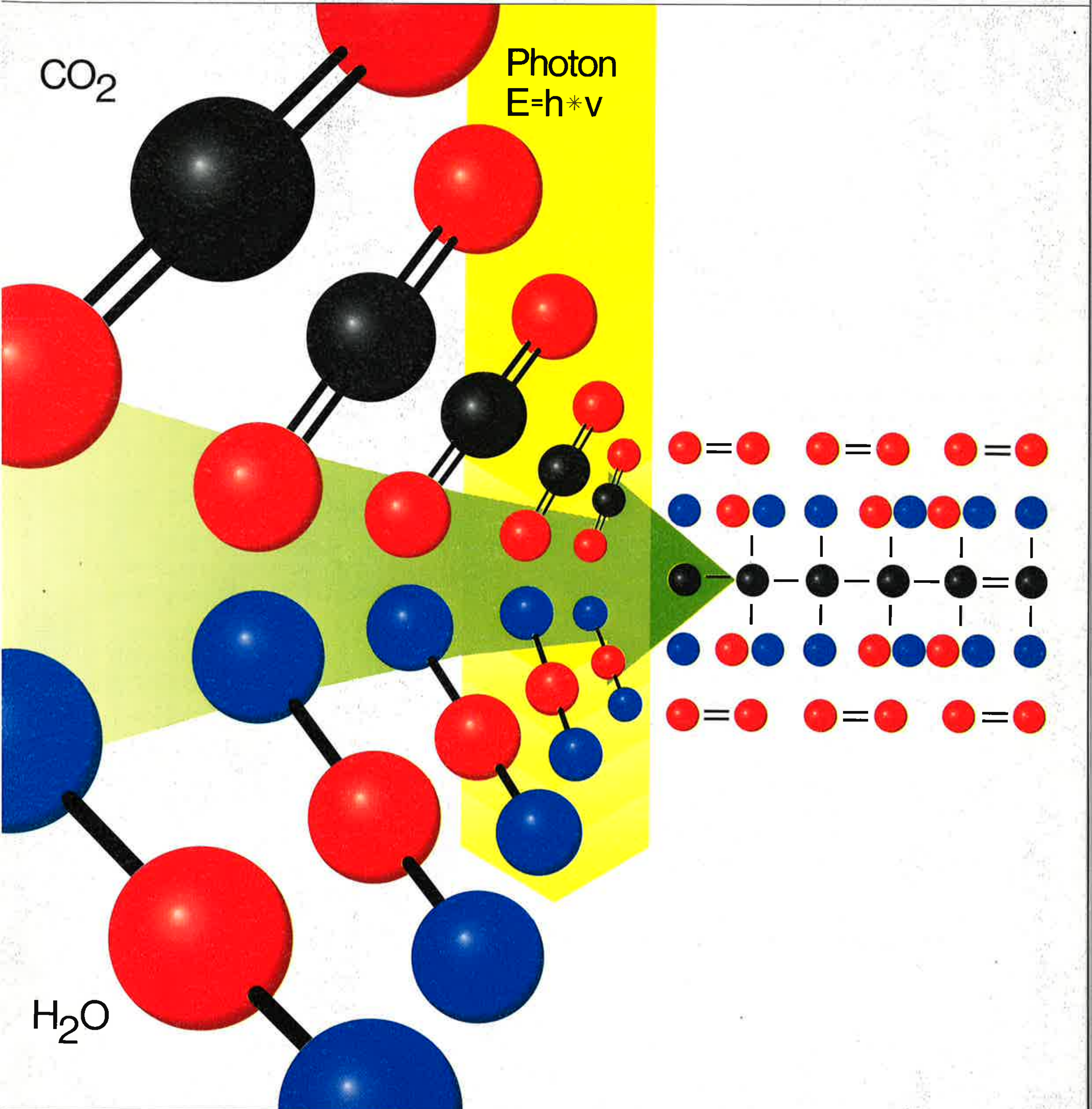
Fundamentals of Light Sources and Photochemistry



SYLVANIA GTE

Fundamentals of Light Sources and Photochemistry

For standard lighting applications, we select light sources for their colour temperature, their colour rendering properties and their luminous efficacy. We design lighting installations to obtain the required illuminance in lux or luminance distribution. There are, however, many applications where the radiation from the light source will lead to photochemical reactions with the materials or goods which are irradiated. They may result in undesired colour fading of textiles, or on the contrary, in necessary photobiological response in the case of plant lighting.

By choosing light sources not only for the above mentioned criteria but also for their particular spectral power distribution, we can influence the rate of photochemical reaction to obtain the desired end result, i.e. reduced or accelerated rates of photochemical reaction.

Radiation from Light Sources

The Electromagnetic Spectrum of Radiations

Cosmic	Gamma	X-Rays	Ultra Violet	Visible	Infra Red	TV, Radio

0.01 0.14 100 400 700 2000 nm

Wavelength in nanometers

Natural or artificial light is radiated electromagnetic power which we can measure and present in the form of spectral power distribution diagrams. We provide this information in our catalogues for the various light sources. These diagrams allow us, for example, to measure the radiated wavelength in milli-Watts (1/1000Watts) against the vertical axis.

For the practical use of this information we have to remember that the measurement of the radiation from a light source is made under laboratory conditions for the naked lamp. In practice the light source is always integrated into a luminaire with which it interacts. Depending on the materials which are used for the reflector or cover, the radiation from the luminaire may vary considerably, particularly the radiations of shorter wavelength in the visible (blue), and in the ultraviolet spectrum.

The following diagrams show typical reflectance and transmission properties of various materials used in luminaire design.

We can also modify the spectral power distribution in the ultraviolet, visible and infrared with specifically selected filter glass or plastic covers.

To judge the suitability of a light source for a given application, we should thus consider the effective range of radiations which irradiate the object or merchandise.

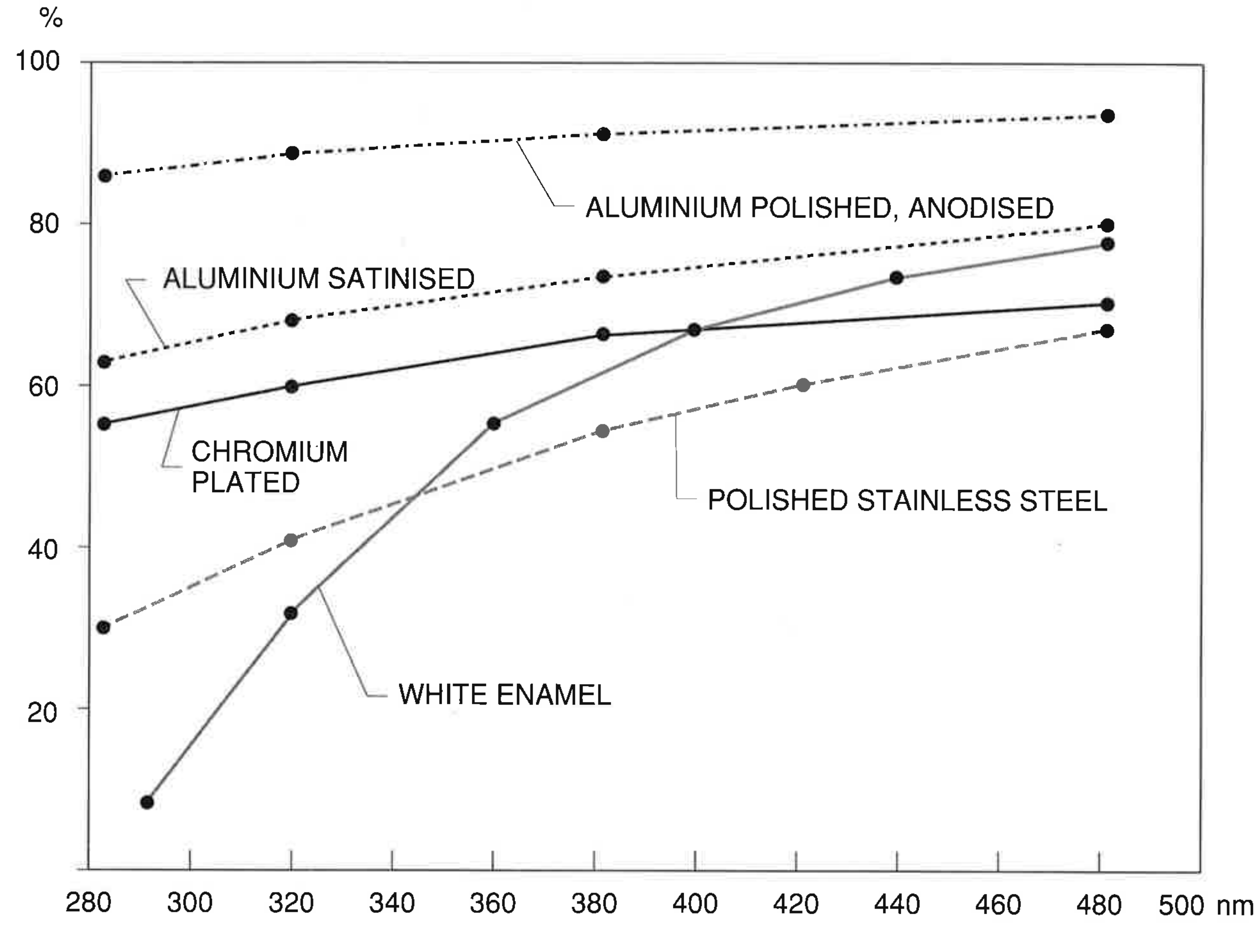


Fig 1 - Reflectance values for various materials in the visible (blue) and ultraviolet

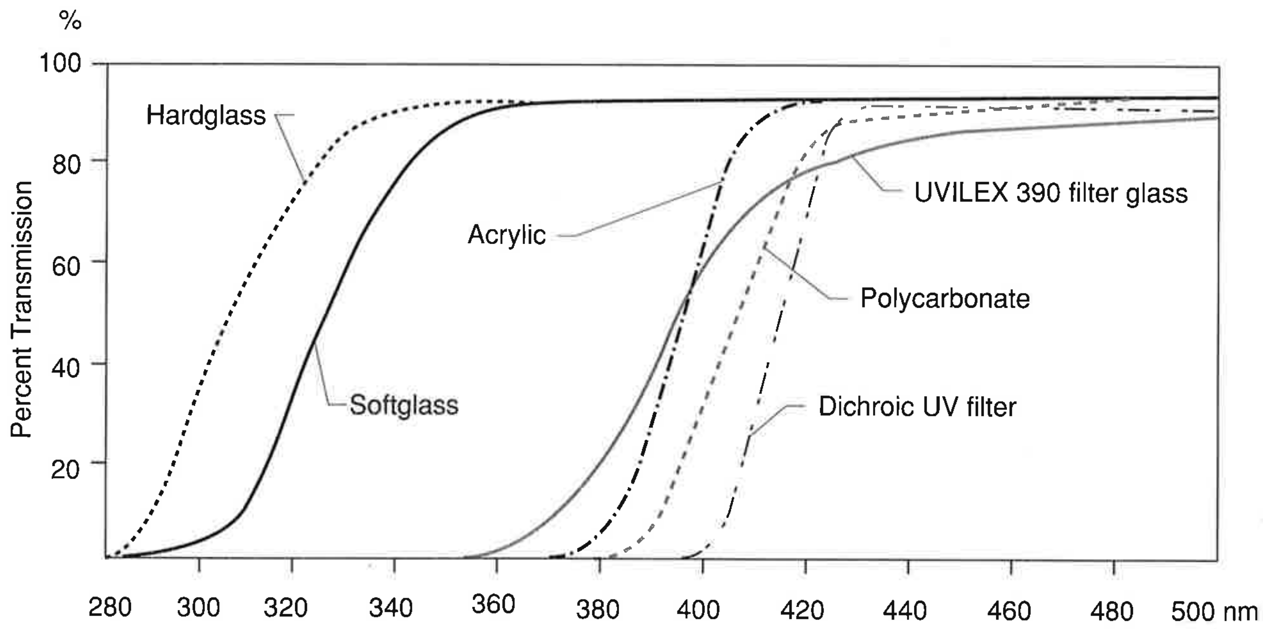
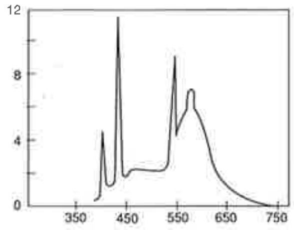
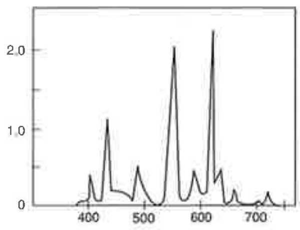


Fig 2 - Transmission values for various materials.

Examples of Spectral Power Distributions of Fluorescent Lamps



Colour 133



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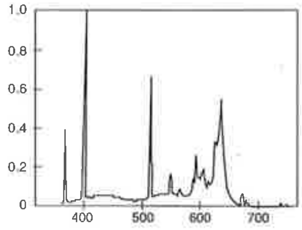
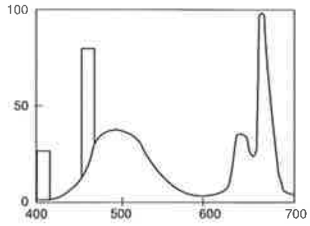
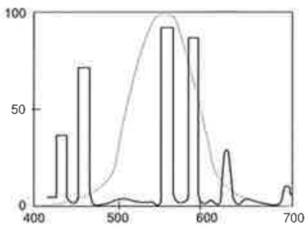


Colour 175

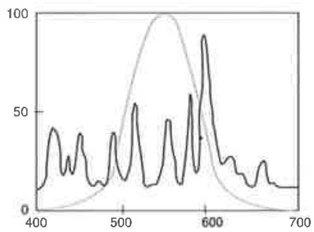


Colour GRO

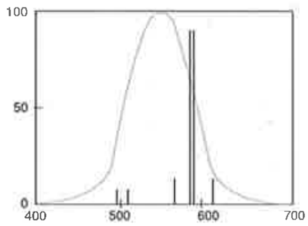
Examples of Spectral Power Distributions of Discharge Lamps



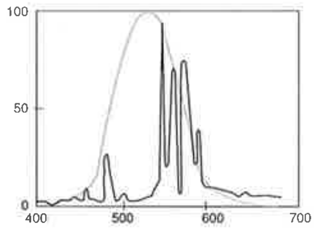
HSL-BW
MERCURY LAMP



M100
METAL HALIDE LAMP

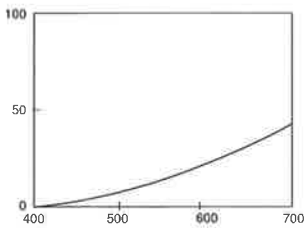


SLP
LOW PRESSURE
SODIUM

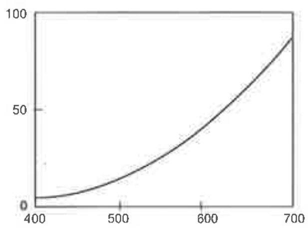


SHP
HIGH PRESSURE
SODIUM

Examples of Spectral Power Distributions of Filament Lamps



GLS
INCANDESCENT



3000K
TUNGSTEN HALOGEN

Fig 3 - Various spectral power distribution diagrams of common light sources

Radiation ... Power and Energy

The composition of electromagnetic radiation from a light source is defined by the spectral power distribution in electrical power units, Watts.

For the effect which this radiation will have on a material, we are interested in energy units.

The commonly considered unit in photochemical studies is the PHOTON, defined by the following formula:

$E = h * v$

h ... the Planck's constant equal to $6{,}6 * 10^{-27}$ erg. sec

v ... the frequency of the radiation

For light sources we are concerned with radiations in the range of 100 to 2000 nanometers or the equivalent of frequencies from $3 * 10^{15}$ to $1.5 * 10^{14}$ Hz.

When we look at the formula for the energy definition of the photon, it becomes apparent that radiation of shorter wavelength has a higher level of energy than radiation of longer wavelength. - Or, blue radiation and especially ultraviolet may cause more photochemical change than red radiation or infrared, for a material equally sensitive to both.

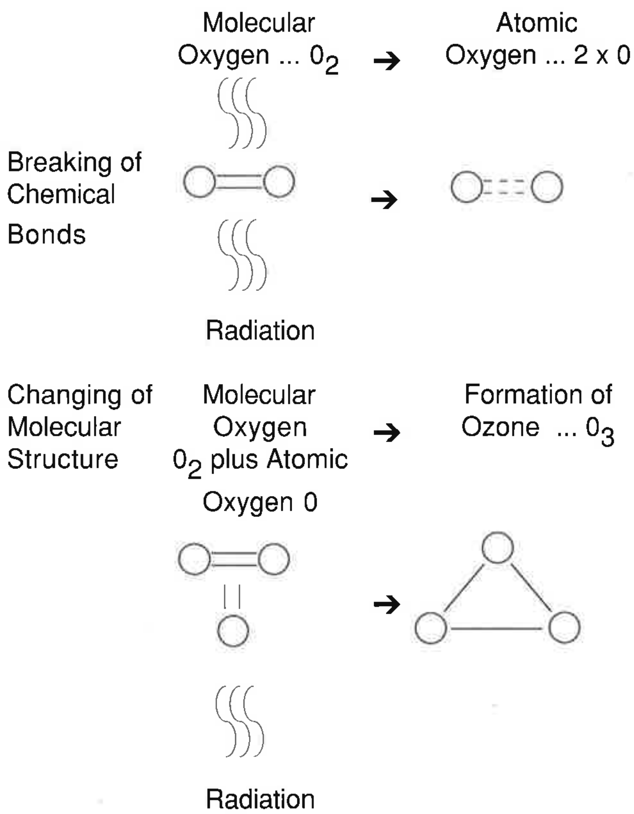
Radiation .... Absorption of Energy .... Photochemical Reaction

Absorption of radiant energy by a molecule is described as a mechanism in which the electron system of the molecule is in tune with a certain frequency (or wavelength) of radiations.

A molecule which has absorbed a photon of energy is then said to be excited or activated. The law of photochemical equivalence states that a molecule is activated for every photon which is absorbed.

This activation may lead to a photochemical reaction in the form of

- the breaking of chemical bonds in the molecular structure, or
- the change of the molecular structure



If this change is achieved by the absorption of **one** photon, then the quantum yield, or quantum efficiency, is 1. - Or, for each absorbed photon in a substance there is one photochemical reaction.

There is, however, the possibility that the activated molecule will lose (dissipate) the absorbed energy in other forms, e.g.:

- by collision and transfer of the energy with/to another molecule
- by heat
- by emission of radiant energy in the form of fluorescence.

The probability of a photochemical reaction depends on the strength or energy of chemical bonds, and on the energy of the photons.

The quantum efficiency can therefore be very low, with hardly any photochemical reactions happening (in the case of a very stable textile dye), or, it can be high, close to 1 (in the case of light sensitive chemicals as used in photographic films).

Primary and Secondary Photochemical Reaction

The mechanism which leads to primary photochemical reactions was explained before. Often, with a molecule being in an excited state, we can observe secondary reactions, typically with elements in the environment like oxygen, water vapour or carbon dioxide.

These secondary reactions may have several steps then, in which radicals are produced, which in turn produce other chemical reactions until a final stage of reaction is reached.

Effect on Materials

The creation of hydrogen-peroxide for example from water and oxygen radicals can lead to the bleaching of a dye or can damage cellulose fibers, both irreversable

Usually the oxygen or water are not consumed in these secondary reactions but serve as carriers or catalysers. This points to the important role which these elements play in secondary photochemical reactions.

Effect on Plants

While the above example leads to radiation damage, the same principle of photochemical reactions is used by catalysers as chlorophyll for example, in which case complex chemical reactions are initiated leading to the production of hydrocarbons, fat and vitamins on the basis of radiant energy, carbondioxide as present in the air, and water and minerals from the

Also in this case the molecule of the catalyser is activated by radiant energy of specific ranges of wavelengths (see the spectrum of GRO-LUX lamps).

How Much Photochemical Change

The energy of the absorbed photons and their quantity will determine the amount of photochemical change in a material.

The quantity of photons will depend on the intensity of radiation which we may measure as the illuminance in lux, but a more correct indication would be the irradiance, for example in milli Watts/ cm^2 for a specific (range of) wavelength(s).

Reducing the intensity of radiation (or reducing the illuminance, lux) will reduce the number of absorbed photons, but not their energy. The amount of photochemical change will be reduced, but will not stop.

Principle of reciprocity .... Irradiance and Time

If there is photochemical change, then two factors will determine the quantity of it, the intensity of irradiation, and time of exposure.

This means that if we take the problem of colour fading of textiles, the same amount of photochemical change is produced when the textile is exposed to 1000 lux for 100 hours, or to 100 lux for 1000 hours. - In both cases the textiles were exposed to 100.000 lux-hours.

We know this principle also from the exposure of a photographic film. The same result can be obtained with an open aperture and short exposure, or a closed aperture and long exposure.

Environmental Conditions

Airborne Impurities

Apart from oxygen, water vapour and carbon dioxide, we may find other volatiles in the environment, available for secondary reactions. Solvents from a multitude of natural or synthetic sources, aromatic hydrocarbons, plastic conditioners, fatty vapours, acid vapours, smoke etc.

These airborne impurities, if they are constantly present and in sufficient concentration, can take part in or accelerate secondary chemical reactions and photochemical damage.

Temperature Effects

Another factor is temperature. That is both the ambient temperature, and the temperature which is created by infrared radiation from the lamp on the surface of a material.

Usually chemical reactions are accelerated at higher temperatures and in some cases so will radiation damage.

This is important to remember, particularly in lighting applications where high illuminance levels are applied, and with light sources which radiate considerable amounts of infrared.

Of course, increased temperatures may bring physical changes by dehydration, or the evaporation of solvents, softeners or conditioners of natural or synthetic materials.

Control of Environmental Conditions

In commercial applications we have usually little to no influence on the environmental conditions. Some degree of protection can be made with air conditioning, heat control and screening of natural light sources.

Museum, Art Galleries

In some specific cases such as the preservsation of important documents or antique textiles, such objects can be housed in suitably designed display cases, in which the environmental conditions are strictly controlled.

In such cases the air can be replaced by an inert gas (absence of oxygen) and the moisture content controlled to a level necessary to maintain the flexibility of the material which is displayed. A relative humidity of 25 to 35 percent is recommended for most installations.

Radiation from Natural and Electrical Light Sources General Effects

Examples of radiation effects caused by infrared, visible or ultraviolet radiation are given in the following chart. They may be caused by physical or photochemical mechanism.

Infrared > 760 nm	Heating, drying, melting, polymerisation, embrittlement, deformation, shrinking, charing, Human beings: skin burns, eye lense cataracts.
Visible 380-760 nm	Foodstuffs: Degradation, change of taste, loss of nutrient value, change of colour. Colour fading of textiles, paper, paint, pigments and dyes. Yellowing of paper, resins, plastic film and surfaces, change of colour in woodwork General vegetation response. Human beings: general activation, photochemical lesion of retina, loss of visual acuity.
Ultraviolet < 380 nm	Colour fading, polymerisation, embrittlement, surface degradation of polymers, fluorescence, sterilisation of gases, liquids and surfaces (< 280 nm), Human beings: direct pigmentation of skin (300-400 nm), erythema (280-315 nm), melanoma, conjunctivitis (< 300 nm).

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