Light Sources and Dye Fading

Mary Beth Gotti, Manager, GE Lighting & Electrical Institute, GE L&I
and
Shelli Sedlak, LC, LEED® AP, Sr. Specification Engineer, GE L&I

Introduction

Electric and natural light sources affect materials and their composition. There are many factors that contribute to how severe this change can be, such as time exposure, actual light source, and actual material composition. The strict management of the collective exposure to light on a material is the most important consideration. By comparison, other secondary factors, such as UV, have relatively small effects by comparison, unless the main light source is daylight.[1]

This article evaluates several light sources and materials so that the proper application of a source can be decided upon. The premiere reference used throughout this article is IES/ANSI RP-30-96 "Museum and Art Gallery Lighting: A Recommended Practice".

Light Energy and Spectral Distribution

A basic understanding of light energy is needed to properly review sources and their applications. The Illuminating Engineering Society (IES) defines light as "radiant energy that is capable of exciting the human retina and creating a visual sensation. James Maxwell advanced the electromagnetic theory, based on three points:

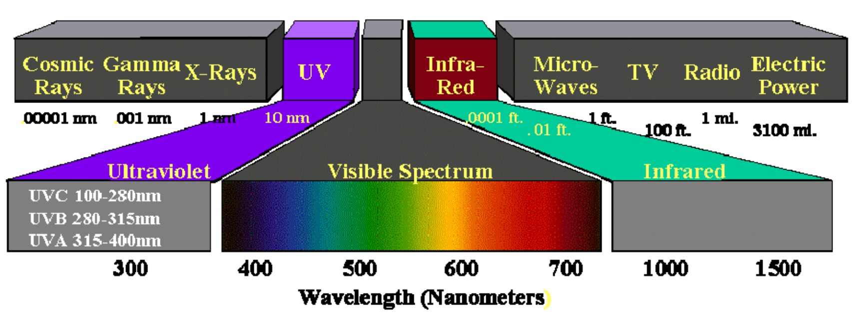
1. Luminous bodies emit light in the form of radiant energy.
2. Radiant energy is propagated in the form of electromagnetic waves.
3. The electromagnetic waves act upon the retina, stimulating a response that produces a visual sensation." [2]

Spectral power distribution (SPD) is defined as a graph of the radiant power emitted by a light source as a function of wavelength. SPDs provide a visual profile or "finger print" of the color characteristics of the source throughout the visible part of the spectrum.[3] To further examine these points, a short discussion on the electromagnetic spectrum and SPDs is given below.

Electromagnetic Spectrum

The electromagnetic spectrum has classified wavelengths, measured in Angstroms, nanometers (nm), and micrometers (μm). These wavelengths range from cosmic rays (10^{-16}) to radio waves (10^{5}). Of all these wavelengths, the visible spectrum is a small amount of energy, from approximately 380nm to 780 nm. Ultraviolet, or UV, energy is approximately 100nm to 400nm. Infrared, or IR, energy is approximately 0.78 μm to 10^{3} μm. The graph below depicts the various ranges within the electromagnetic spectrum.

Figure 1
Electromagnetic Spectrum [4]



Spectral Power Distribution of Incident Energy
Lighting an object involves the narrow band of wavelengths from approximately 380 –780 nanometers, as depicted in Figure 1. Light is accompanied by some amounts of Infrared (IR) and Ultraviolet (UV). It is important to note that light contributes to vision and damage, whereas non-visible IR and UV contribute to damage, but not to vision.[5]

Damage to objects
The following section on "Damage" is from the IES Recommended Practice on Museum Lighting[6]

Light has the potential to cause damage to objects. There are four primary topics to consider for the application. They are:

- Effect of exposure to light
- Categories of susceptibility
- Assessment of exposure
- Control of damage

The following is a further examination of these four areas.

Effect of exposure to light
A simple formula puts the exposure effects into perspective.

Light = radiant energy = damage to objects

"When radiant energy is incident on the surface of a material, some portion of that energy is absorbed promoting two different processes: radiant heating effect and/or photochemical action." [7]

Radiant Heating Effect
On the surface of a material, a temperature increase is produced. This increase causes chemical changes including, but not limited to, loss of color, cracking and lifting. IR energy is associated with this effect.

Photochemical Action
This process is different and more permanent than radiant heating. The changes occur at a molecular level, when the actual molecular structure is changed. Typical changes that occur are yellowing or color change and deterioration of materials. UV energy is associated with this effect.

Susceptibility of Materials
Materials react differently to light exposure with some able to withstand the exposure, while others are highly susceptible.

Examples:

Wood and Leather
- moderately susceptible, BUT when dyed, become highly susceptible

Pigments
- moderately susceptible in an oil painting, but highly susceptible in a watercolor

Geological Materials
- susceptible to color changes, decomposition:
- light-accelerated surface reactions with air, moisture and pollutants

Table 1 [8]
Susceptibility and Materials

Types of Materials	Maximum Illuminance	Footcandle-hrs per yr
Highly susceptible displayed materials: (cotton, natural fibers, furs, silk, writing inks, paper documents, lace, fugitive dyes, watercolors, wool, some minerals)	**5 footcandles**	**5,000**
Moderately susceptible displayed materials: (textiles with stable dyes, oil paintings, wood finishes, leather, some plastics)	**20 footcandles**	**48,000**
Least susceptible displayed materials: (metal, stone, glass, ceramic, most minerals)	**(Depends on exhibition)**	

Assessment of Exposure
The Reciprocity Principle is H=(E)(t), or luminous exposure is equal to illuminance multiplied by exposure time.[9]

Example: Illumination of paper documents

Max. illuminance: 5 fc
Max. fc-hours per year: 5000

5.0 fc	x 125 days	x 8 hours/day	= 5000 fc-hours
2.5 fc	x 250 days	x 8 hours/day	= 5000 fc-hours
5.0 fc	x 250 days	x 4 hours/day	= 5000 fc-hours

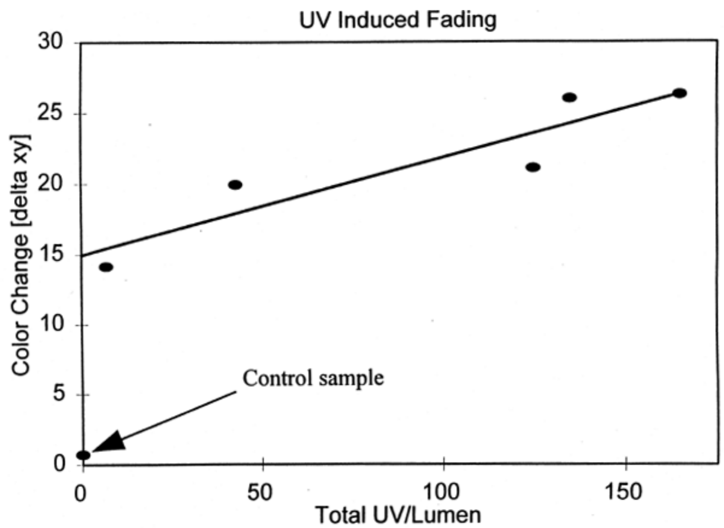
Control of Damage
Depending on the application, the consideration for damage control may be a high priority. Used with the information provided previously, here are some suggestions:

- Eliminating or at least restricting IR and UV to the lowest level by the light source selection, filters, and monitoring/taking measurements.
    a. Reduce the UV with: acrylic or polycarbonate filters, UV absorbing glass, dichroic glass filter, sleeved fluorescent lamps, doped halogen quartz capsules, indirect lighting (non-UV reflecting surfaces), multi-layer films on capsules and reflectors.
    b. Reduce the heat by using more efficient light sources (reduced radiated heat per visible light produced such as HIR, fluorescent, CMH. Also, use "cool beam" lamps or fixtures such as MR16s, MR11s, IR (infrared) filters, or dichroic glass, external cooling and/or venting.
- Limiting Illuminance
    a. Manage the reduction of illuminance with color discrimination ability
- Limiting duration of exposure by:
    a. Rotate items on display - special events, flexible schedules
    b. Use of replicas for detailed viewing
    c. Timed exposures - e.g. motion sensors

Figure 2 [10]

Light sources and fading
UV causes fading –
but so does visible light!

The control sample is in darkness.
When all the UV is filtered out of
a light source, there is still 15
"points" of color change.
More UV content accelerates fading.



Ultraviolet (UV) & Today's Light Sources - How is UV output of lamps measured?
A spectroradiometer is used. This equipment measures watts of UV output as a function of wavelength (nm). To better compare light sources, calculate total watts of UV generated per lumen of visible light or microwatts (.000001 watts) per lumen

Table 3 [11]
Some typical values – microwatts/lumen

Type of Light Source	UV (microwatts/lumen)	UV%
Incandescent	**75**	**1.7%**
Halogen PAR38	**67**	**1.4%**
Halogen MR16, dichroic, glass cover	**36**	**0.9%**
Halogen MR16, aluminized, glass cover	**95**	**1.9%**
Fluorescent	**130**	**3.4%**
Daylight + glass	**275**	**6.7%**
Metal halide	**350**	**9.0%**

Table 4 [12]
Ultraviolet (UV) & Today's Light Sources
Approximate UV output at 50 fc

Type of Light Source	Microwatts/cm^2
F40T12/SP41	6.8
F32T8/SP	6.2
F32T8/WM	5.4
T5/HO	3.3
MR16/CG	1.5
Halogen PAR	3.0
Halogen-IR	1.5
Incandescent	3.5
Ceramic MH (single ended, doped quartz)	4.6

Other important facts about UV & Light Sources

Fact 1:
Sunlight is far more damaging than most electric light sources. Indirect daylight is less damaging, especially if reflected from UV-absorbing materials or finishes, such as zinc oxide or titanium dioxide based paints.

Fact 2:
Aluminized reflectors with no cover glass provide more UV than dichroic-coated reflectors.
The cover glass eliminates much of the UVB and all UVC.

Figure 3 [13]

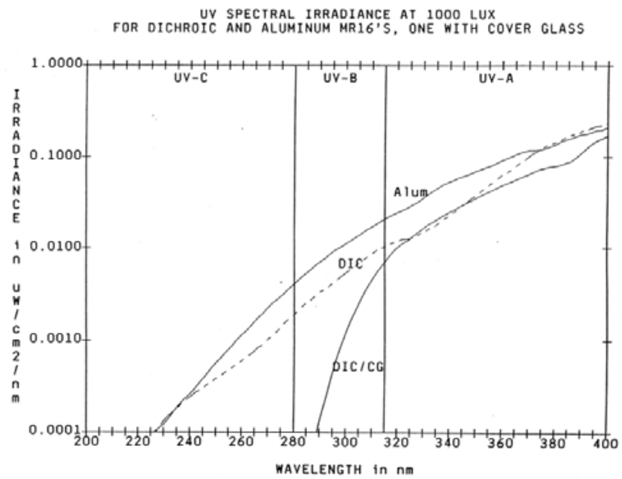


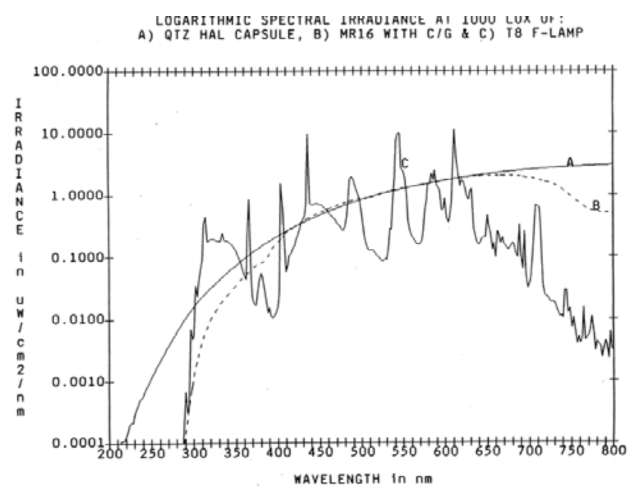
Figure 4 shows how the glass cuts off UV at about 300 nm

Figure 4 [14]

A: Bare quartz tube

B: MR16 with cover glass

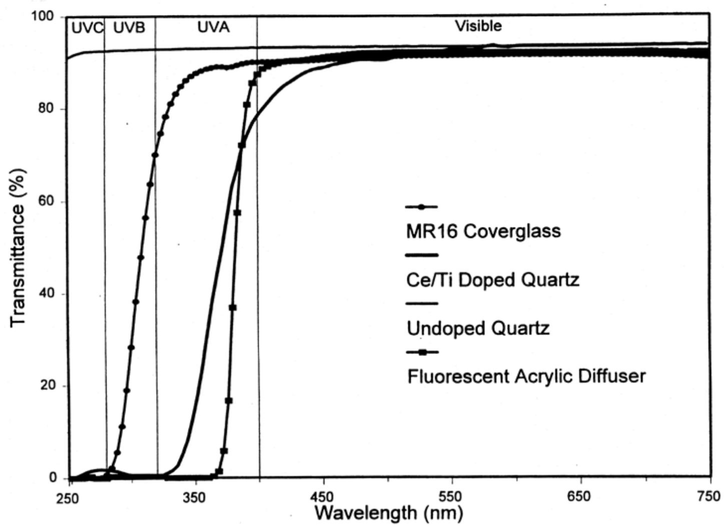
C: T8 Fluorescent



Fact 3:
One can also compare UV output based on irradiance or watts of UV that strikes a surface at a given distance or at a given light level. This is typically expressed as microwatts per square centimeter.

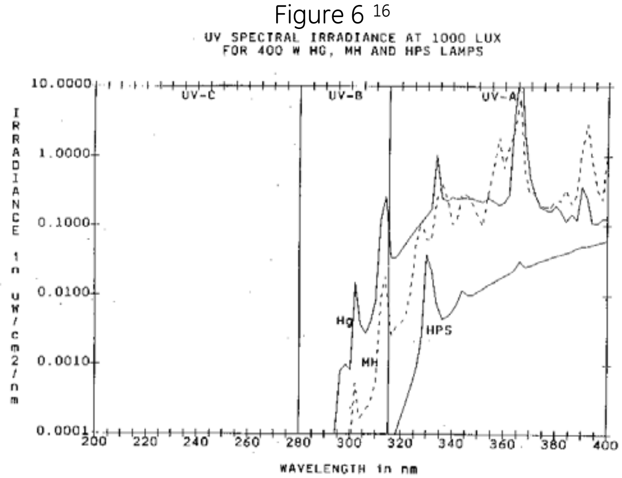
Fact 4:
Even a simple prismatic lens on a fluorescent fixture cuts out a significant amount of UV.

Figure 5 [15]



Fact 5:
HID light sources have UV control. The outer bulb of mercury and metal halide lamps blocks UV below 300 nm, whereas HPS has the lowest UV output.

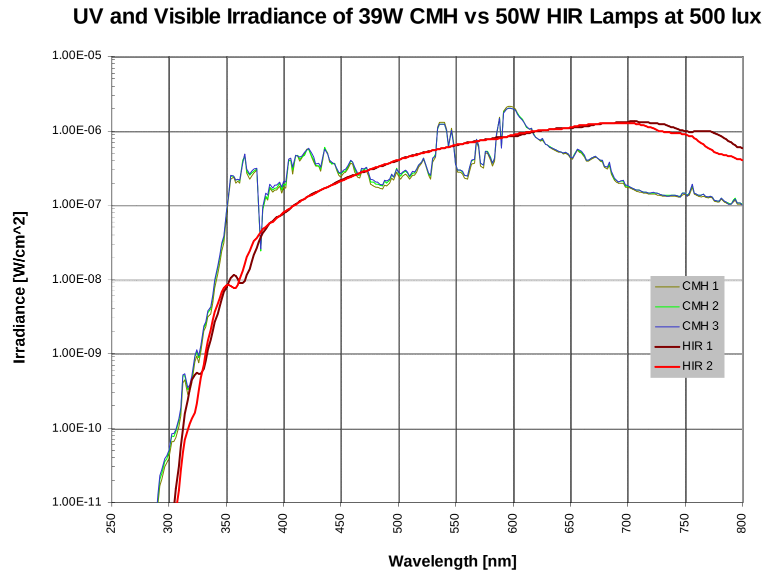
Figure 6 [16]



Fact 6:
UV Output...
CMH vs. HIR Lamps – which one should be used?

Figure 7 [17]

UV filters recommended for use with ceramic metal halide lamps in museum applications



It's all about light source suitability.....
Halogen lamps provide point source capabilities for museum lighting applications. IR reflecting films on capsules increase efficacy, reduce UV, and heat content in the beam. Doped quartz capsules also reduce UV. Dichroic coatings on reflectors reduce heat content in the beam by 75%. Other external filters used to eliminate UV and reduce IR.

Fluorescent lamps with high CRI are ideal for continuous lighting effects, large luminaire surfaces, wall washing and back lighting. Polycarbonate sleeves eliminate 99% of UV. Other external filters used to eliminate UV.

Ceramic metal halide lamps, with their high efficacy and excellent color rendering, open up new possibilities for HID lighting in museum applications. Doped quartz and external filters used to eliminate UV.

Conclusion
The factors that contribute to how severe a change can be on a material have been investigated. These factors of time exposure, actual light source, and actual material composition, are shown to have direct correlations to one another, with light exposure over time as the most critical, and effects of UV as a secondary consideration.

References:

1 A. James Henderson, Ph.D., P.E., Frank F. LaGiusa, FIES, Terry K. McGowan, FIES "Light Sources and Dye Fading" presented at the 1990 IES Annual Conference.
2 The IESNA Lighting Handbook, 9th Edition
3 Hwww.GELighting.comH glossary
4 GE Lighting & Electrical Institute
5 The IESNA Lighting Handbook, 9th Edition
6 ANSI/IES RP-30-96 (reafirrmed 2008) "Museum and Art Gallery Lighting: A Recommended Practice" Section 3.0 p. 12
7 ANSI/IES RP-30-96(reafirrmed 2008) p. 12
8 ANSI/IES RP-30-96 (reafirrmed 2008) Table 3.1
9 The IESNA Lighting Handbook, 9th Edition
10 Bergman, Parham, McGowan 1994 and D. Saunders, "UV Filters for Artificial Light Sources," National Gallery Technical Bulletin 13 (1989), National Gallery Publications Ltd., National Gallery, London
11 ANSI/IES RP-30-96 (reafirrmed 2008) and Henderson, LaGiusa, McGowan 1990
12 GE Lighting & Electrical Institute
13 Bergman, Parham, McGowan 1994
14 Bergman, Parham, McGowan 1994
15 Bergman, Parham, McGowan 1994
16 Bergman, Parham, McGowan 1994
17 Bergman, Parham, McGowan 1994