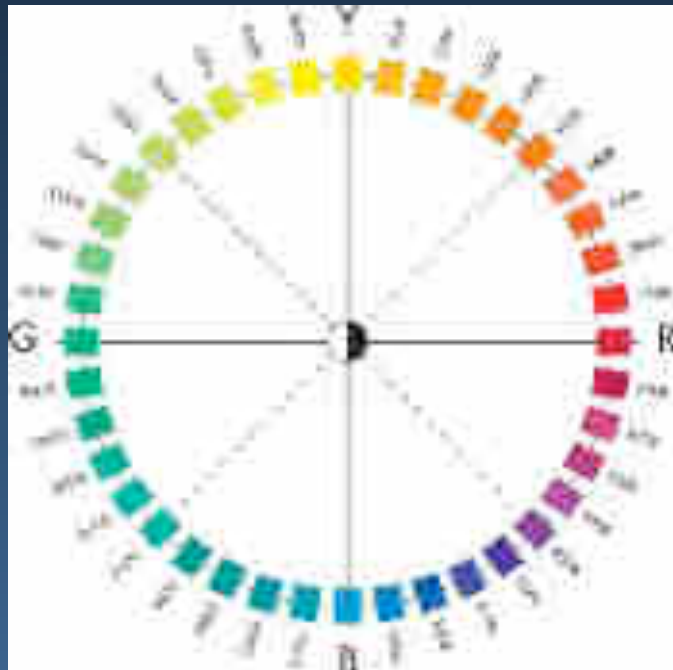
By the nineteenth century these were more scientifically based

How do we categorise colour?

Colour order systems

Two significant current colour systems are the Munsell system and the NCS system

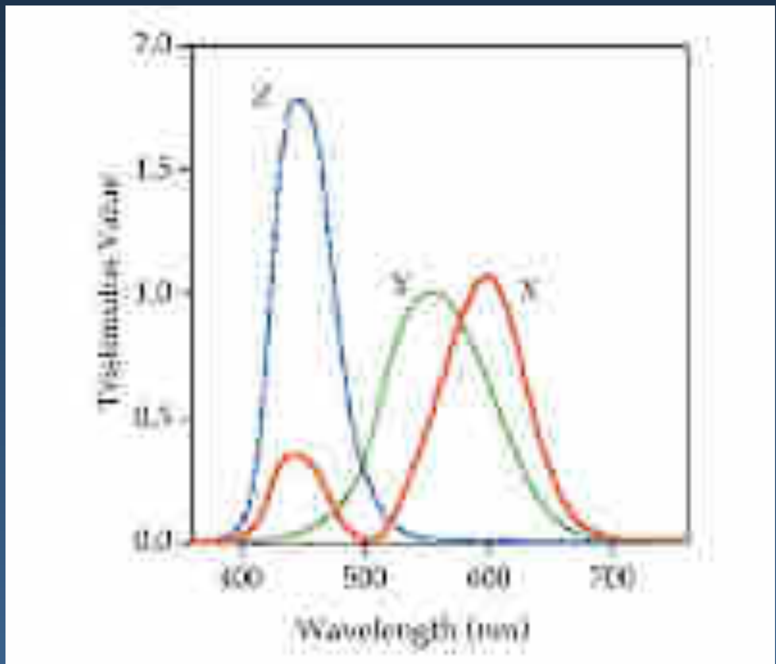
Both provide atlases of colour patches against which to make comparisons (although these are increasingly computerized)

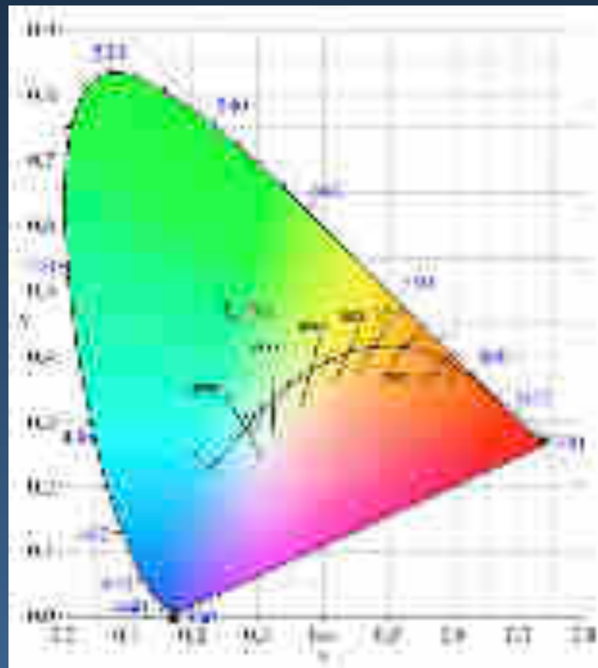


How do we categorise colour?

Systems based on human vision

The Commission Internationale de l'Eclairage (CIE) defines systems based on the human visual process. These were first codified in 1931, and many of the equations still in use date from that time and form the basis of modern colorimetry

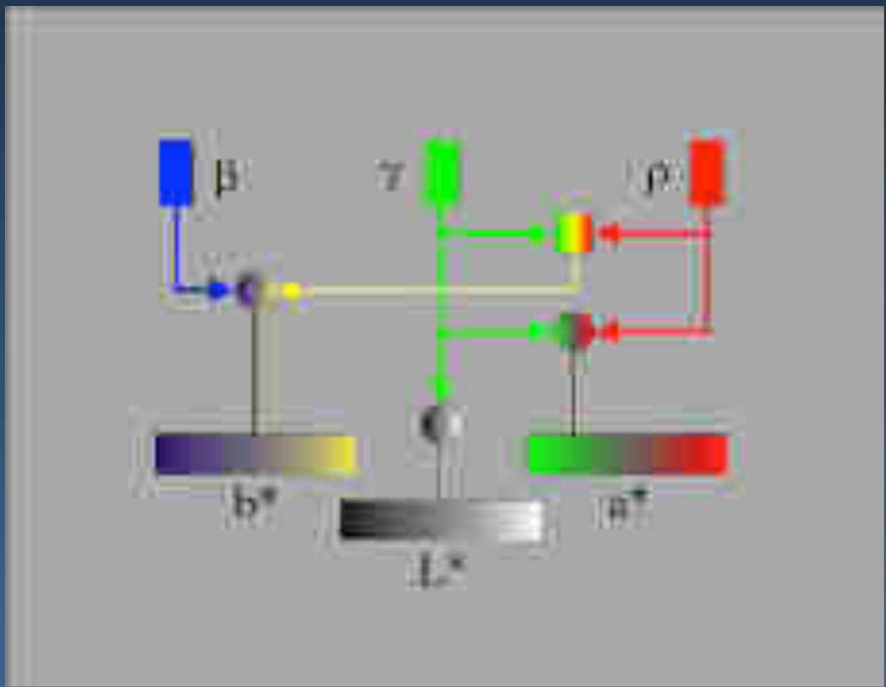




How do we categorise colour?

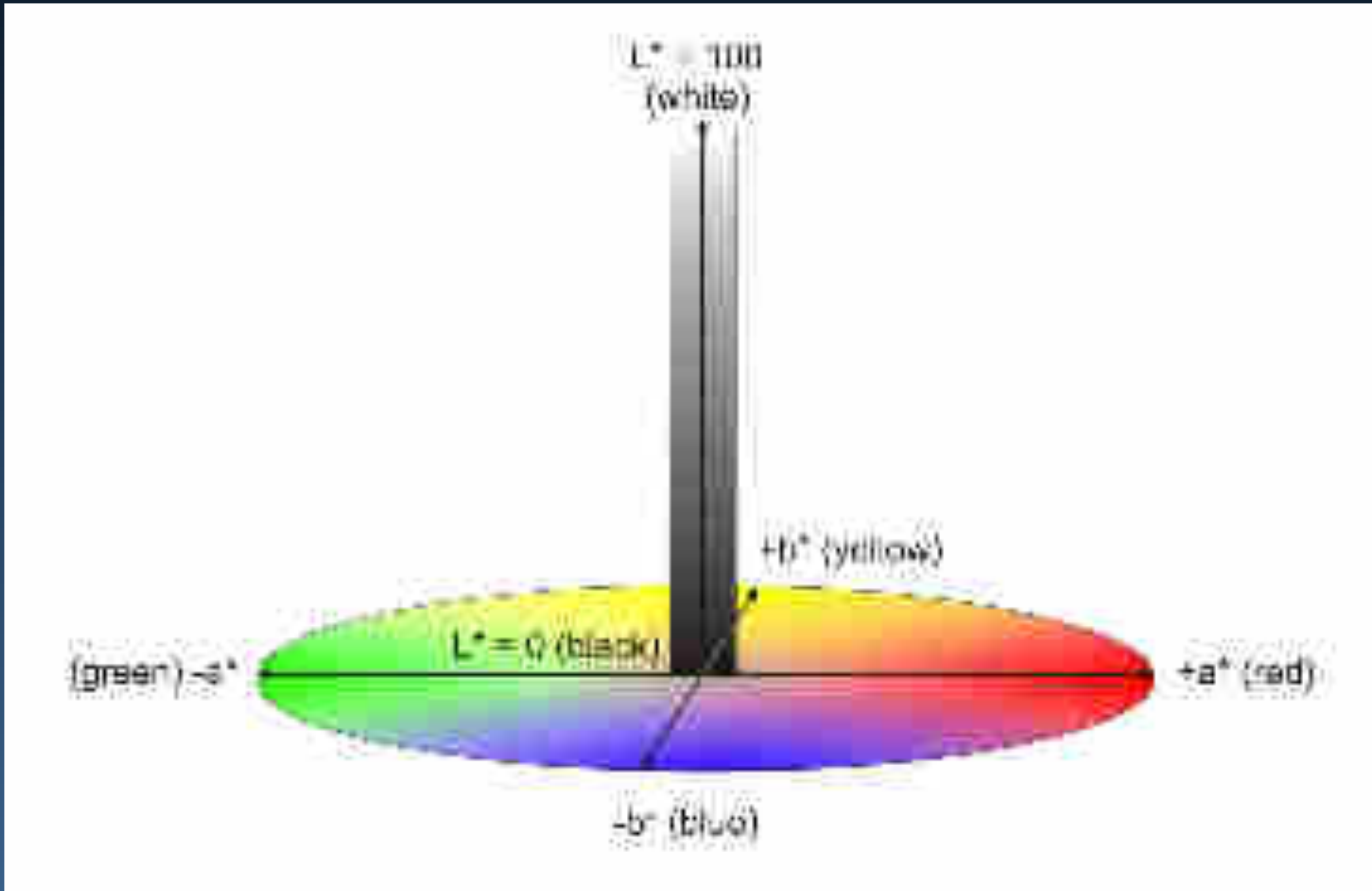
Systems based on human vision

The current CIE system has been in use for many decades and is known as CIELab It takes as its basis the three signals (known as L*, a* and b*) produced by the human visual system that we saw earlier



How do we categorise colour?

Systems based on human vision

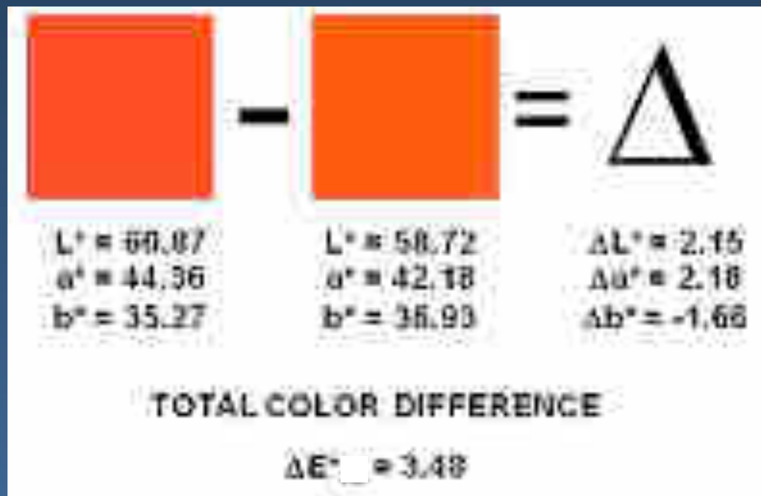


How do we categorise colour?

Systems based on human vision

Any colour can be categorized by a set of L*, a* and b* coordinates
The system is routinely used to determine colour differences using a series of equations that was developed over the last quarter of the twentieth century to reflect how measured differences in colour relate to perceived differences

The currently used measure of colour difference is the ΔE_{00} unit (developed in 2000), although it is common to see references to ΔE_{94} or ΔE_{76}



How do we categorise colour?

The colour of white light

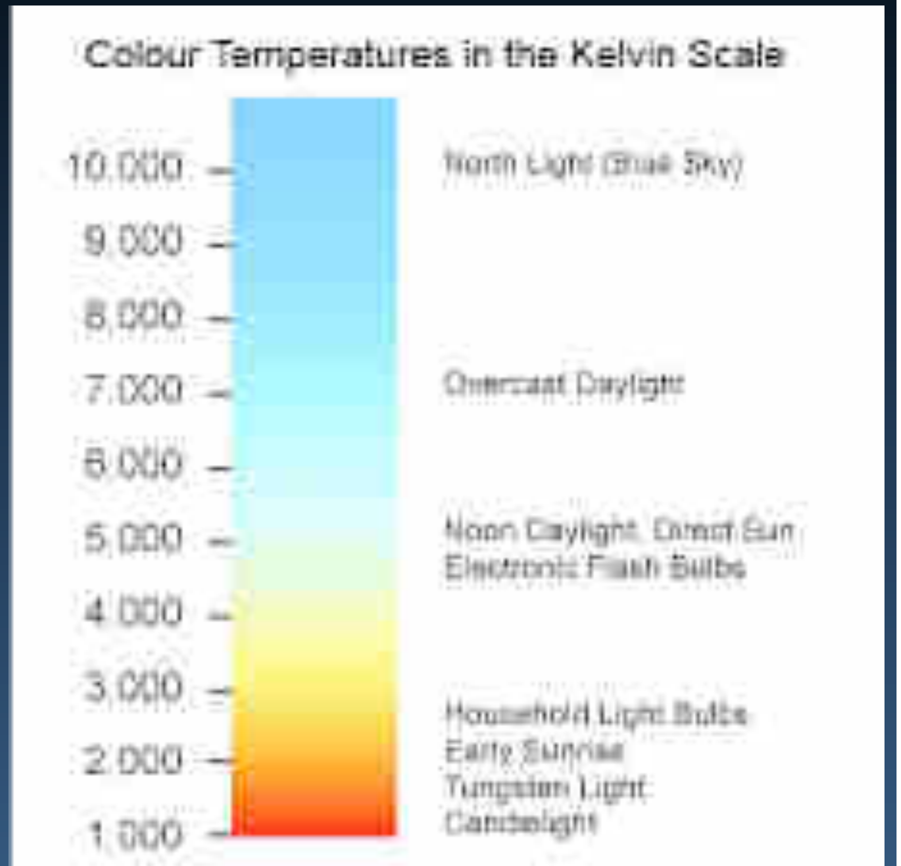
We have seen that 'white' light can vary greatly

A useful way of categorizing most sources is by relating the light they emit to a that produced by heating an object. As the temperature of the object increases the proportion of blue to red light increases

How do we categorise colour?

The colour of white light

White light is, therefore, often characterized by its so-called colour temperature, which is quoted in Kelvin – the standard scientific unit of temperature

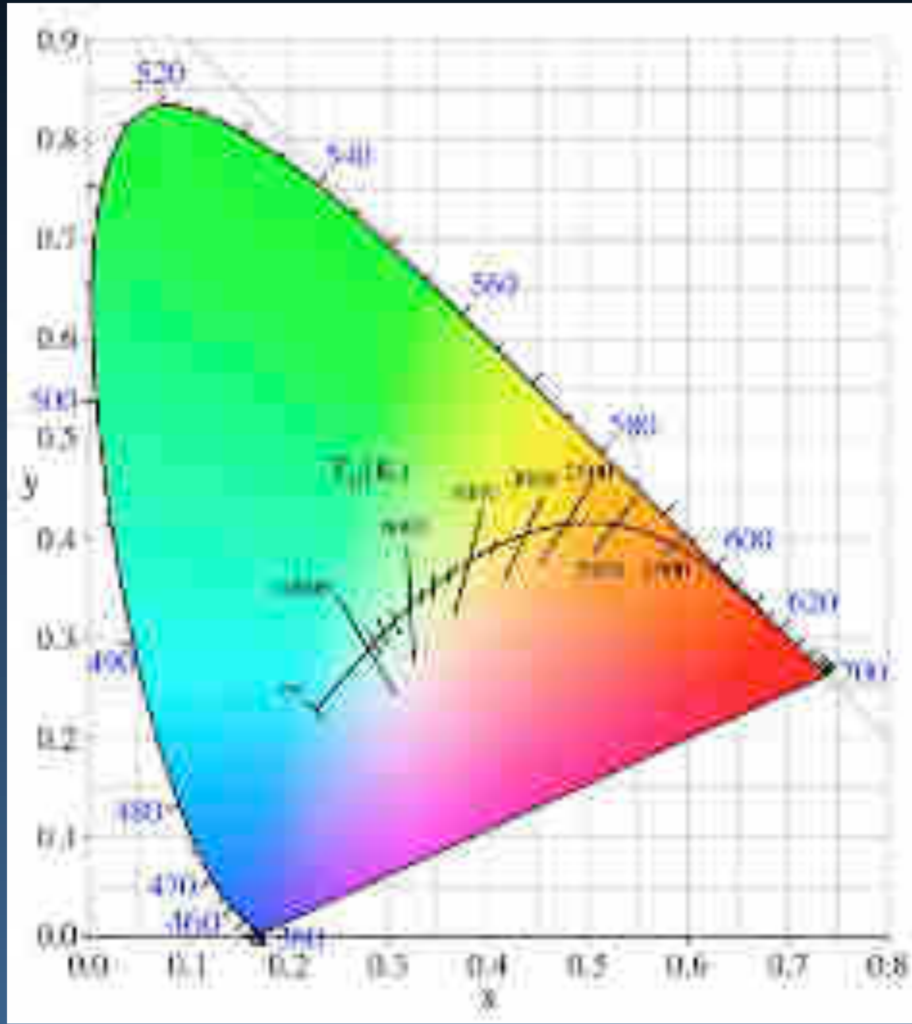


Confusingly, light with a high proportion of blue is often termed 'cool' and light with a high proportion of red, 'warm', which is the opposite of the temperatures of the objects emitting these types of light

How do we categorise colour?

The colour of white light

These colour can also be plotted on the chromaticity diagram that we saw earlier – the curved line or locus to the right that moves from the yellow to blue region as temperature increases



Damage caused by light

Does light cause damage to museum objects?

How susceptible to light are the materials in an object?

How acceptable is such a change?

Does light cause damage to museum objects?

Pathways for light damage

Direct photolytic action

bond-breaking by light or structural changes
mainly affects organic materials

Light-induced catalysis of other processes

for example hydrolysis or oxidation/reduction
affects all material classes

Does light cause damage to museum objects?

Damage can be very gradual and is often unseen – in this instance only revealed when the painting was unframed

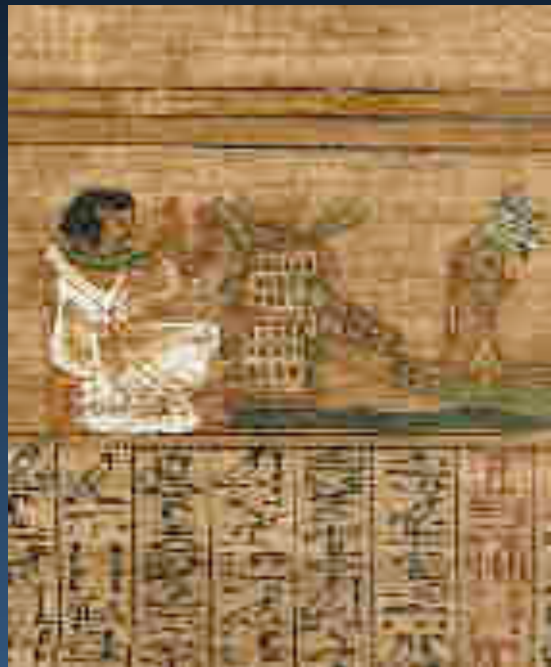
Portrait of Henry Dawkins, Maurice-Quentin de La Tour
National Gallery, London

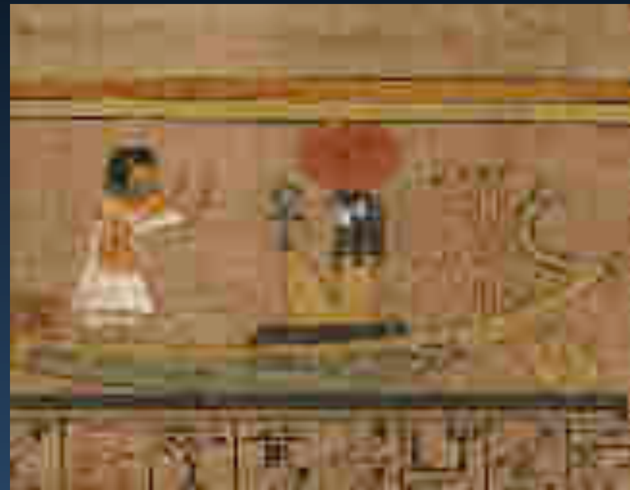
Does light cause damage to museum objects?

In this tapestry, the fading of the colours – particularly the yellow – is most apparent when the front and back are compared

Does light cause damage to museum objects?

In this instance the damage was evident when an exposed papyrus was compared directly to a very similar sheet that had not been on display





Book of the Dead of Ani
(c.1250 BC), British Museum

Does light cause damage to museum objects?

Although colour change is the most immediate sign of damage, it is often accompanied by loss of strength – as in this silk banner

Tibetan Buddhist banner (early C19), British Museum

Does light cause damage to museum objects?

… or the more visible and serious degradation as in this curtain

How susceptible to light are the materials in an object?

From experience we know different types of material have different susceptibilities to light damage

A Girl with a Dead Canary, Jean-Baptiste Greuze, National Galleries Scotland

A Girl with a Dead Canary, Enamelled box, Thurn und Taxis Palace, Regensburg

How susceptible to light are the materials in an object?

But sometimes objects that are similar, or we think of as being similar, should be looked at more carefully

Woodcut print from the *Life of the Virgin* series, Albrecht Dürer

Venice, a storm; rain clouds over the city at left, a boat near the foreground J.M.W. Turner

How susceptible to light are the materials in an object?

Tabulated information on susceptibility (1)

Thomson: *The Museum Environment* (1986)

Unstable or fugitive	**Intermediate**	**Excellent**
ISO≤3	**ISO 3-6**	**ISO ≥6**
50 lux	**200 lux**	**300+ lux**
Textiles **Costumes** **Watercolours** **Tapestries** **Prints and drawings** **Manuscripts** **Miniatures** **Paintings in distemper medium** **Wallpaper** **Gouache** **Dyed leather** **Most natural history objects, including botanical specimens, fur and feathers**	**Oil and tempera paintings** **Undyed leather** **Horn** **Bone** **Ivory** **Oriental lacquer**	**Metal** **Stone** **Glass** **Ceramics** **Jewellery** **Enamel**

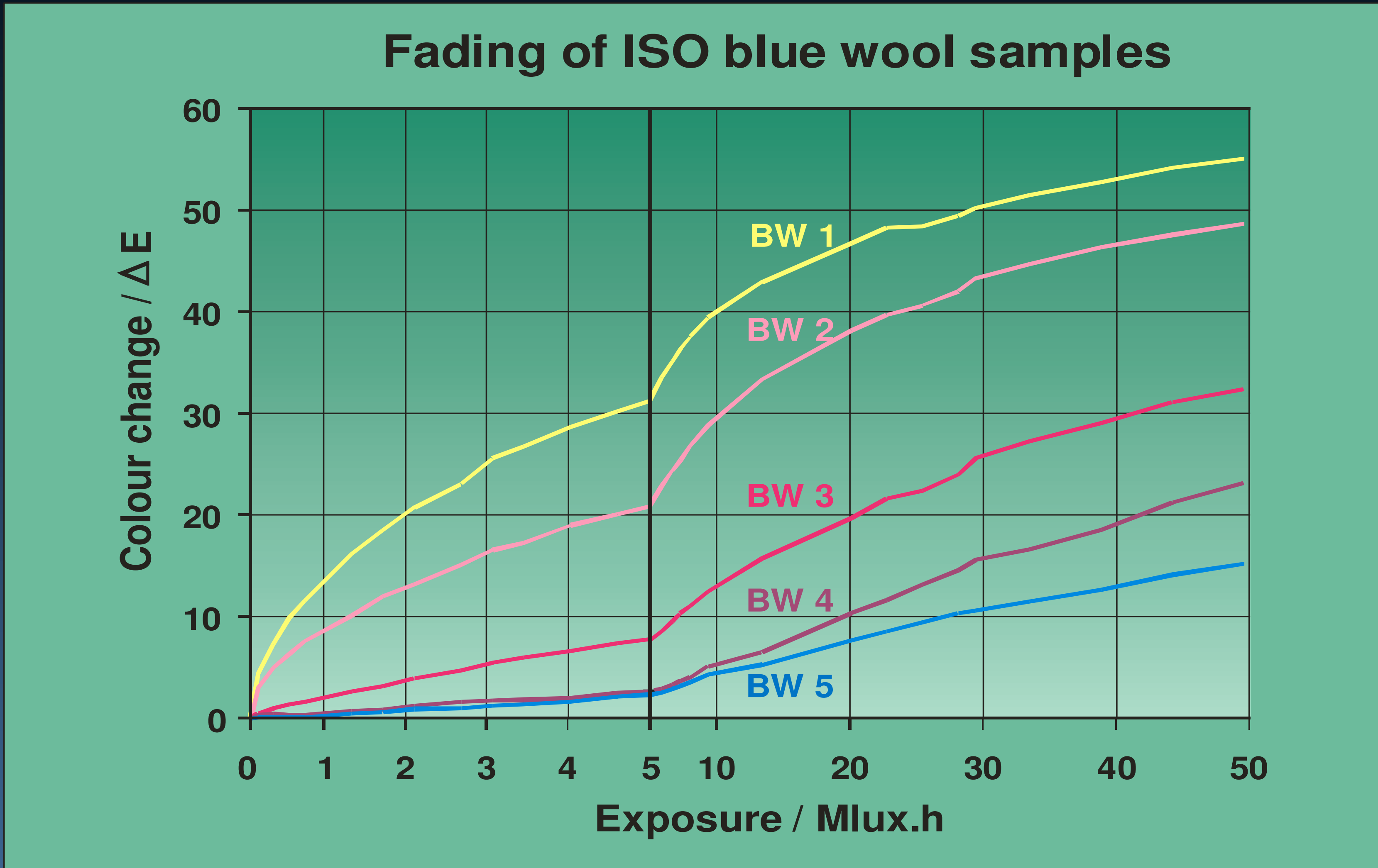
How susceptible to light are the materials in an object?

ISO Blue wool standards are a convenient – and hopefully consistent – reference point for comparisons of susceptibility to light damage

ISO blue wool scale

1 2 3 4 5 6 7 8

How susceptible to light are the materials in an object?



How susceptible to light are the materials in an object?

Reciprocity

When considering light levels, and devising guidelines, it is important to consider the reciprocity principle

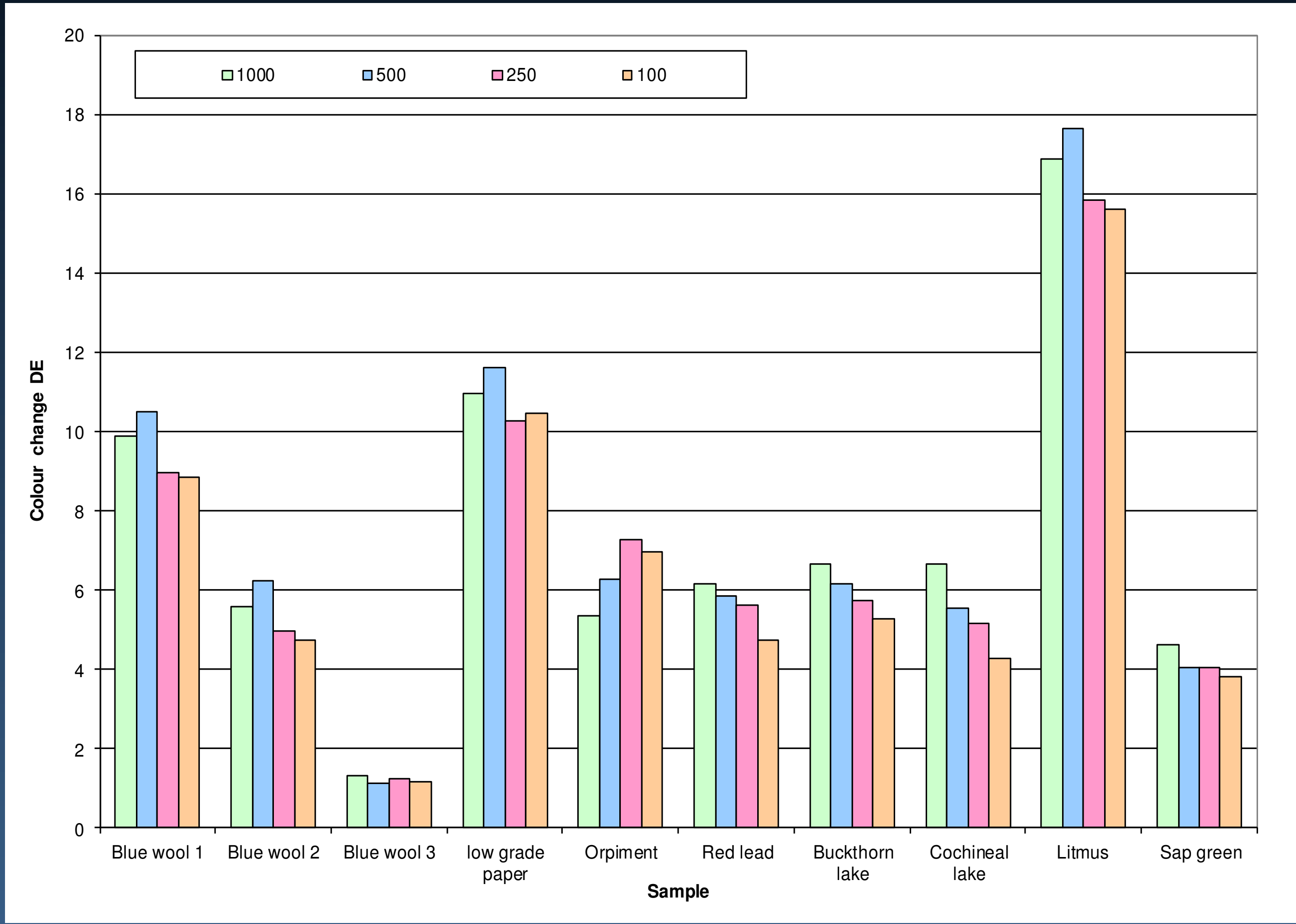
This states that the amount of damage will be determined by the product of the light level and the length of time for which objects are exposed at that level – the light 'dose'

So, for example, the same damage will result from exposing an object for three months at a level of 200 lux or for a year at 50 lux (assuming the same museum display hours)

Dose is measured in lux hours (lux x hours)

How susceptible to light are the materials in an object?

Reciprocity



Plot of colour change (in ΔE_{00} units) caused by 400 klux.h delivered at different light levels

How susceptible to light are the materials in an object?

Tabulated information on susceptibility (2)

Victoria & Albert Museum (1999)

(paper-based collections)

Zero tolerance	Sensitive	Durable
	ISO 1-4	ISO 5-8
Display not recommended	50 lux for 20% of display time	150 lux unlimited display time
Light-sensitive objects Objects where colour is of archival importance Some objects in pristine condition	Coloured objects Objects on poor quality or discoloured paper	Black-and-white objects on good quality paper

How susceptible to light are the materials in an object?

Tabulated information on susceptibility (3)

V&A (2002)

Vulnerable	Sensitive	Durable	Permanent
	ISO≤4	ISO≥5	
Display not recommended	50 lux for 20% of display time	250 lux unlimited display time	300 lux unlimited display time
Photogenic drawings Sensitive objects in pristine condition	Watercolours Pastels Japanese prints Portrait miniatures Indian miniatures Coloured prints Leather-bound books Colour photographs Plastics Textiles Furniture with original upholstery Discoloured paper Coloured wax	Black-and-white etchings and engravings Drawings in graphite (pencil), black chalk and charcoal Black-and-white fibre-based photographs Easel paintings Painted furniture Painted sculpture	Stone Glass Metal Ceramics Enamels

How susceptible to light are the materials in an object?

Tabulated information on susceptibility (4)

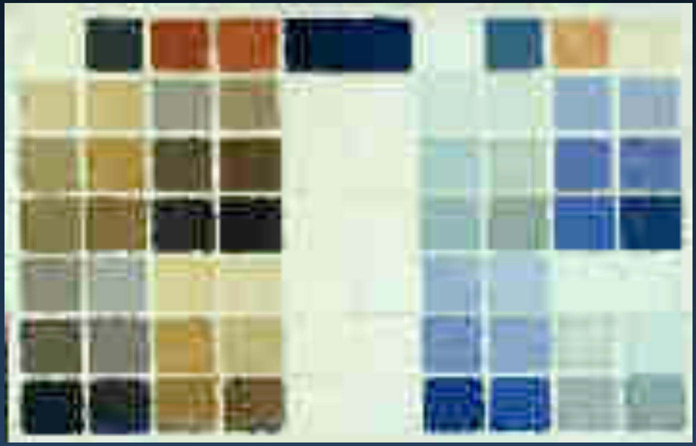
CIE 2004
(CIE 157.2004 Control of damage to Museum Objects by Optical Radiation)

High responsivity	Medium responsivity	Low responsivity	Irresponsive
	ISO≤4	ISO≥5	
Display not recommended	50 lux for 20% of display time	250 lux unlimited display time	300 lux unlimited display time
Silks Colourants known to be highly fugitive Some photographic materials	Costumes Watercolours Pastels Tapestries Prints and drawings Manuscripts Miniatures Paintings in distemper medium Wallpaper Gouache Dyed leather Most natural history objects, including botanical specimens, fur and feathers	Oil and tempera paintings Fresco Undyed leather and wood Horn Bone Ivory Some plastics	Stone Most glass Most metals Ceramics Enamels Most minerals

How susceptible to light are the materials in an object?

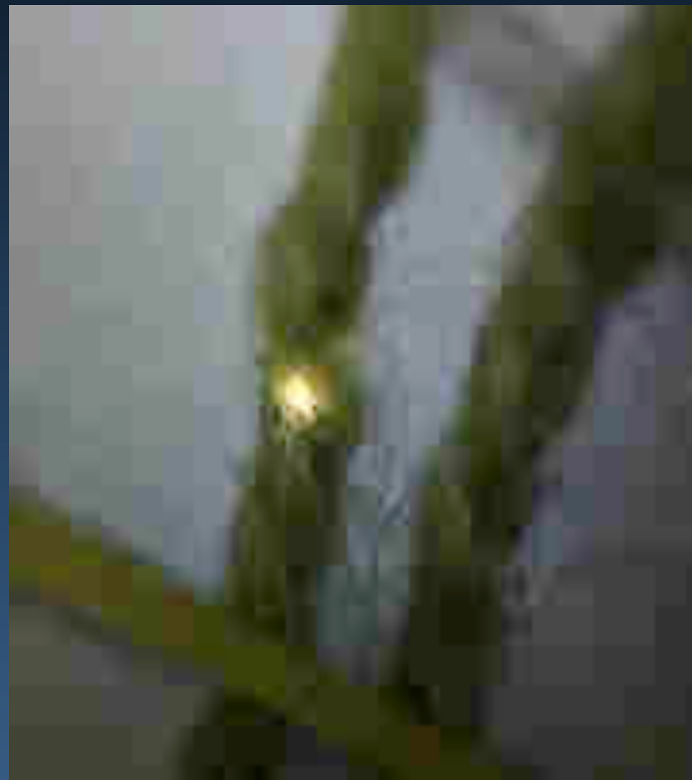
Classifying materials in different sensitivity categories





How susceptible to light are the materials in an object?

Classifying materials in different sensitivity categories



How susceptible to light are the materials in an object?

Tabulated information on susceptibility (5)

Michalski (CCI)

High sensitivity	Medium sensitivity	Low sensitivity	No sensitivity
ISO 1-3	ISO 4-6	ISO 7-8	ISO ≥8
Most plant extracts (historic dyes and lake pigments) Insect extracts (lac, cochineal, carmine) Most early synthetic colours such as the anilines Many cheap synthetic colourants Most felt tip pens Most red and blue ballpoint inks C20 paper tint dyes Certain colour photographs e.g. Kodacolour, Fujicolour	Alizarin dyes and lakes. Madder-type reds containing primarily alizarin, as a dye or lake pigment The colour of most furs and feathers Certain colour photographs e.g. Cibachrome, Kodachrome	Artists palettes classified as 'permanent' e.g. ASTM D4303 Category I; Winsor and Newton AA Structural colours in insects Certain historic plant extracts, especially indigo Silver/gelatine black-and-white prints (not resin coated paper) Many high-quality modern pigments Vermilion	Most mineral pigments True fresco palette Glass Enamels Ceramics Many monochrome images on paper, such as carbon inks Many high-quality modern pigments developed for exterior use

How susceptible to light are the materials in an object?

Relating susceptibility to a degree of change

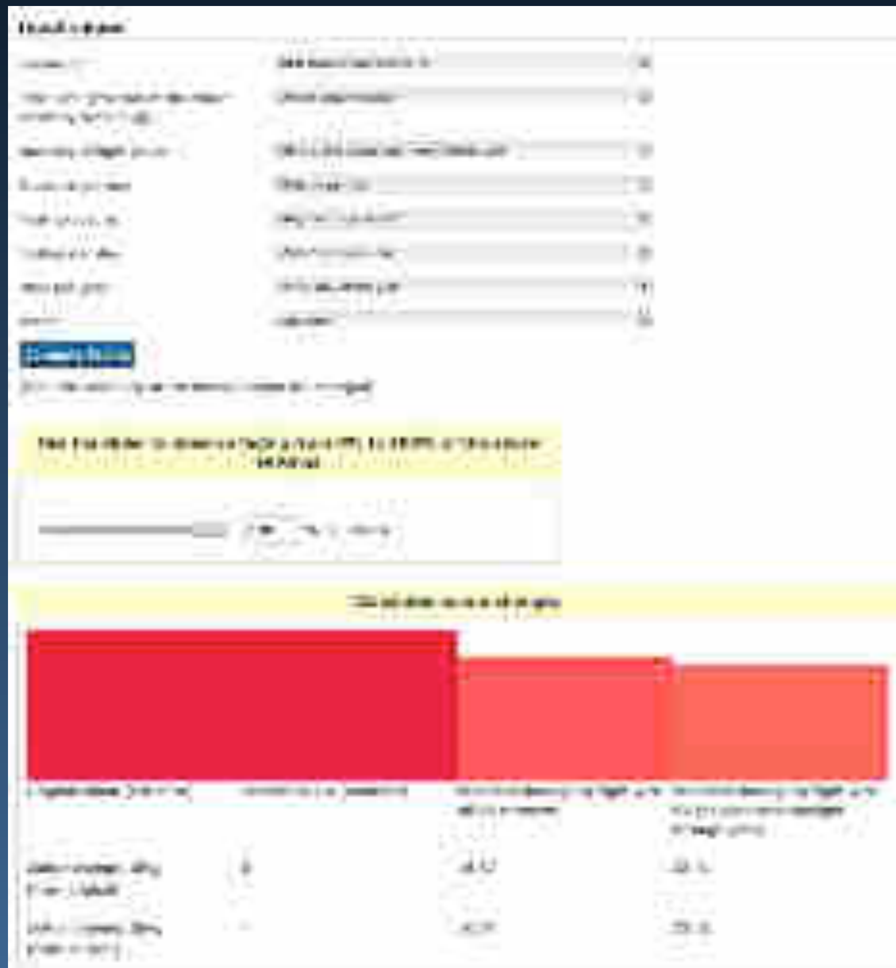
Michalski (CCI)

Exposure Amount	Fade Amount	Low sensitivity	Medium sensitivity	High sensitivity
50 lux	Just noticeable fade	300 – 7000 y	20 – 700 y	1.5 – 20 y
	Almost total fade	10,000 – 200,000 y	700 – 20,000 y	50 – 600 y
150 lux	Just noticeable fade	100 – 2,000 y	7 – 200 y	1/2 – 7y
	Almost total fade	3,000 – 70,000 y	200 – 7,000 y	15 – 200 y
500 lux	Just noticeable fade	30 – 700 y	2 – 70 y	1/7 – 2 y
	Almost total fade	1,000 – 20,000 y	70 – 2,000 y	5 – 60 y
5,000 lux	Just noticeable fade	3 – 70 y	2 m – 7 y	5 d – 2 m
	Almost total fade	100 – 2,000 y	7 – 200 y	6 m – 6 y
30,000 lux	Just noticeable fade	6 m – 10 y	2 w – 1 y	1 d – 2 w
	Almost total fade	20 – 300 y	1 – 30 y	1 m – 1 y

How susceptible to light are the materials in an object?

Relating susceptibility to a degree of change

Michalski (CCI)



https://www.cci-icc.gc.ca/resources-ressources/tools-outils/ldc-cdl/index-eng.aspx

How acceptable is such a change?

People's perceptions of how long an object should last differ, as well as their view of what constitutes an unacceptable change in state

Concepts such as 'loss of value', 'loss of use' and 'end of life' are subjective points, but there are no objective measures of an essentially emotional response

This makes it very difficult to establish policies and guidelines, particularly as the desired life is usually beyond the lifetimes of those involved in making the decision

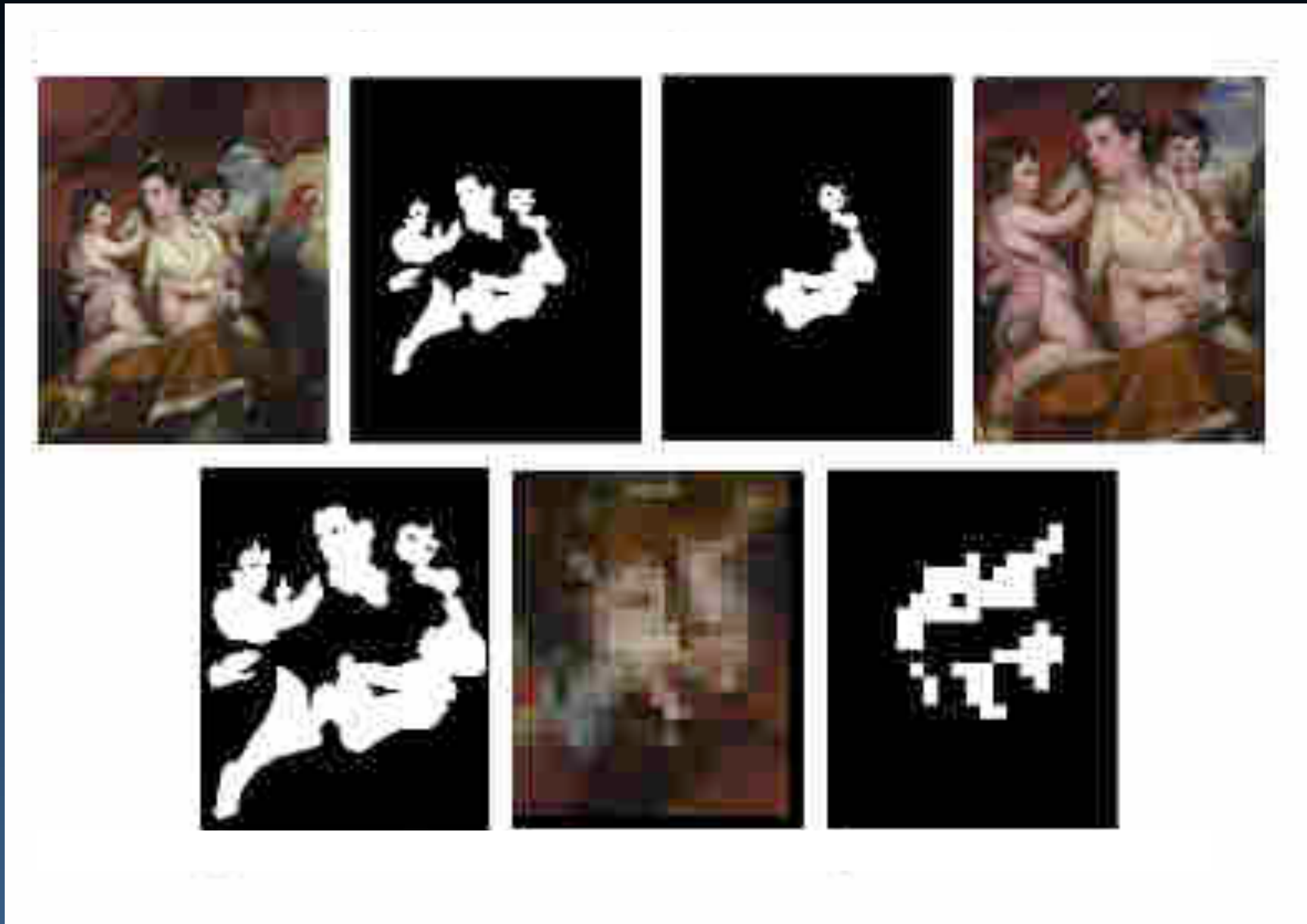
A study by Lindsay found that although museum professionals applied personal perspectives, they generally considered that preserving something for 'the future' implied preservation for a period of around 100 years

Lindsay, *The Conservator* (2005).

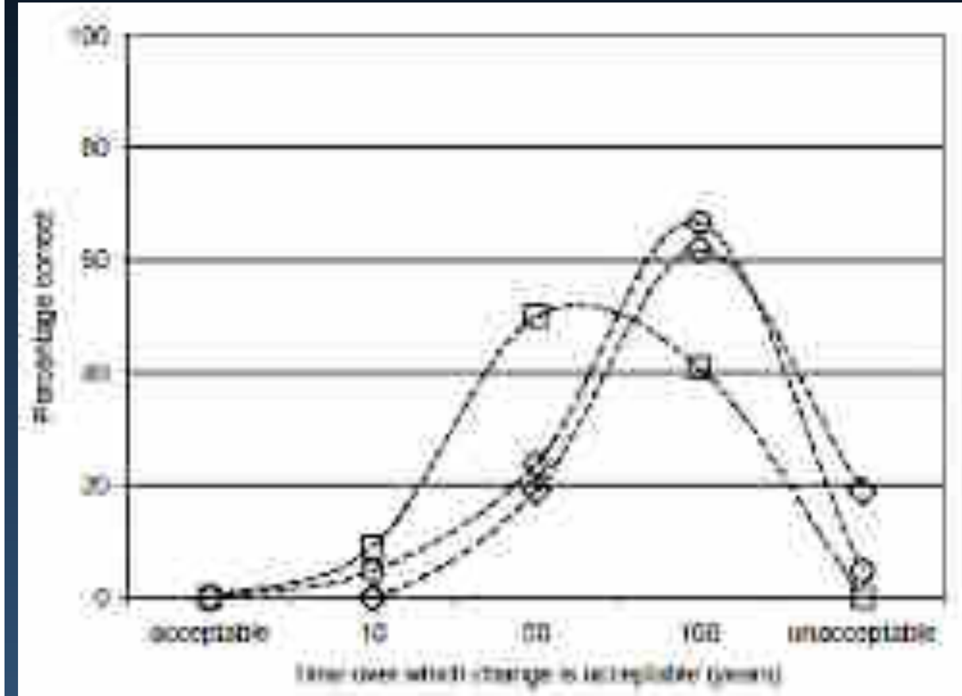
How acceptable is such a change?

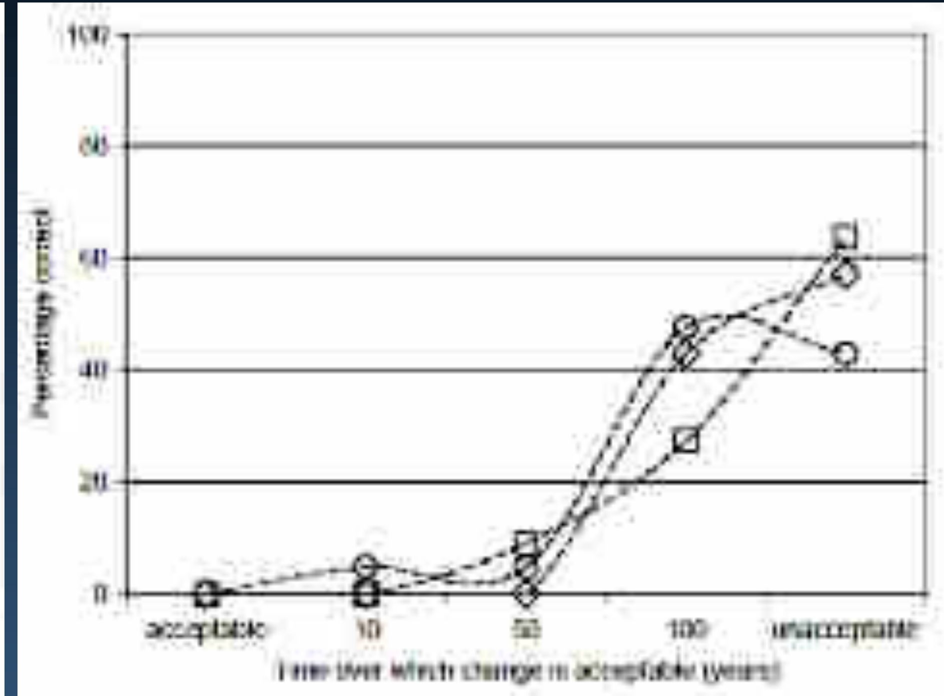
Lady Cockburn and her Three Eldest Sons
Joshua Reynolds
National Gallery, London

How acceptable is such a change?



How acceptable is such a change?





4 ΔE

10 ΔE

Square = whole painting
Diamond = cropped painting
Circle = peripheral changes

How acceptable is such a change?

A study of the fading of Japanese woodblock prints found a loose correlation between the perceived loss of value and the length of time over which a change of this magnitude was deemed acceptable

For example, a change that was judged by a panel to constitute around a 9% 'loss of value' was thought to be acceptable if it occurred over 160 years. The results implied reducing access to this particular collection in future

Average loss of value (%)	Average period of acceptance (years)
6	148
9	163
19	261
46	469
58	490
63	535
82	871

Brokerhof et al., *Conservation and Access* (2008).

Group exercise

Your museum has recently acquired several works by a local artist who died recently. These comprise acrylic paintings that were left in his studio, screenprints from his early career that were hanging on the walls of his apartment and a group of screenprints and charcoal drawings that were in portfolios held by his agent.

You have been asked to call a meeting to decide how best to care for and display these works, including a consideration of how long the works might be expected to last in different display/storage scenarios

- How vulnerable to light do you think these objects are likely to be?
- Will you treat the two groups of screenprints differently?
- What other information will you need before the meeting?
- Who might you involve in the meeting?

Setting and maintaining appropriate light levels

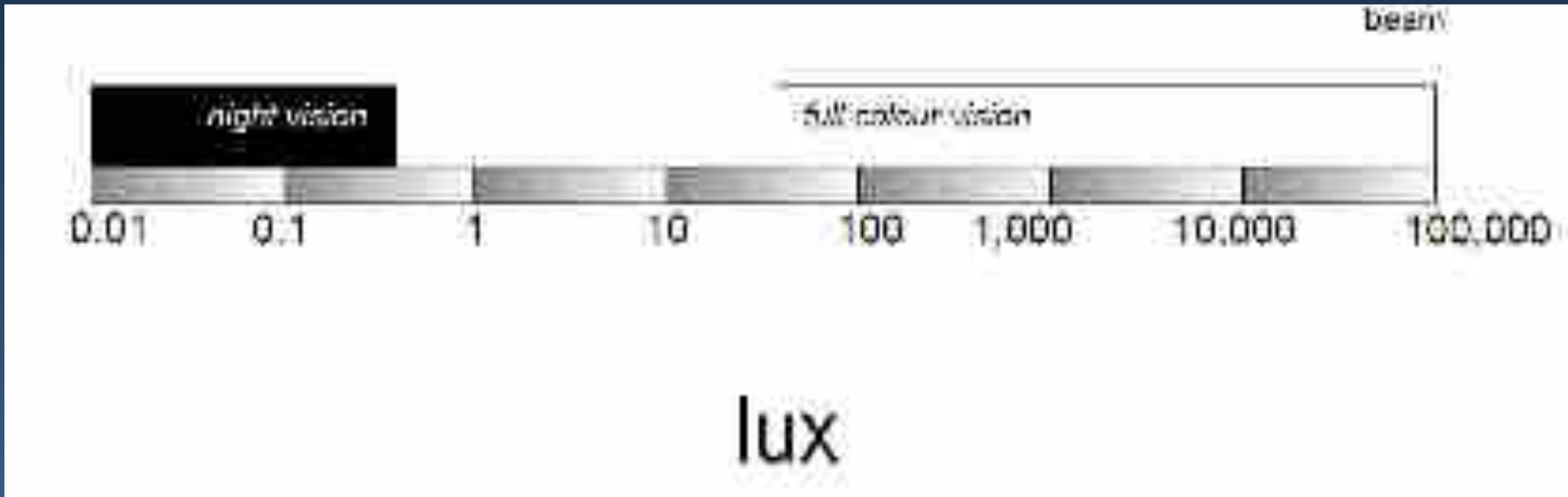
How much light do we (and others) need to see the object?
(and what guidelines have arisen from this?)

Is there a way to modify the type of light to reduce damage?

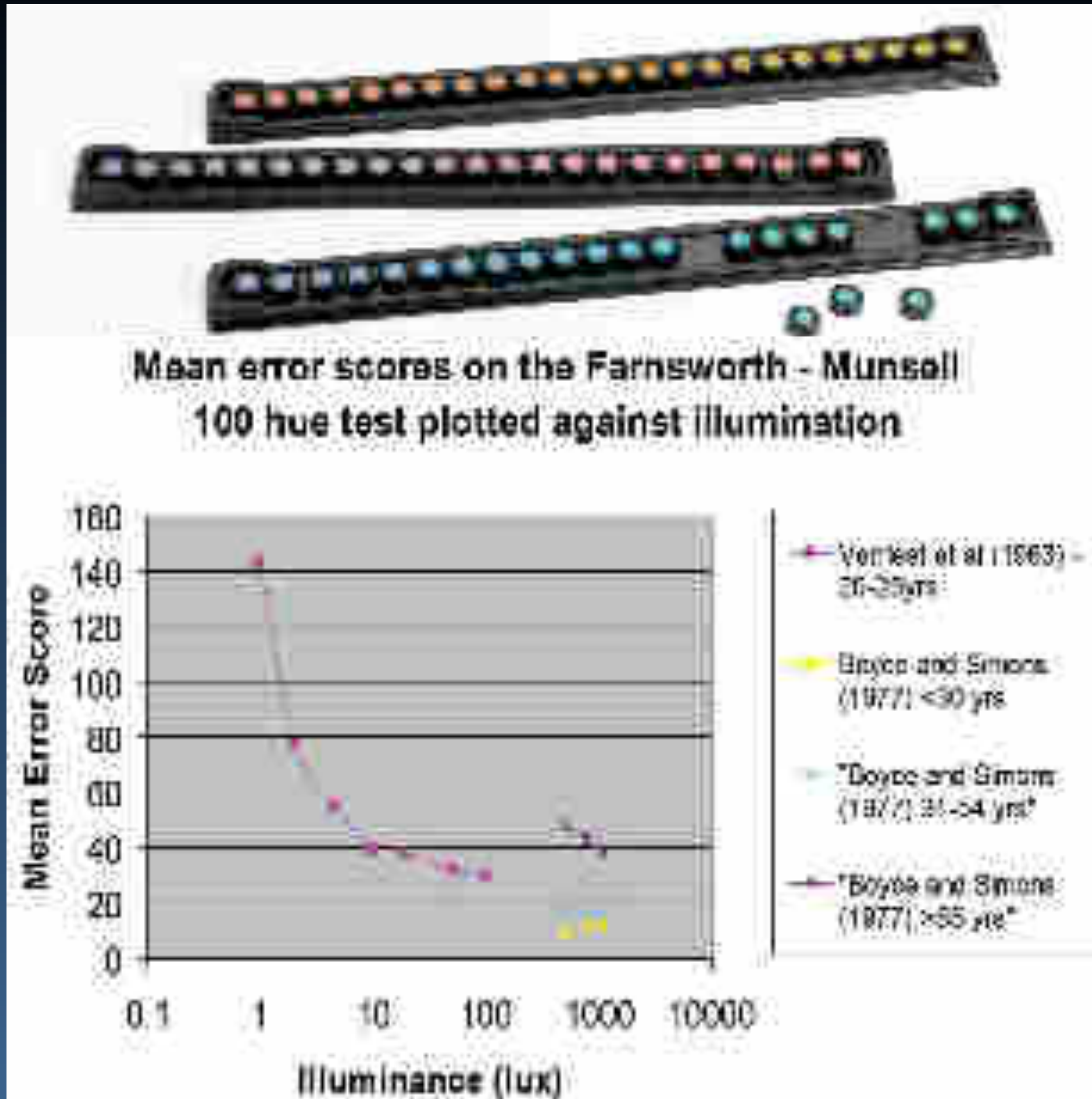
What else can we do to reduce damage?

How much light do we need to see an object?

For comparison, the recommended level on an office desk is 500 lux for 'normal' work and 1000 lux for detailed work



How much light do we need to see an object?



Cannon Brookes (2014)

How much light do we need to see an object?

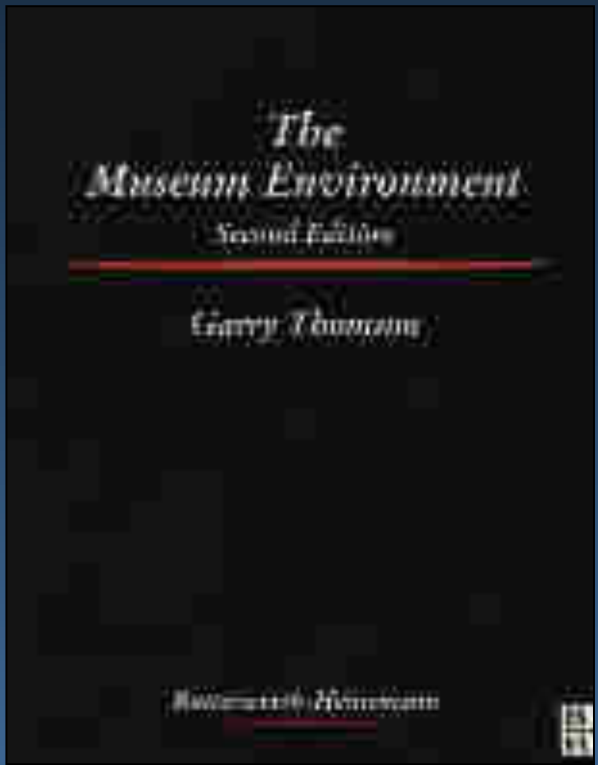
Experiments in museum type environments in the second half of the twentieth century established levels of light that provided comfortable viewing of complex objects at 150 lux, which was later revised to 200 lux

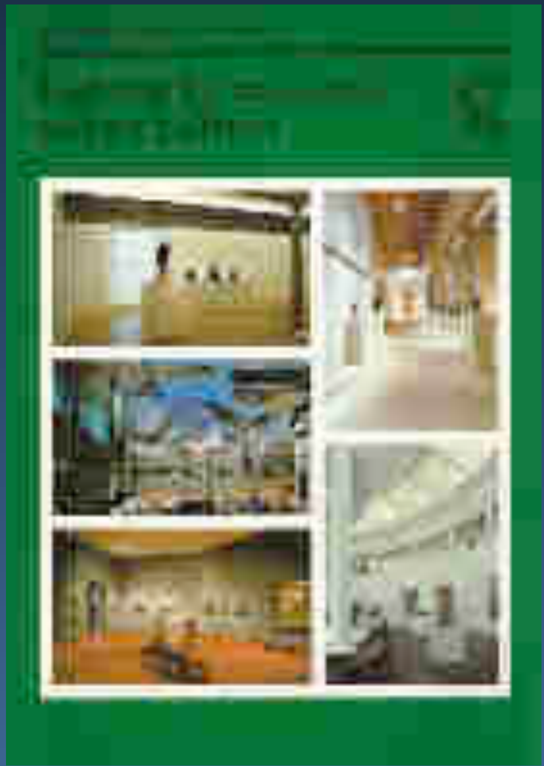
A lower level of 50 lux was considered the minimum level for the average visitor to see objects if well adapted and is often applied to more sensitive objects – for example in prints and drawings galleries

Loe et al., *Lighting Research and Technology* (1982)

How much light do we need to see an object?

Insensitive to light	Objects moderately sensitive to light	Objects highly sensitive to light
Subject to heating effects (300+ lux)	200 lux	50 lux

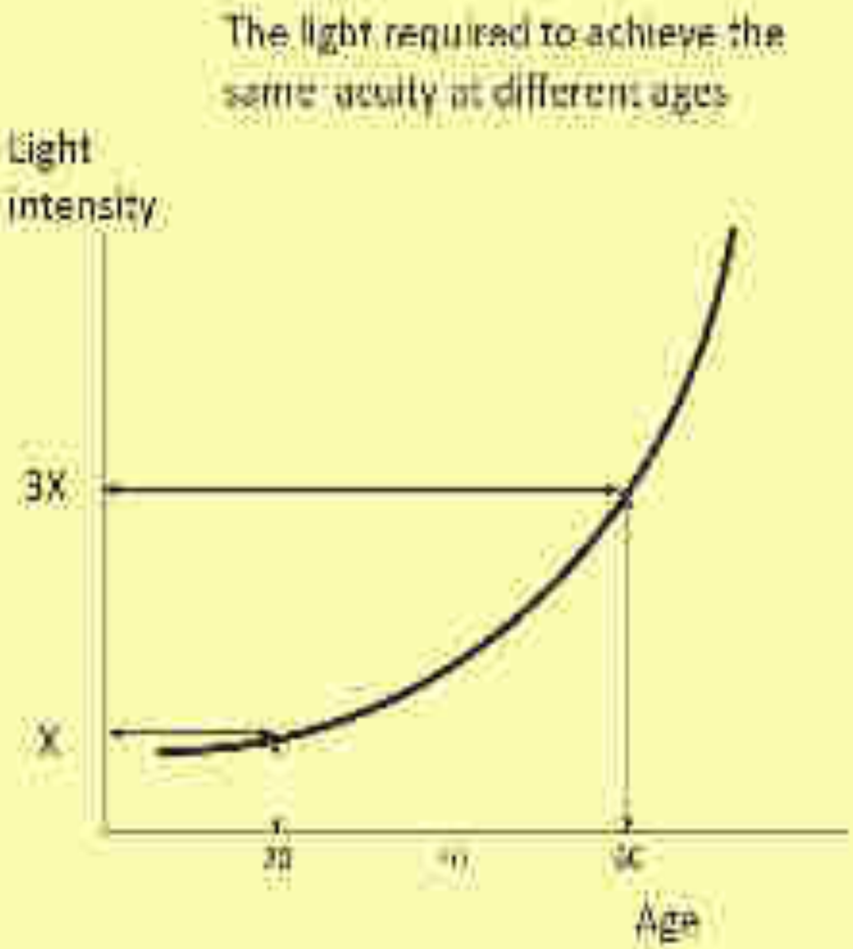


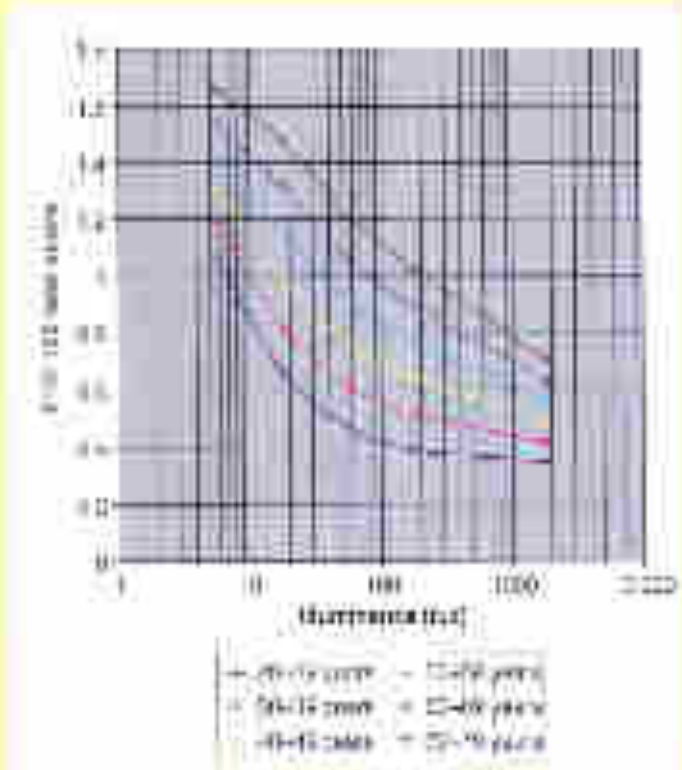


How much light do we need to see an object?

Insensitive to light	Objects with low sensitivity to light	Objects with medium sensitivity to light	Objects with high sensitivity to light
No limit	200 lux	50 lux	50 lux with periodic display
No limit	600,000 lux hours	150,000 lux hours	15,000 lux hours

How much light do we need to see an object?





Tests of colour discrimination using Farnsworth Munsell colour charts. These clearly indicate that visual performance of older people declines.

Cannon Brookes (2014)

How much light do we need to see an object?

50 lux base level

x 3 for older viewers

x 3 for complex viewing tasks

x 3 for darker objects

3 for low contrast objects

= POTENTIALLY ~4000 lux

Modifying the type of light to reduce damage

$$E = h \times \lambda / c$$

The shorter the wavelength, the higher the energy, the more damage can potentially be caused

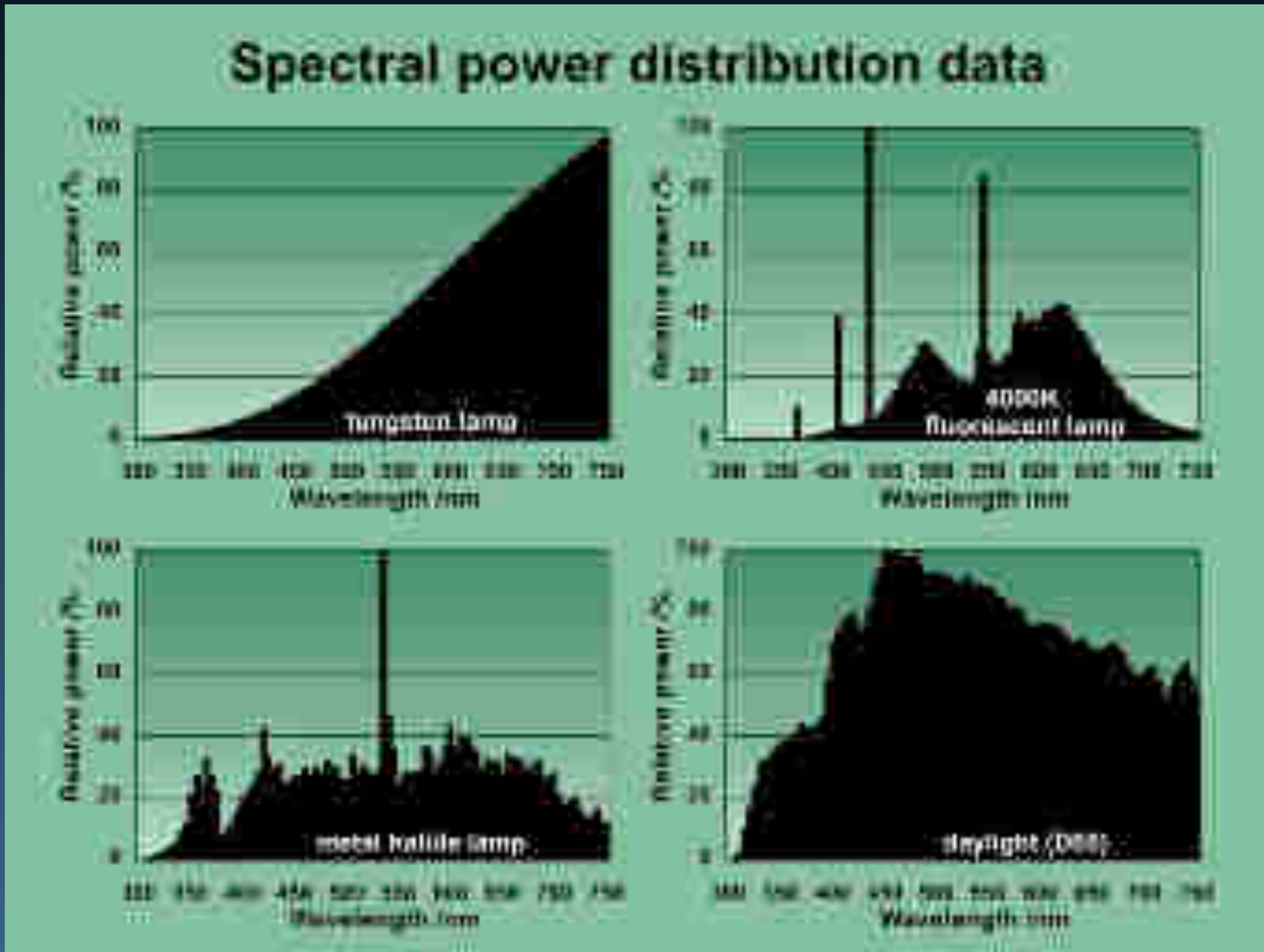
Ultraviolet (UV) has a short wavelength and is not needed to perceive objects, so can be eliminated without affecting their appearance*

We can select sources that have low UV or can apply filters to windows, roofs or lamps to reduce ultraviolet reaching the object

*A minor caveat is that the appearance of fluorescent materials may be altered if ultraviolet is absent

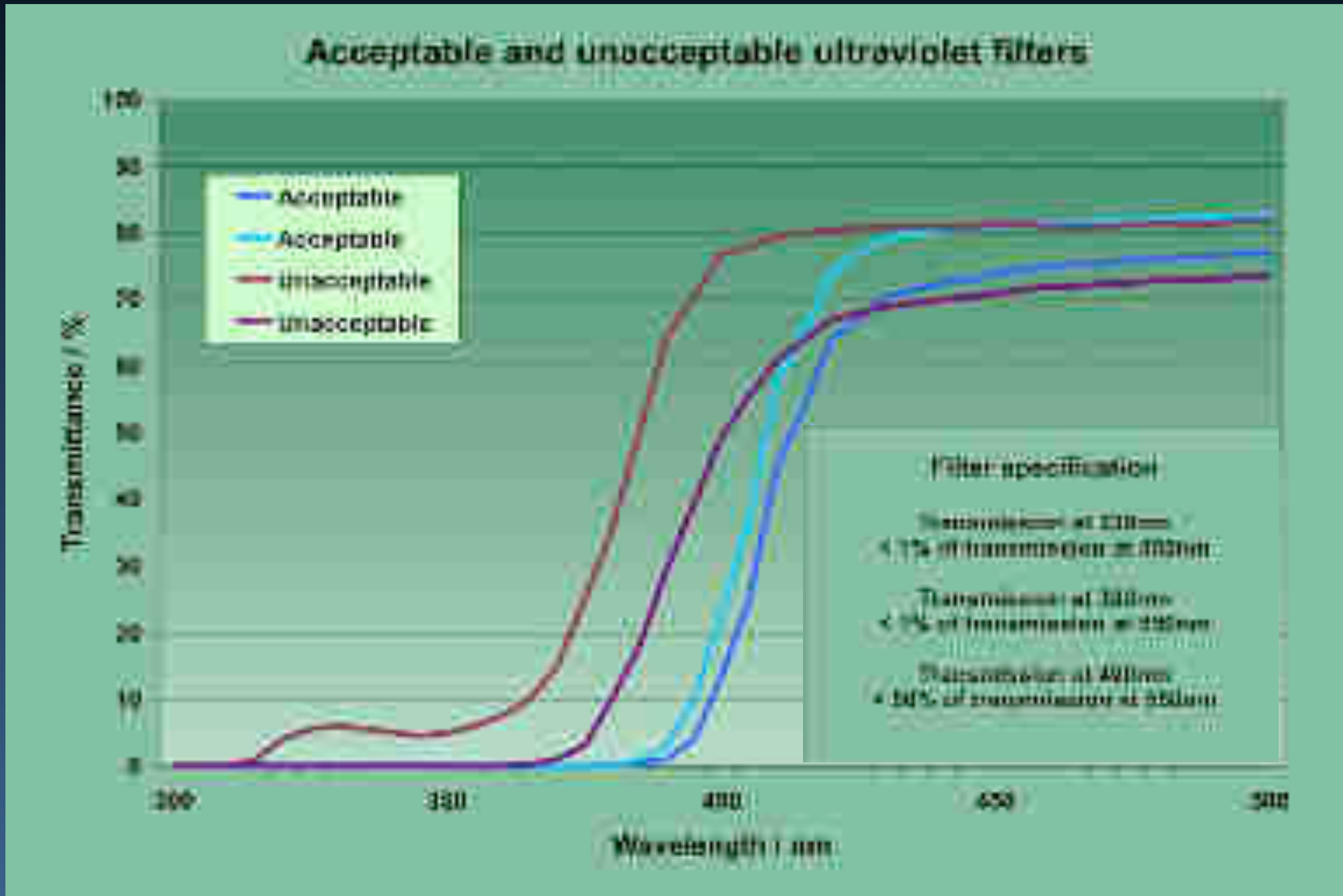
Modifying the type of light to reduce damage

Removing ultraviolet radiation



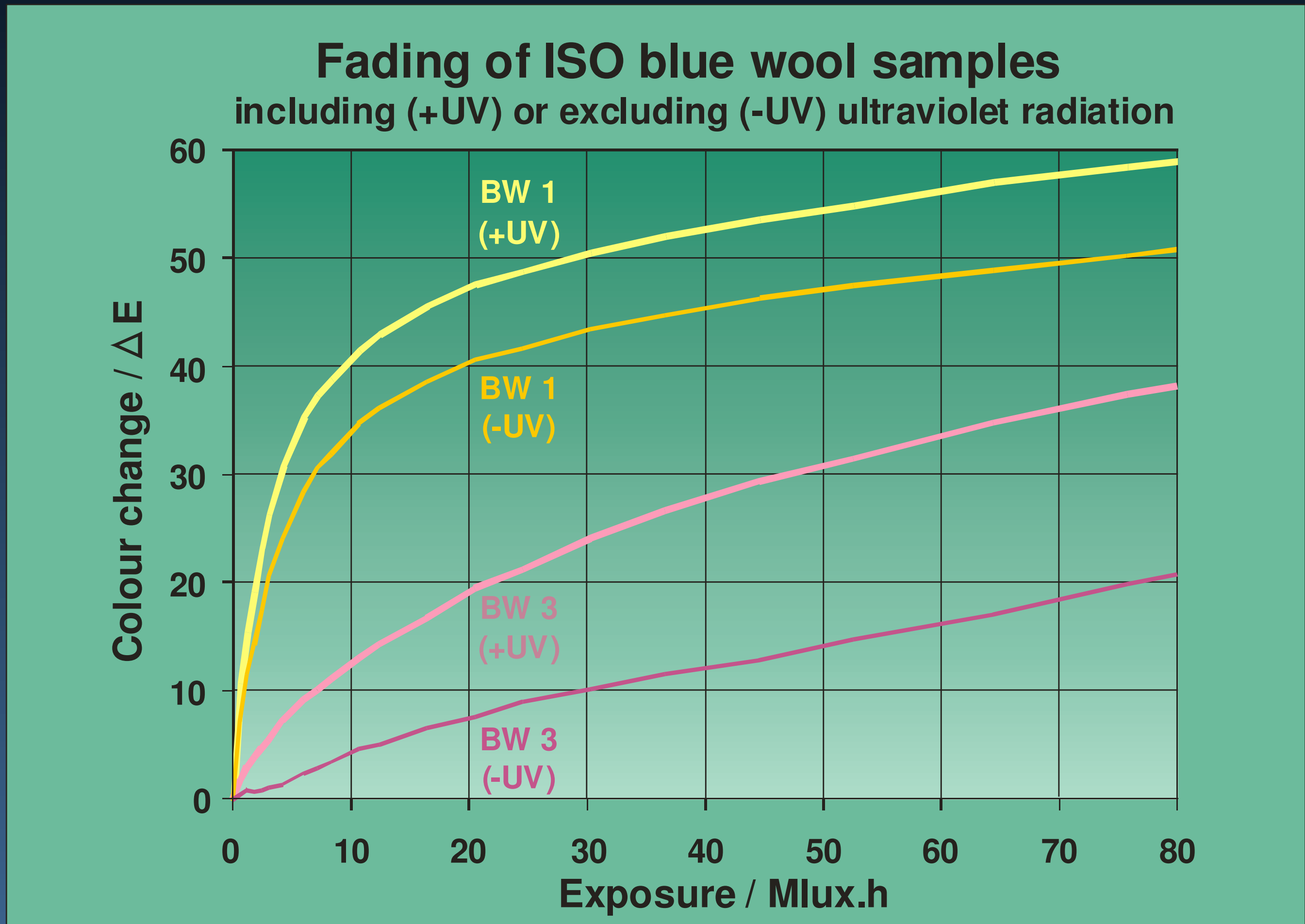
Modifying the type of light to reduce damage

Removing ultraviolet radiation



Modifying the type of light to reduce damage

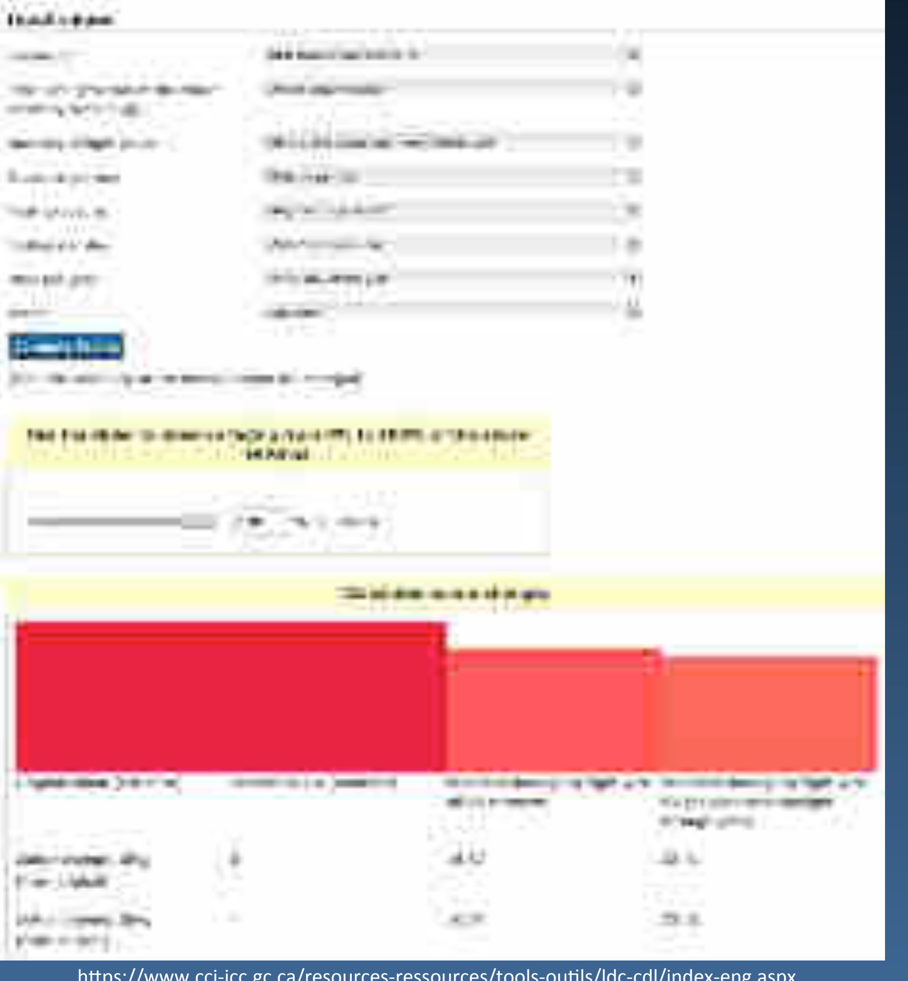
Removing ultraviolet radiation



Modifying the type of light to reduce damage

Removing ultraviolet radiation

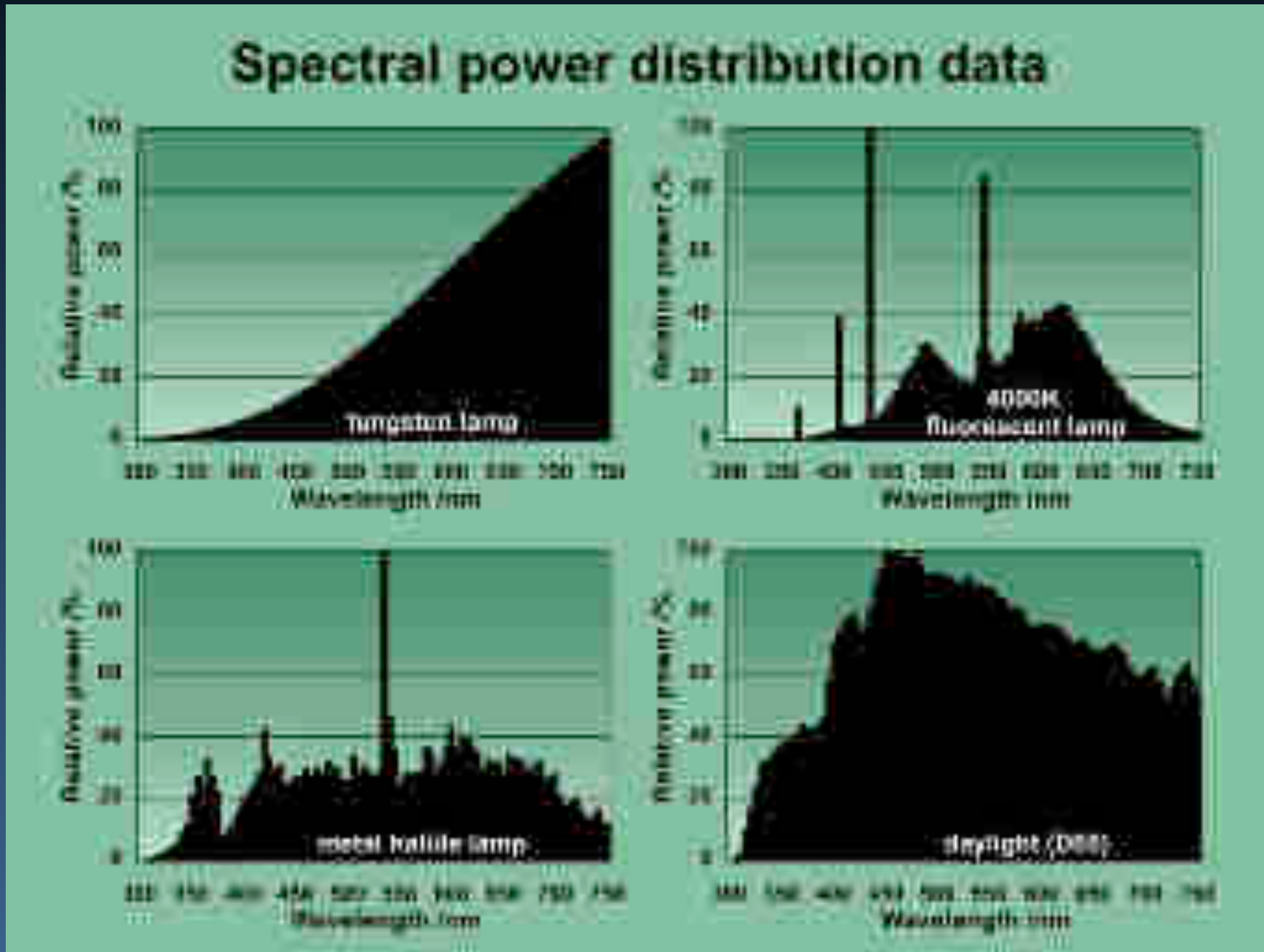
Michalski (CCI)



https://www.cci-icc.gc.ca/resources-ressources/tools-outils/ldc-cdl/index-eng.aspx

Modifying the type of light to reduce damage

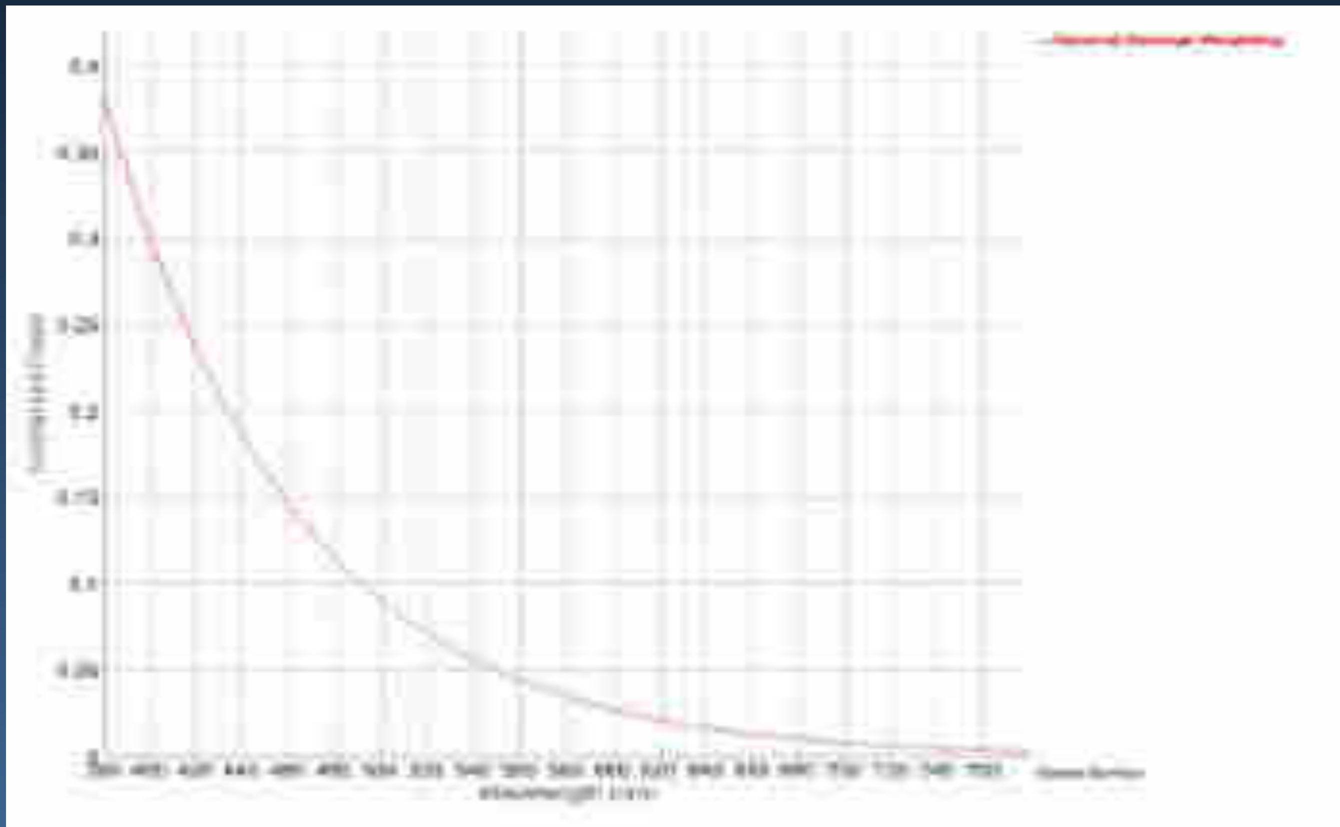
Relative Damage Factor



Modifying the type of light to reduce damage

Relative Damage Factor

$$E = h \times \lambda / c$$

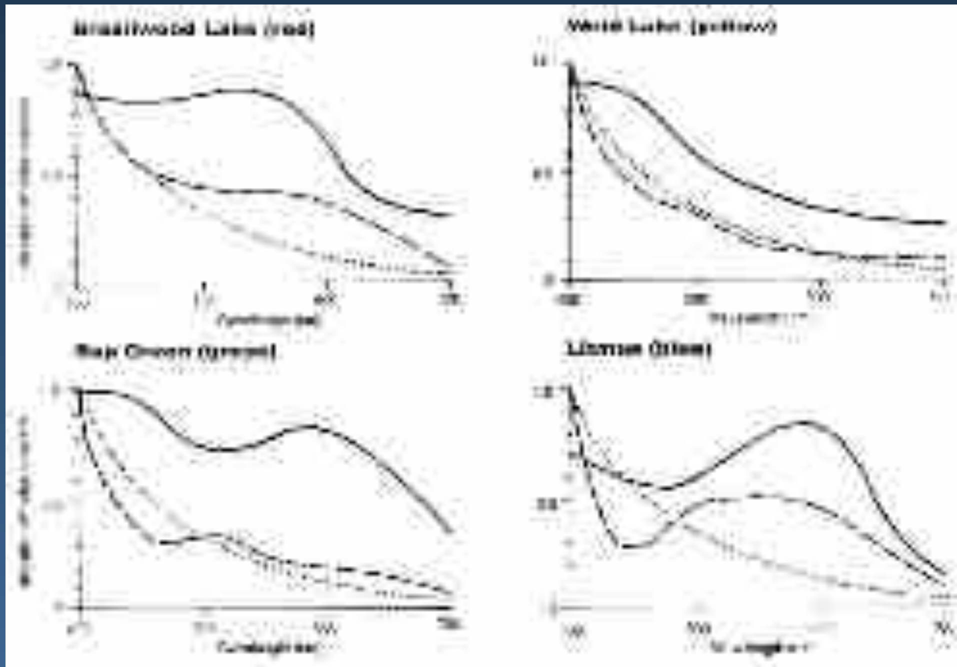


Modifying the type of light to reduce damage

Relative Damage Factor

This implies that blue radiation will be more damaging than green radiation and green radiation more damaging than red radiation, etc.

This is generally found to be the case, but the behaviour is affected by the colour of the object / pigment / dye, as the degree of damage is affected by both the energy of the radiation and the extent to which it is reflected or absorbed

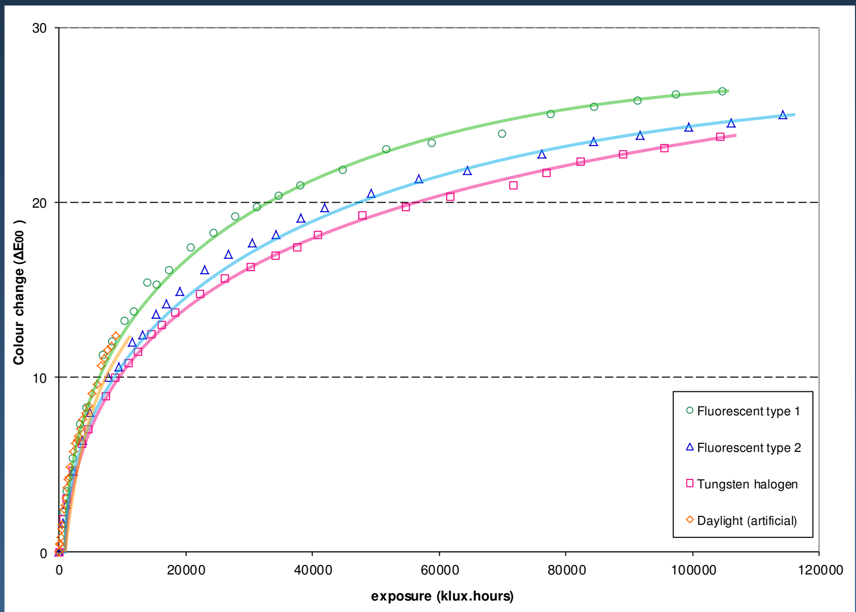


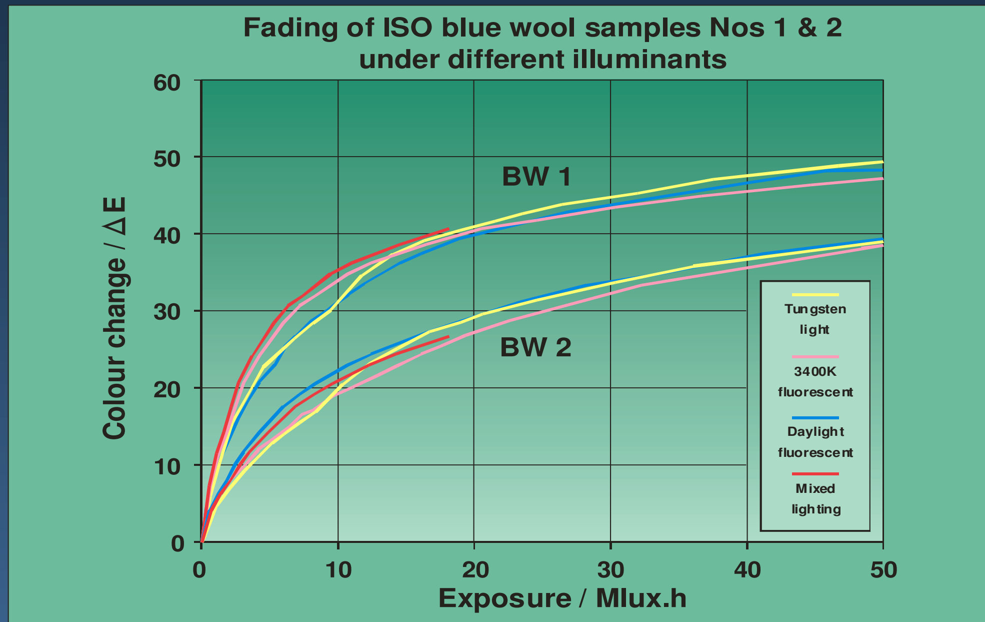
Modifying the type of light to reduce damage

Relative Damage Factor

In reality, direct comparison of damage caused by common light sources used in museums shows little difference in deterioration

This is probably not a factor that should concern us greatly in a mixed collection, providing we eliminate ultraviolet and control light levels





Modifying the light to reduce damage

Main guidance

Eliminate ultraviolet radiation if possible

Reduce light levels while making sure visitors can still see objects

Reduce exposure time – more of this in the next section

The practicalities of lighting objects

Classifying light sources

Types of light available – their pros and cons

Measuring and monitoring light

Lighting for design and preservation

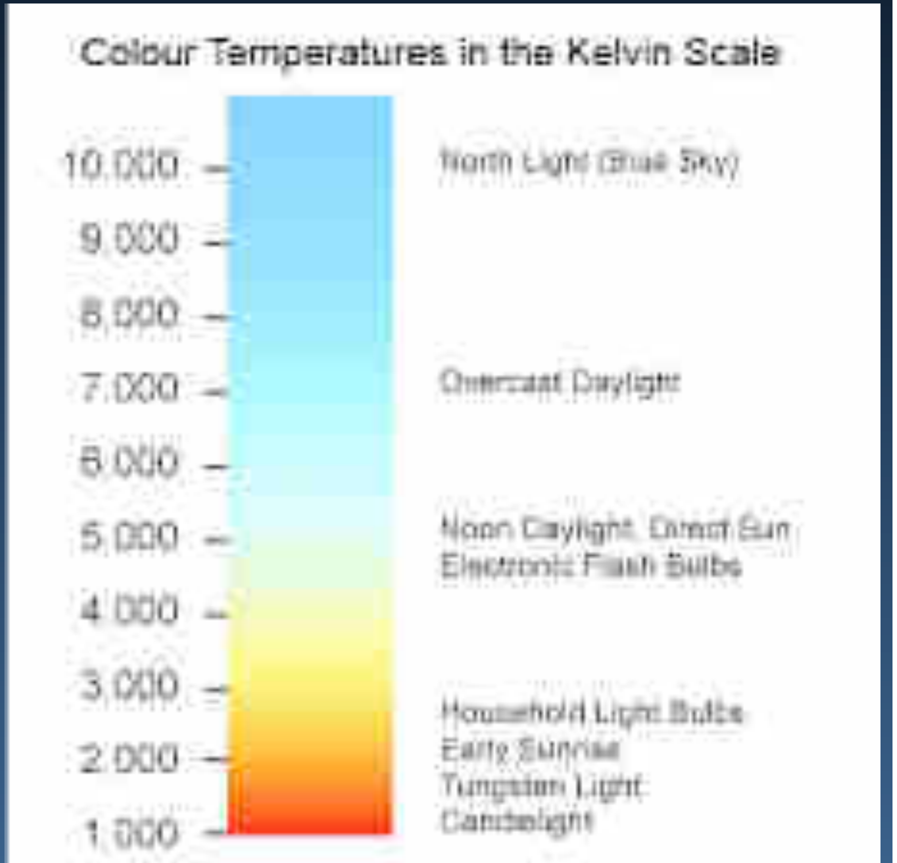
Sustainability

Policy and guidelines

The practicalities of lighting objects

Classifying light sources

Colour temperature



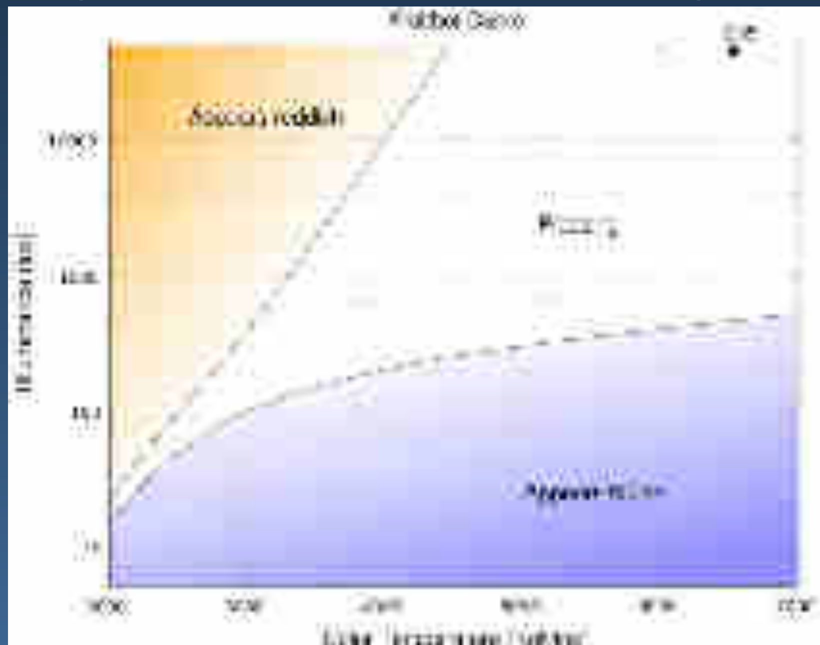
The practicalities of lighting objects

Classifying light sources

Colour temperature preference

In 1941 Kruithof published a graph summarizing the relationship between colour temperature and light levels if a 'pleasant ' illumination were to be provided. Essentially it showed that warmer lights were preferred at lower levels of illumination and cooler lights when the levels were higher

This research has informed much lighting design in museums since



The practicalities of lighting objects

Classifying light sources

Colour temperature preference

In 2000 Weintraub reported experiments that combined cool and warm lights to produce an illumination of *c*.300 lux on paintings. A panel of observers selected lights with a colour temperatures of 3500–3700 K as most pleasing

More recently, experiments with LED lamps by Shaw and others have found that the relationship between colour temperature, level and preference is not as straightforward – and is quite strongly dictated by the object being lit

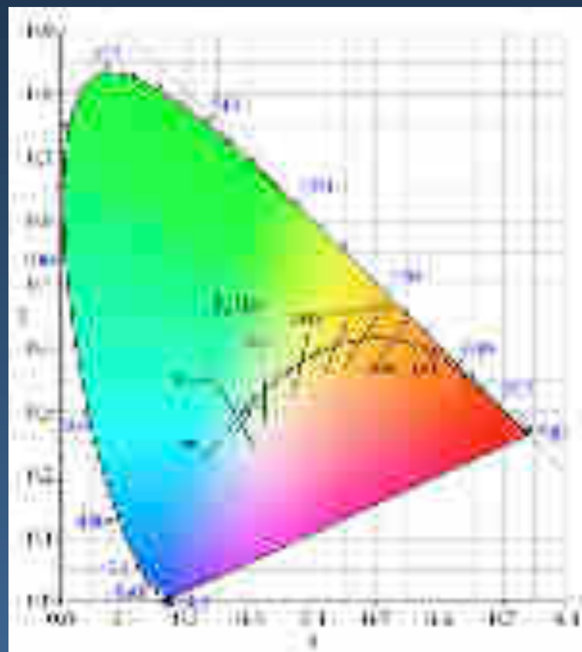
The practicalities of lighting objects

Classifying light sources

Colour rendering index

A method, published by the CIE for quantifying the colour quality of a source. Based on the premise that light sources that correspond closely to the perfect light sources on the locus seen earlier produce the highest quality light

Any type of daylight and any light produced by heating a filament are by definition most likely to produce light of very high quality



The practicalities of lighting objects

Classifying light sources

Colour rendering index (CRI)

Based on how well eight standard test colours are represented under the light from the source (CIE 13.2 - 1974). The general colour rendering index (Ra) is the average of the indices for the eight test colours
Rw is the worst of the eight indices

On this scale 100 is 'perfection' and museums aim for Ra >90 and Rw > 80

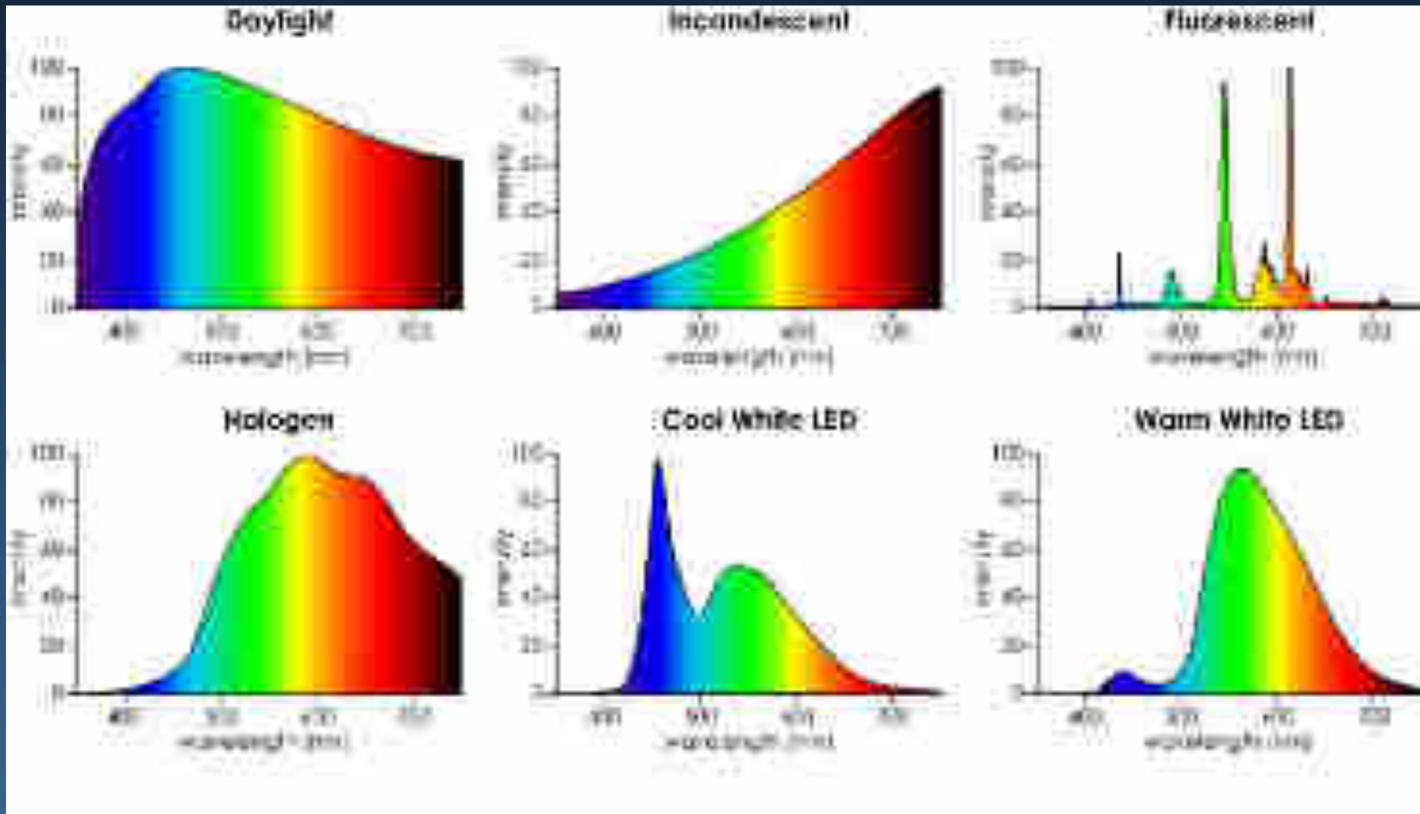
The CRI method has come under increasing criticism, particularly when it is used to describe light sources with 'spiky' SPD curves, such as fluorescent lamps or white LEDs

A new metric, the Colour Quality Scale (CQS) is currently under development

The practicalities of lighting objects

Classifying light sources

Colour rendering index



The practicalities of lighting objects

Pros and cons of light sources

Daylight

Free

Highly sustainable

Highly variable and unpredictable
(which can provide interest but make control extremely problematic)

Colour temperature is dependent on sun component

Very high ultraviolet component

Colour rendering theoretically perfect

Sunlight is strongly directional: skylight is highly diffuse

Has a very ‘natural’ feel

The practicalities of lighting objects

Pros and cons of light sources

Incandescent lighting (tungsten and tungsten halogen)

Comparatively expensive to run

Require frequent replacement

Although lamp performance decreases with time they give reproducible levels (wattage can be selected and lamps can be dimmed)

Colour temperature range rather limited without inefficient filtration

Modern lamps have low ultraviolet content

Colour rendering close to perfect

Point sources allow light distribution to be sculpted from narrow beam to diffuse wash

The practicalities of lighting objects

Pros and cons of light sources

Fluorescent lamps

Moderately expensive to run

Moderately frequent replacement – but contain toxic waste (mercury)

Although lamp performance decreases with time they give reproducible levels
(wattage can be selected and lamps can be dimmed)

Wide colour temperature range through choice of phosphors

Modern lamps have low ultraviolet content

Colour rendering variable – lamps with best CRI often less efficacious

Difficult to sculpt light from more diffuse sources – better for washes

The practicalities of lighting objects

Pros and cons of light sources

LED lamps

Inexpensive to run

Very infrequent replacement – some care needed with disposal

Although lamp performance decreases with time they give reproducible levels (different lamps can be selected and dimmed as needed)

Wide colour temperature range available – but beam colour may be inhomogeneous

Very low ultraviolet content

Colour rendering variable – CRI may not be an appropriate metric?

Point sources allow light distribution to be sculpted from narrow beam to diffuse wash

The practicalities of lighting objects

Measuring and monitoring light

Light meters

These measure lux, which is a measure of how the human eye sees brightness

When comparing the intensity or power output of a single type of light source, for example tungsten halogen, lux levels allow for a good comparison of the overall relative light exposure

The geometry of light meters can differ which may cause some differences in readings

There may be some issues when light sources with very different spectral distributions are compared but these need not be considered in most circumstances

Light meters should be recalibrated routinely to ensure reliable data are gathered

The practicalities of lighting objects

Measuring and monitoring light

Light logging

Measuring lux over a period of time automatically allows the overall exposure of objects to light to be calculated – useful if applying an exposure policy based on lux hours

Dosimeters that change colour in response to light are often placed close to susceptible items

If resources allow, electronic lights sensors can be placed on the wall or plinth (or in cases) near objects. In some instances remote wall-watching sensors are used

The practicalities of lighting objects

Measuring and monitoring light

Light logging

In many instances the resources for constant light logging are not available, so light plans or maps are made of rooms and display cases

These indicate the levels on set up, inform decisions about where certain types of object can be safely placed and act as a basis for housekeeping practices such as closing blinds and curtains or switching on lights

The practicalities of lighting objects

Measuring and monitoring light

Ultraviolet meters

In museums the practice is to measure ultraviolet radiation as a proportion of visible light

The unit frequently applied is microwatts (of UV) per lumen (of visible light). Most organizations aim to maintain a level below **75 microwatts per lumen**

It must be borne in mid that if the light level increases UV increases, thus a small ultraviolet content can represent a great deal of UV if the light level is high

The practicalities of lighting objects

Measuring and monitoring light

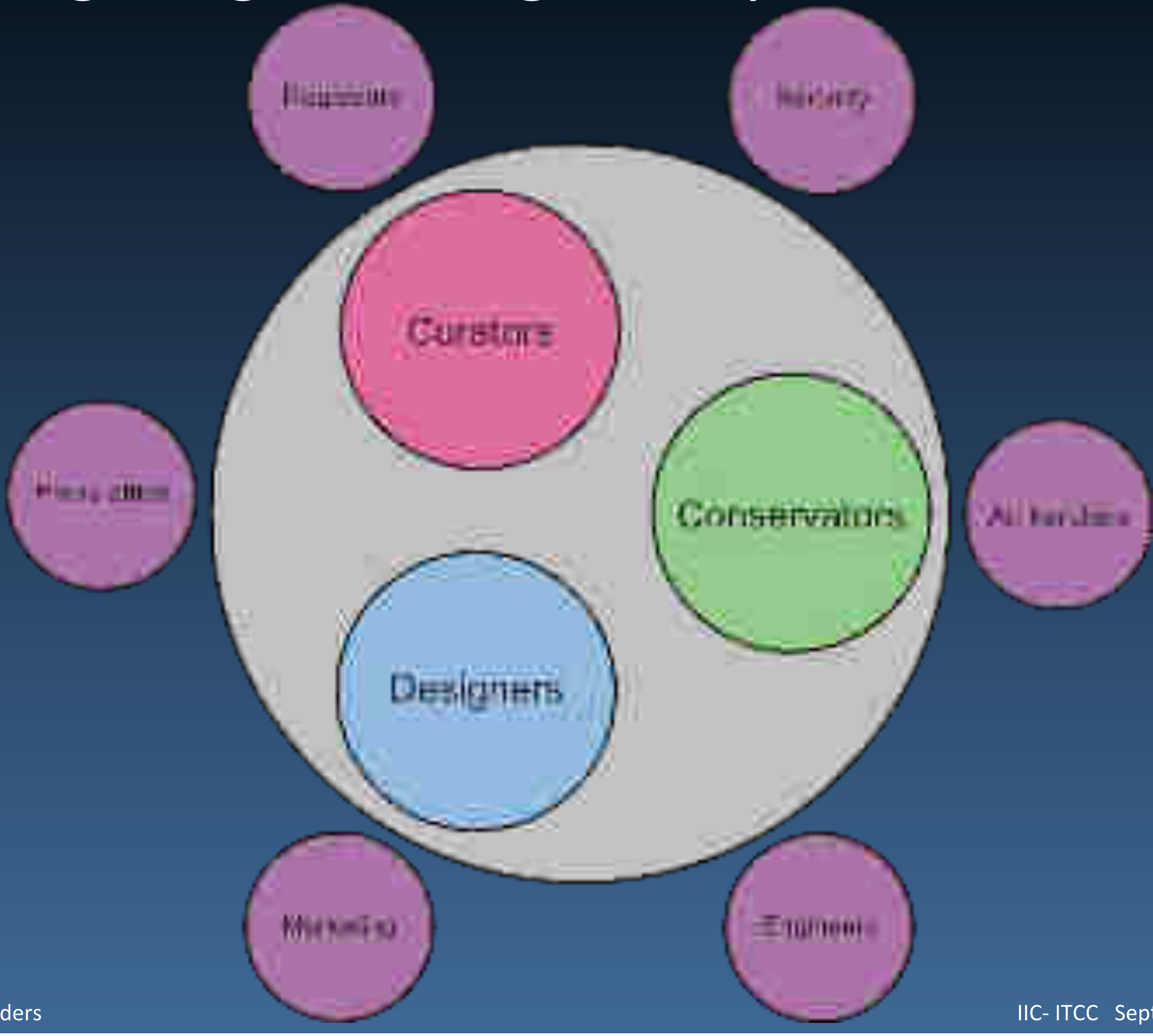
Ultraviolet meters

There is little standardization of the response of ultraviolet meters, but those most frequently used in museums respond to the region 300 – 400 nm

Ultraviolet logging is less widespread and normally takes the form of a survey – perhaps to produce a plan indicating levels. Regular review will highlight failing filters or problem lamps

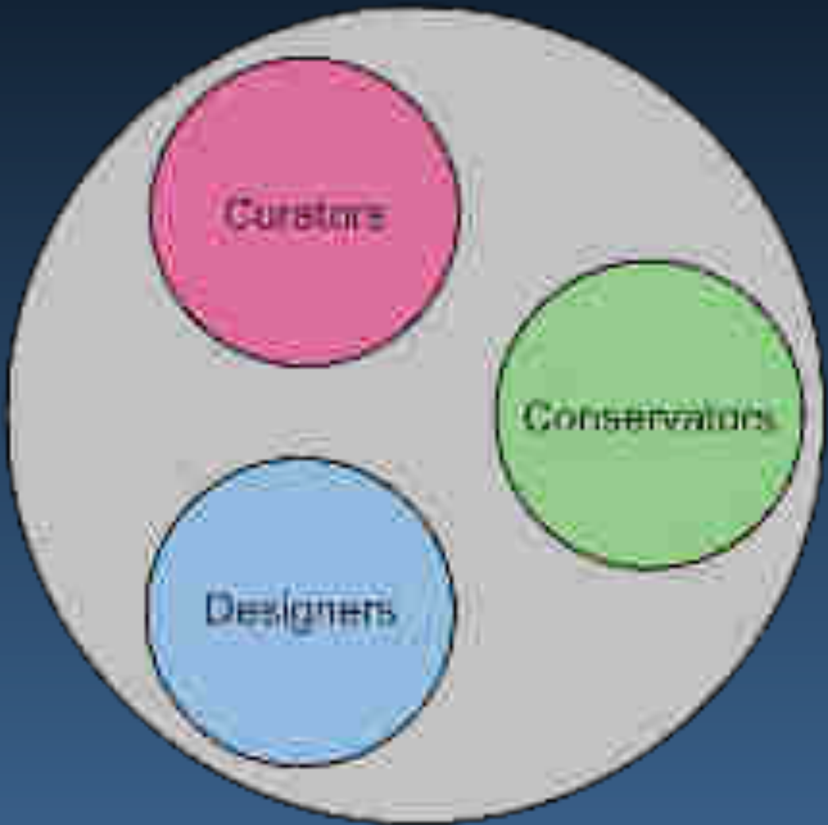
The practicalities of lighting objects

Lighting for design and preservation



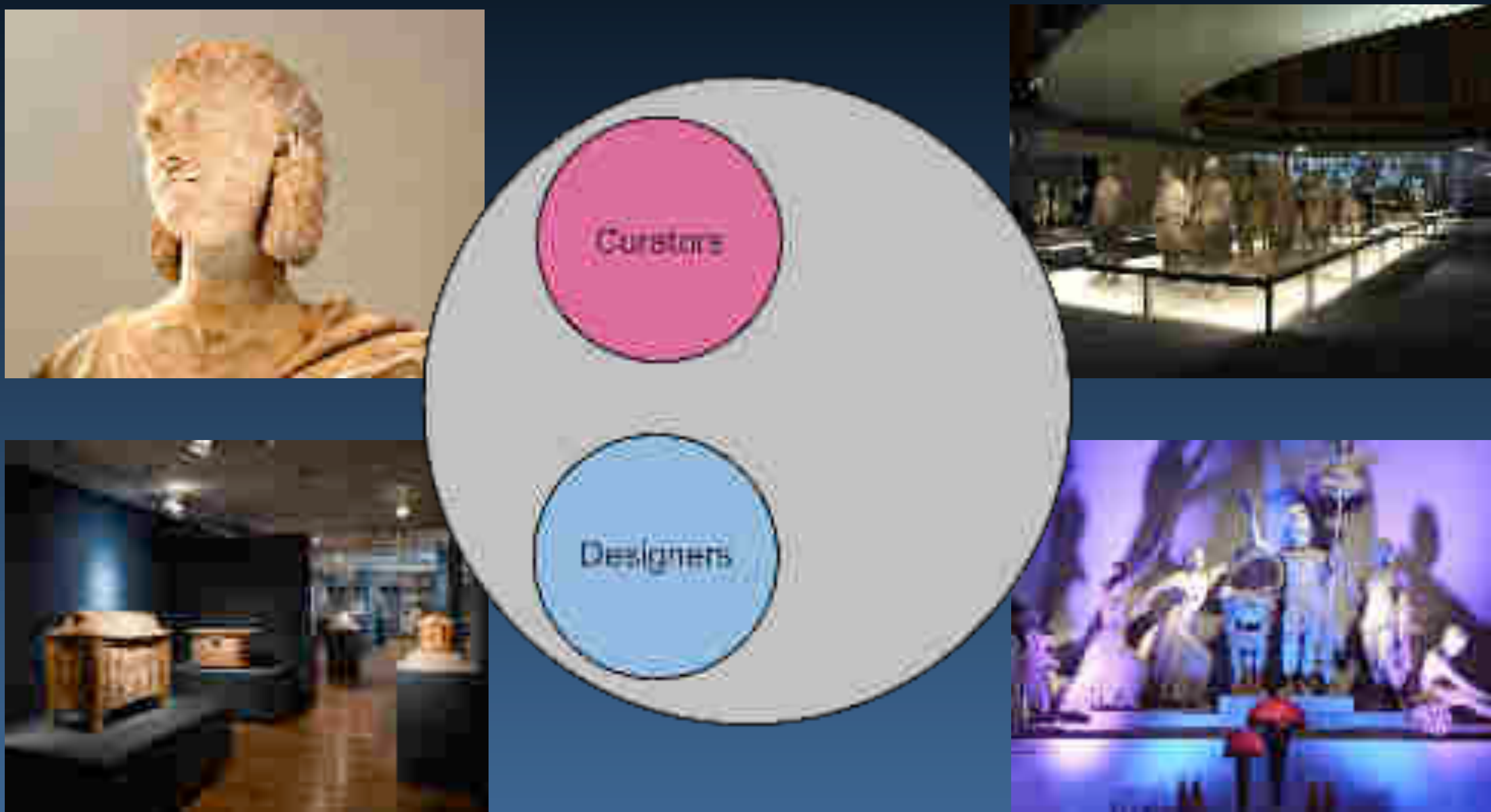
The practicalities of lighting objects

Lighting for design and preservation



The practicalities of lighting objects

Lighting for design and preservation



The practicalities of lighting objects

Lighting for design and preservation

The practicalities of lighting objects

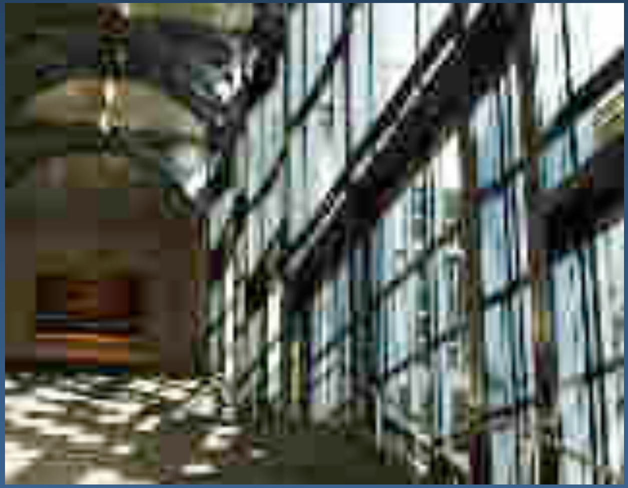
Lighting for design and preservation

Making sure that all light that is used is used to good effect

Ensure that objects are the brightest things in the field of view

Remove or reduce glare from reflected light or adjacent windows

Design routes to allow adaptation to different light levels.



The practicalities of lighting objects

Lighting for design and preservation

Making sure that all light that is used is used to good effect

Reduce levels to those that are still comfortable for the viewer

Differentially light objects or place objects in shade

The practicalities of lighting objects

Lighting for design and preservation

Making sure that all light that is used is used to good effect

Reduce ultraviolet levels by treating windows, rooflights and light sources

Reduce exposure time by blacking out rooms when not in use

The practicalities of lighting objects

Lighting for design and preservation

Making sure that all light that is used is used to good effect

Periodically remove sensitive objects from display to store (rotation)

Reduce exposure time by placing objects behind curtains or covers

The practicalities of lighting objects

Lighting for design and preservation

Making sure that all light that is used is used to good effect

Reduce exposure time by using sensors to detect visitors

The practicalities of lighting objects

Lighting for design and preservation

Making sure that all light that is used is used to good effect

Reduce exposure time by using sensors to detect visitors

The practicalities of lighting objects

Lighting for design and preservation

Making sure that all light that is used is used to good effect

Automatically increase light levels during advertised periods each day to allow improved appreciation and enjoyment while limiting overall exposure

The practicalities of lighting objects

Sustainability

Details of the merits of sources given earlier, but sustainability (e.g. energy use, frequency of replacement and recycling potential) is often at odds with aesthetic properties

Additionally, lower light levels that favour preservation will generally save energy but this is sometimes at the expense of visibility and enjoyment

This quandary is not new. In the 1980s many museums were trialing high quality, high efficacy fluorescent lamps as a replacement for incandescent lamps. Despite the increased energy costs and shorter lamps lives, tungsten halogen lamps were frequently adopted for aesthetic reasons – in a time when energy use by museums was rarely questioned

© National Gallery, London

The practicalities of lighting objects

Sustainability

More recently , museums have reinvestigated fluorescent lamps as a means of saving energy and have been particularly active in researching the use of LED lamps, which offer low energy use and long lamp life. The high cost of retrofitting LED lamps has been deemed worthwhile in many museums and they are frequently employed in new displays

Despite the difficulties of controlling its variability, more effort has been put into maximizing daylight use, as this is a (more-or-less) free and carbon-neutral light source

The practicalities of lighting objects

Sustainability: case study

At the National Gallery in London, government targets for energy consumption reduction were a driver for making increased use of daylight and replacing energy-hungry tungsten halogen lamps with LED lamps

As well as reducing energy consumption, expensive relamping has been much less frequent (reportedly up to 25 times less frequent)

The colour temperature of the LEDs was selected in trials involving curators, conservators and other

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A positive – if unexpected – outcome was that a lower level of artificial light (130 lux as opposed to 150 lux) was preferred when the change was made

The practicalities of lighting objects

Sustainability: case study

Following a pilot study, the LED systems were installed across the whole National Gallery

Some of the costs of the retrofit were borne by the lighting system manufacturer. The estimated savings were:

Gallery	Energy savings	Electric savings	Maintenance savings	CO_2 savings
Sainsbury Wing	£13,100	187,500 Kwh	£11,000	102 tn CO_2
Wilkins Building	£40,500	578,000 Kwh	£25,000	315 tn CO_2
Total	£53,600.00	765,000 Kwh	£36,000.00	417 tn CO_2

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Minor projects to upgrade corridor, restaurant and grand stair lighting to LEDs has saved a further *c*.100 tonnes of CO_2 per annum

The practicalities of lighting objects

Policy and guidelines

Policy

What are we aiming to achieve?

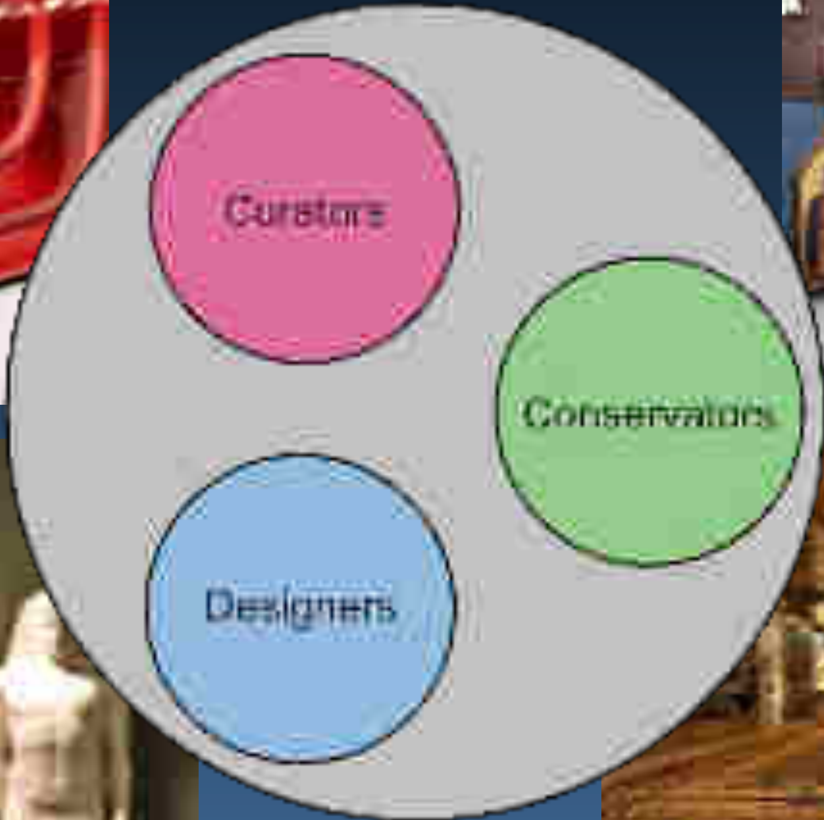
Consider both access and preservation

Inclusivity

Collection lifetime

The practicalities of lighting objects

Policy and guidelines



The practicalities of lighting objects

Policy and guidelines

Guidelines

Need to take account of:

Light and ultraviolet radiation only one of ten agents of deterioration

Materials have different susceptibilities to light damage
(provide straightforward categorisation)

Older viewers, darker objects and complex visual tasks need more light

Control overall light exposure

Eliminate ultraviolet

The practicalities of lighting objects

Policy and guidelines

Guidelines

Insensitive to light	Objects moderately sensitive to light	Objects highly sensitive to light
Subject to heating effects (300+ lux)	200 lux	50 lux

Insensitive to light	Objects with low sensitivity to light	Objects with medium sensitivity to light	Objects with high sensitivity to light
No limit	200 lux	50 lux	50 lux with periodic display
No limit	600,000 lux hours	150,000 lux hours	15,000 lux hours

The practicalities of lighting objects

Policy and guidelines

Criterion code	Description	Examples of Object	Specific Objects	Light level (lux)	Cumulative exposure (lux.h.year^{-1})*	Ultraviolet level (μW.lumen^{-1})
E	**Highly Sensitive:** Light-sensitive objects restricted to temporary light exposure	Certain Chinese and Japanese scrolls or screens and Japanese prints, rare coloured prints, watercolours and pristine material.		50 (10% display in any 10 years)	15,000† (i.e. 150,000 in any 10 years)	75
D	**Very Sensitive:** Light-sensitive objects not suitable for permanent display	Coloured prints and drawings. Organic materials with sensitive dyes and pigments including textiles, ivory and bone, waxes, sugars and quillwork. Also unstable plastics, feathers, semi-tanned skin, gut-skin, and some plant fibre materials including bark-cloth.		50 (20% display in any 10 years)	30,000 † (i.e. 300,000 in any 10 years)	75
C	**Sensitive:** Light-sensitive objects	Black and white prints. Oriental lacquer. Fayum mummy portraits. Leather. Large scale Egyptian material with fugitive pigments/dyes and brittle varnish that it is not practical to rotate. Mummies. Cartonnages and coffins with madder or original pistachio/mastic varnishes. Papyrus	Lindow man. Vindolanda writing tablets. South Cerney head/foot.	50	150,000 † (i.e. 1,500,000 in any 10 years)	75
B	**Moderately sensitive:** Moderately light-sensitive objects	Most organic materials, including coffins, cartonnages, icons, paintings on canvas, unpainted ivory, bone, wax or sugar. Silver objects with silver chloride patina.		200	600,000	75
A	**Insensitive:** Objects unaffected by light	Most inorganic material, including stone, ceramics, iron, copper alloys, glass, enamels. Stable monumental wooden sculpture	Amaravati sculptures	500+	No criterion	75

* Assumes opening hours of 3000 hours per annum (current BM hours ~3020)
† Maximum 100 lux

Lighting criteria for display and loan of the BM collection

The practicalities of lighting objects

Policy and guidelines

Category	Light level (lux)	Cumulative exposure (lux.h.year^{-1})*	Number of three-month exhibitions per 10 years assuming a light level of:		
			50 lux	70 lux	
E Highly sensitive	50 lux (10% display in any 10 years)	15,000 † (150,000 in any 10 years)	**4**	**3**	
D Very sensitive	50 lux (20% display in any 10 years)	30,000 † (300,000 in any 10 years)	**8**	**6**	
			Months per year on display assuming a light level of:		
			50 lux	70 lux	100 lux
C Sensitive	50 lux	150,000 † (1,500,000 in any 10 years)	**12**	**9**	**6**

* Assumes opening hours of 3000 per annum (current BM hours ~ 3020)
† Maximum 100 lux

Lighting calculator for drawings and watercolours

Group exercise

A collection of watercolour paintings is being considered for loan to the country in which they were painted to celebrate an important national anniversary

You have been asked to develop a short lighting policy and a set of guidelines for the storage and display of these objects while on loan

What might be its major elements?

After developing the policy, it is decided to lend the collection to two other museums in that country

How might this affect your policy and guidelines?

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