ULTRAVIOLET LIGHT (Radiation)

> ***"Objects do not 'recover' from light exposure, light induced damage is irreversible and cumulative."***
>
> ***– Toby Raphael*** [1]

Light is itself an environmental factor and a cause of damage. It is also a major component in all the other risks to art and artifacts. (Dim lighting is even a factor in accidents.)

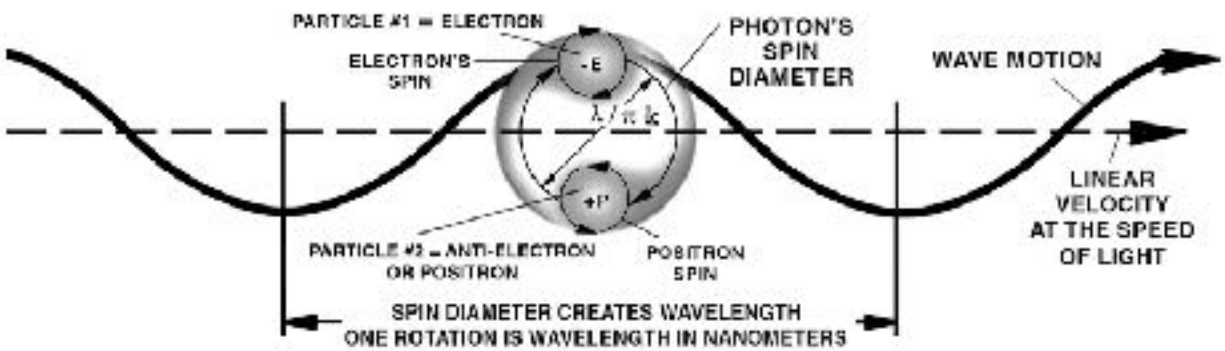

Figure 2-1. The structure of a photon as described by quantum electrodynamics.

For the present purposes you need only to understand that light and radiation are synonymous terms. All light is comprised of photons. A photon is made up of two particles, an electron and a positron, spinning around each other.

Light is made up of physical particles with mass that impact the atomic structure of any object they strike. Ultraviolet light is made up of photons with a tight, small diameter compared to visible light and infrared. The particles, the movement, the speed forward, the mass…everything is identical except the distance between the two spinning particles.

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[1] Toby Raphael, B:6, p. 2.

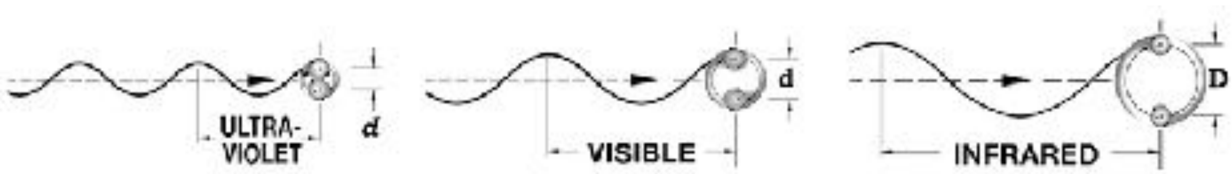

Figure 2-2.
The structures of ultraviolet, visible and infrared light.

The wave of light is created by the movement of the two particles as they spin around each other. Ultraviolet has a shorter wave. There are more rotations over the same distance. But UV is identical except for the distance to all other light.

Defining Ultraviolet Light (Radiation)

The understanding of light and its ability to cause damage to art and artifacts is a fairly recent development in museum and lighting science. As late as 1971 major lighting suppliers were stating authoritatively that the ultraviolet energy in fluorescent or incandescent light sources (and even sunlight) were “unimportant” factors in fading. Here is a quotation from the *1971 Westinghouse Lighting Handbook:*

> “The relatively small amount of ultraviolet energy in sunlight has been shown to be an unimportant factor in the fading of textiles. Since artificial sources contain only about one-tenth as much ultraviolet per lumen as sunlight, the effect of the ultraviolet in incandescent or fluorescent light is negligible.”[2]

The same handbook goes on to relate that 25% of a representative group of fabric samples showed fading after 25,000 footcandle hours of exposure to fluorescent or incandescent light.[3]

At a conservation lighting level of 10 footcandles, this is equivalent to only one year of display, 8 hours a day, 6 days a week. Having one quarter of your textiles fade under the equivalent of a single year of museum level lighting does not make the photochemical danger of this lighting sound “unimportant”.

Fading does not just harm interpretation and the beauty of an object. Fading can change the perception of history. Portraits loose the blush on checks, watercolor turn pastel, ball gowns become tinted yellow, flags are muted instead

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[2] Lighting Handbook (Bloomfield, New Jersey: Westinghouse Electric Corporation, 1971), p.9-12.

[3] Lighting Handbook, p. 9-12.

**Figure 2-3.
Detail of fading on silk dress after
less than 30 days under fluorescent lighting.**

of bright, signatures become hard to read…the list of dangers is endless and it does not just happen in museums.

We purchased the silk dress shown in the accompanying photograph (Figure 2-1) at a significant discount because of its damage. The fading shown occurred while the dress hung on a clothing rack, protected by other dresses, under normal fluorescent store lighting for less than 30 days. As the UV output of a fluorescent lamp is roughly the same as that of a xenon lamp,[4] most people today would attribute this damage to the relatively high UV content of fluorescent lighting.

They would be partially right. But, the other factors that caused damage, IR radiation and mismatched color visible light are also significant. See other pdf files for further discussion.

However, you need to be aware of several problems associated with the protection of collections from UV radiation. The first problem relates to a

[4] Terry T. Schaeffer, Effects of Light on Materials in Collections, Research in Conservation (Los Angeles: The Getty Conservation Institute, 2001), p. 22.

definition of terms. UV is defined and described in several different and sometimes conflicting ways.

As you can see from the chart (Fig. 2-2), UV can be described by letters, "A," "B," or "C", by "short" or "long" wave and by quite a number of other terms. When marketing types add in words like "dangerous" or "harmful," it can get quite confusing. As the quotation from the *1971 Westinghouse Lighting Handbook* shows, opinions of what might be harmful or dangerous can vary greatly. One person's cancer risk is another person's source of vitamin D.

ULTRAVIOLET RADIATION

Wavelength in Nanometers	Terms	Comments
5-100	Vacuum UV	Effectively filtered by air
100-280	UV-C	Fluorescent UV at 180 & 250 nm
180-220	Ozone producing	Light energy creating pollution
220-300	Bactericidal	Roughly "Short Wave UV"
280-315	UV-B	Matches erythermal
280-320	Erythermal	Causes sunburn
315-400	UV-A	"Long Wave" or "Black light"
380-400	Visible Violet	UV-A overlaps visible spectrum

Figure 2-4 Ultraviolet terms and descriptions by wavelength.

Here is a place where it is important to stay with numbers and study spectral curves. Quite often advertising materials refer only to long wave UV or to a part of the spectrum that someone (usually in marketing, not research) has decided to call harmful or potentially damaging. A major archival materials company catalog describes UV fluorescent light filters as transmitting "practically none of the harmful ultraviolet light." This statement is on a par with the quote from the *Westinghouse Lighting Handbook* which started this section.

Your immediate questions should be what does "practically" mean and what is the definition of "harmful ultraviolet light?" You need to know exactly what wavelengths a product will filter and how effectively they filter those wavelengths. Be sure that you get meaningful data on effectiveness. Insist on seeing spectral transmission curves or actual test data before purchasing "safe" lighting or UV filtering materials. Beware of products that cannot promise specific reductions or limitations at specific wavelengths.[5]

Ask about product warranties. Make sure they include an adequate service life. The life of conservation materials has to be defined as the time that they are effective, not simply the amount of time that they will exist. How long can the filter material that you purchased to protect your artwork from the damage of UV absorb this UV before it becomes damaged itself?

The same fluorescent light filters described above are promised to "last indefinitely." Does "last" mean "remain effective?" You will hear lots of promises about life and effectiveness. Those that are true will be documented in a written warranty.

Detecting Ultraviolet Light

You must also be careful when purchasing UV monitors or meters. Again, look at the numbers. A major archival materials company sells an ultraviolet monitor for museum use for a little over $1400.00. The monitor "features high sensitivity (between 300-400 nm)."

You should immediately ask, "What about the rest of the UV spectrum?" Good! This meter won't measure short wave UV. It is blind to the major mercury emission spikes of fluorescent and HID sources at 250 nanometers.[6] The shorter the frequency, the deeper the photon will penetrate the surface and the deeper photochemical damage will occur. That is because the spin diameter is small enough to slip past more molecules as it travels into an object before it encounters an atom. These meters ignore a major and very destructive part of the UV spectrum.

To be effective for conservation purposes, a UV meter must be calibrated for and measure both long wave and short wave UV. In actuality this will mean a monitor that has at least two sensor heads.[7] It simply isn't possible to measure

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[5] You must even suspect some spectral data. Quite often spectral output information for light sources or conservation materials is incomplete. In our study of UV output we found it quite common for spectral graphs to simply stop somewhere in the 2 or 3 percent range when they approached the UV end of the graph. A "floating" graph isn't showing all of the information. And, it isn't showing exactly the information that you, as a conservator, really need to know.

Much more often the spectral information you need just isn't there. Charts showing UV filtering performance in both Garry Thomson's and Barbara Appelbaum's books simply end at around 300 nanometers. They ignore the short wave UV spectrum.

[6] Mercury emission spikes occur at around 360 nanometers, 250 nanometers and again at 180 nanometers in fluorescent and gas discharge lamps. You must be able to measure all of these.

[7] The two heads must both measure UV, one long wave and one short wave. Some two-headed meters sold are dual purpose, measuring visible light with one and one type of UV with the other.

the entire UV spectrum with a single photo sensor head. Ultraviolet Products in Ontario, California makes a very good meter of this type.

You might also ask, “Isn’t 400 nanometer energy visible light?” Again, good for you! Many meters including Crawford™ meters read violet visible light between 380 and 400 nanometers as UV. Visible violet is not UV.

Depending on the color of your art, it might be important. It could well be the “purple mountain’s majesty” in your paintings, the sheen in iridescent blue feathers or butterflies, the support color of a skin tone that makes a portrait alive, or the depth of color in an amethyst. While Garry Thomson claims that “the residual sensitivity of the eye between 380 and 400 nm is too small to affect color rendering…”[8] the truth is that this depends entirely on the colors of the artifact itself.

There is one further item that causes confusion when we attempt to quantify UV. Again, it is a problem with the terms we use. Microwatts per lumen have become somewhat of a UV measurement standard for conservators. Seventy-five microwatts per lumen (75 µw/l) is often recommended as a maximum UV exposure. It is supposed to be roughly the UV output of a standard incandescent lamp. Because it is a percentage, not an absolute value, as visible light levels go up or down, so does the amount of UV. That makes it really hard to set any absolute standards. You might remember that the *Westinghouse Lighting Handbook* used “per lumen” measurements to unrealistically minimize the fading effects of UV.

When you consider the definition of a lumen, things get really complicated. A lumen is a measure of “visually effective radiation (i.e. light) for a standard human observer.”[9] In simple terms, it is a measure of the light intensity that you can see across the visible spectrum. In other words it is the visible spectrum adjusted for the response of the human eye. It is a photometric term relating to vision, not a radiometric term relating to energy.[10]

This means that for any light source, lumens per watt will vary according to the efficiency of that source. It also means that lumens per watt vary in relationship to the color of a light source. By using microwatts per lumen as a standard, we have attempted to set standards for UV, radiometric energy, which we can’t see, in terms of photometric energy, which we can see. We are comparing apples and oranges. But, we have also based that standard on data that varies radically source to source. So, we are comparing apples to oranges using a constantly changing scale. No wonder it’s confusing!

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[8] Garry Thomson, p.17

[9] The IESNA Lighting Handbook: Reference and Application, ed. Rea, Mark S. (New York: The Illuminating Engineering Society of North America, 2000), p. 1-6.

[10] Understanding the difference between photometric data relating to what you can see and radiometric data relating to the total energy striking an artifact is vital to conservation science. The next section on IR energy continues to explain this vital distinction.

A lumen is equal to 1/683 light watts.[11] Simple math reduces this to .00146 watts or 1460 μw. Replacing the term "lumen" with this value in the expression 75 μw per lumen gives us 75μw divided by 1460μw. This equals .051 or 5.1%. A 75 μw per lumen standard for an artifact gives us UV energy equal to 5% of that artifact's illumination. This is a little simpler.

But this percentage only applies to an incandescent lamp at about 3000° K. Change the color temperature to 2750 ° K and the percentage drops to 1.5%. Use a fluorescent or a HID source and it changes again. We help avoid confusion and are much more accurate if we express UV conservation limits in the absolute term of microwatts per square centimeter. This is a pure radiometric measurement and describes exactly the energy impacting an artifact.

There should be absolutely no UV in museum artifact lighting. The goal should be zero.[12] Today's lighting technology makes this a perfectly achievable goal. If budgets or building designs don't allow you to achieve zero UV, you should come as close as you can. An absolute measurement allows you to more easily evaluate lighting and more closely achieve this goal. It also makes it much more difficult for others to manipulate numbers or misrepresent UV dangers.

There is one more thing that you need to consider when you look at UV meters that express UV as a percentage of light output. The basic circuit used to measure UV as a percentage of visible light (microwatts per lumen) is a Wheatstone bridge. Electrically it divides UV by the total light present. This process by itself creates inaccuracies at very low (museum) lighting levels.

Every school child learns that it is illegal to divide by zero. This is because as a denominator approaches zero, the numerator approaches infinity. What happens in UV microwatt per lumen meters is that as the number of lumens gets very small (most museum light levels are relatively low), the value of the microwatts (the UV measurement) becomes unrealistically large. We have had indications of high levels of UV from such meters inside of a completely dark closet where there were no energy sources at all. The meter was actually reading a nearby FM radio station.

To be accurate, you should take UV measurements in absolute terms (microwatts per square centimeter). Measure both long wave and short wave UV and add your measurements. If you must use meters that measure UV in μw/l, make measurements at or near sources where overall light levels are high. You can then calculate the UV exposure for your artifacts in absolute terms as a percentage of light intensity.[13]

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[11] The IESNA Lighting Handbook: Reference and Application, p. 2-2.

[12] I am ignoring specialized displays of the fluorescence of minerals or perhaps glow-in-the-dark art from the 60's. Such displays should be designed to use the minimum intensity of UV of the longest frequency possible. They should also be designed so that UV from the display never impinges on other artifacts.

[13] 1 footcandle is 1 lumen over 1 square foot. As 1 lumen = 1460 μw; 1 footcandle = 1.57 μw/cm2.

Reflected Energy Matching Documents

Knowing that light energy is comprised of photons that impact an artifact surface, we can assume (and testing proves) that the only safe light is light that will be reflected.[14] Any energy absorbed by a surface results in change. Photochemical damage then is a function of absorbed energy. Lighting a blue object with red light will greatly increase the absorbed energy and the damage. Measured data shows mismatching the color of light to the color of an object can increase damage 30 to 70 times.[15]

Here is a practical example. Several years ago we had the opportunity to supply the lighting for a temporary exhibit showing among other things the original check that the United States used to purchase the Alaskan Territories (Figure 2-5). The National Archives specified a maximum light level of fewer than 3 footcandles for that particular artifact. They also specified no fluorescent light, due to its high UV content. The desire was for there to be zero UV content. Finally they limited the exhibit display to 30 days (roughly 700 footcandle hours) under normal halogen lighting.

Figure 2-5.
The original United Sates Treasury Warrant (check)
for the purchase of the Alaskan Territory.

A light meter reading of 3 footcandles of quartz-halogen track lighting (94% IR, 1% UV) would have exposed this fragile artifact to roughly 60 footcandles of total light energy. More energy-efficient fluorescent lighting at the same 3 footcandle light meter reading would still have a total energy level almost 5 times the recommended light level even had it been UV filtered. Because the

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[14] The mechanics of photon reflection and refraction are described in Light and Matter: The Dangerous Romance.

[15] Jack Miller, Evaluating Fading Characteristics of Light Sources (Seaford, DE: NoUVIR Research, 1993).

NoUVIR fiber optic lighting used had absolutely no IR and no UV, the artifact was lit with 2.7 footcandles of visible light and exposed to only 2.7 footcandles of total energy. Because of the quality of the lighting and the huge reduction in total energy, the National Archives extended the exhibit time to 120 days.

The point is that a light meter alone cannot give you enough information to safeguard your collection. You have to identify (and eliminate) any energy outside the visible spectrum. To do that you must know the exact spectral output of your light sources.

Even then, following the IES guidelines of no ultraviolet and no infrared may not be enough. The spectral output of the visible light is important. Your light meter only measures a portion of the energy in the red and blue parts of the spectrum. The life of the check was extended not just because the UV was gone. The light color is important, not just for presentation, but as a conservation factor.

Reflected Energy Matching Theory states that the visible blue light would be absorbed and damage the check. The check was brown and yellow. It did not reflect blue light. To give credit to the National Archives, their current specifications today for rare documents (like The Declaration of Independence, The Constitution and The Bill of Rights) require an absolute energy cut off at 500 nanometers. This removes visible light.

This specification not only eliminates all of the UV (380 nanometers and below), but also the very blue and violet visible light that would be totally absorbed by a sepia colored parchment. Unfortunately, National Archive's current specifications ignore the other end of the spectrum and the IR radiation of conventional light sources.[16] See humidity for more data.

Matching the color of lighting to the color of the object to decrease absorbed energy and photochemical damage is called Reflected Energy Matching. Ruth Ellen Miller at NoUVIR Lighting developed the theory of Reflected Energy Matching and demonstrated its effectiveness as a conservation tool. It is described in detail with actual fading test data in NoUVIR Lighting Publications.[17] See the pdf list for a large file of two combined papers titled *Reflected Energy Matching as a Conservation Tool*.

Because photochemical damage is a function of absorbed energy, we commonly think of it as being directly related to light intensity. This is true. Reflected Energy Matching is not so commonly understood, but is just as true. And, while Reflected Energy Matching helps explain the necessity of removing UV and IR from museum lighting, it goes much further than that.

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[16] As Figure 2-6 demonstrates, NoUVIR fiber optic lighting corrects this oversight by eliminating all energy above 770 nanometers (all IR). An accessory notch filter at the projector removes all the energy between 380 and 500 nanometers to absolutely meet National Archive standards.

[17] Ruth Ellen Miller, Jack V. Miller, <u>Fading of Fugitive Colors By Museum Light Sources</u> (Seaford, DE: NoUVIR Research, 1993).

Reflected Energy Matching also demonstrates that within the visible spectrum, photochemical damage is directly related to color. In particular, photochemical damage is related to the difference between the color of an object and the color of the light illuminating it. That difference determines the percentage of total energy of visible light absorbed by an object. In some cases this difference is more important to a conservator than the actual intensity of the light.

Even partially filtering a light source to match the color of an artifact can extend its exhibit life 50 times or more. Interestingly, such filtering does not change the appearance of the object illuminated. This is because only the light that will be absorbed by an object is removed.

There is no change in reflected light . Therefore. there is no change in what the eye sees. In demonstrations to conservation and museum professionals, they have been unable to guess which objects were lit with Reflected Energy Matching filters and which were not. The same has been true with several tests conducted in museums. Visitors could not detect the color filtered light even with an object, lit unfiltered next to the further protected object.

The best comparisons have been lighting a cradled book with one side removing visible blue light and the opposite page leaving the blue content. The first step was to remove all UV and all IR. Books are especially damaged by UV since it mismatches the warm, brown tones of aged paper. The next step was to filter one side of the book removing light below 500 nanometers. The gains in preservation were remarkable as it further reduced the light (radiation) that was absorbed. But visitors and even professionals could not tell which side was further filtered and which side was not filtered. The reflected light as data for the eye was the same. The pages looked identical.

It is possible to determine the photochemical danger of any light source to any particular object. You do this by comparing the spectral power distribution of the light source to the reflection spectrum of the object.[18] The difference between the two curves identifies the percentage of light energy that will be absorbed by an object. We call this value a coefficient of damage.

Observable Warning Signs of Ultraviolet Light Damage

Can you observe the photochemical damage caused by ultraviolet light? Because the UV photon reaches deeper inside of an object, the damage is harder to detect. The damage tends to become structural within the artifact.

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[18] Spectral power distribution curves should be available from any reputable lighting manufacturer. Spectral curves for the most common light sources can be found in the Illuminating Engineering Society North America Lighting Handbook, Mark Rea Editor. Reflectance curves can be found in sources like Artists' Pigments, A Handbook of their History and Characteristics edited by Robert L. Feller. Both of these books are listed in the bibliography.

To be consistent, let’s use a paper document that is a check as an example. This check was radiated with UV. The check did not fade. Actually the color is quite bright. But it shows the structural damage. The paper is so fragile that it chips and flakes into pieces. It is embrittled.

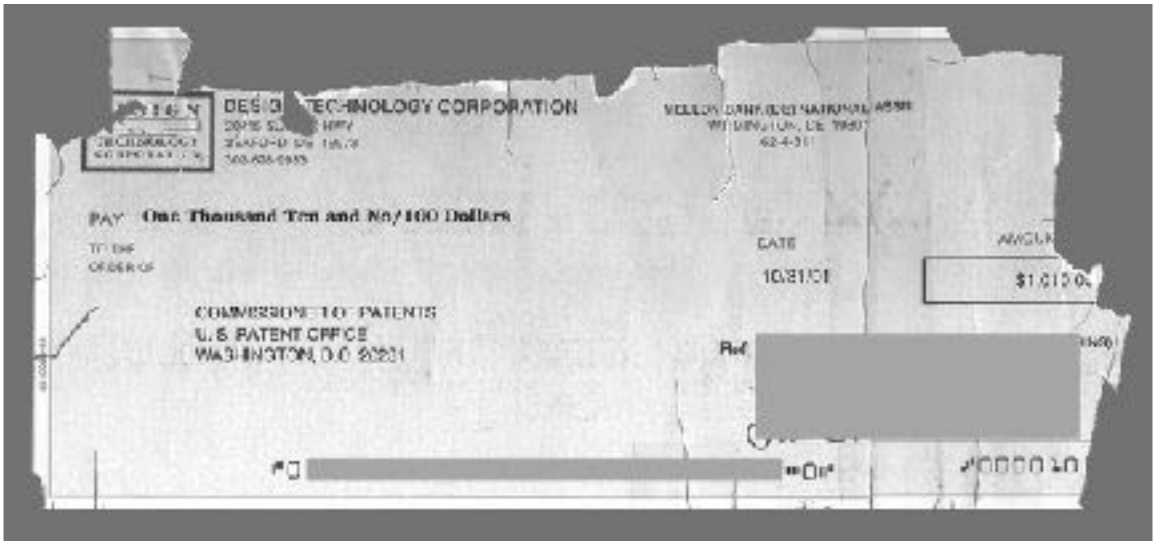

Figure 2-6. A modern check damaged by UV light.

The first signs of UV damage is usually fading. But the light has often penetrated deep enough to structurally break large chains of a single molecule that provides strength into smaller molecules. Paper embrittles. It feels dry. And humidity can be a factor, but UV damage can easily occur under ideal humidity conditions. The document, book, art print, journal, letter feels drier then it should to the touch. The object looses its ability to spring back and it taunt.

Fabric do the same thing. They will fade. But the threads will become dusty inside and want to collapse. The fabric will loose its softness. It will want to shred. This weakening inside is a UV damage characteristic of most organic based materials. Plastic fibers tend to cross-link. They do not collapse, but will crack and split. Look for fraying or a slight feathering along the threads.

Fossils, woods, bone, ivory can hollow and crack internally. The fine fissure across the surface is deeper and wider inside the object. The sign to look for are very fine hair lines. This tiny fissuring is especially evident in musical instruments, Chinese lacquer items and other objects with a high-gloss finish where the pattern is not a checking and the line can be seen to reflect past the finish into the object. Handle these types of objects with extreme care until you know it is not going to collapse from the pressure of your finger tips.

Of course inspect any object with conservation gloves. Do not use rubber gloves unless they cover the hands with a fie cotton glove between hands and the object. A head mounted light is also a good way to examine for these details.

All photochemical damage for collections has a hidden cost. Because the object escalates in value, often the financial losses are never realized. As an example, let's pick an artifact with numerous auction activity to establish value.

This Superman #1 comic book is worth over $3M dollars. The comic is not only rare. But it is in excellent condition. UV damage would fade the colors and chip the edges. The value of Superman #1 comics with these condition issues drops under $100,000.

A Charles Russel illustrated letter in watercolor with the same subject, size and detail will have a division in value of over $80,000 depending upon condition. The collector will look at an increase in value. The artwork sold for far more than its purchase price. But if the color had turned slightly pastel and the paper slightly embrittled, the work did not bring at auction nearly the value of one that is bright, colorful and the paper in good shape.

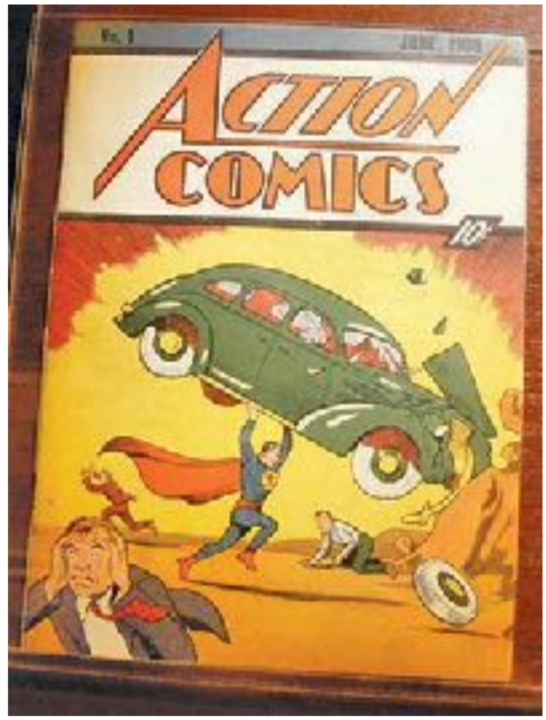

Figure 2-7.
Action Comics Superman #1
lit by NoUVIR lighting with zero UV content and zero IR content.

A Hollywood costume from a very famous movie can have a spread of over $150,000 just based on condition and if there is light damage. Some costumes shift from being valuable and museum pieces to being semi-collectable and selling to fans instead of being added into a serious memorabilia collection.

A well-known institution raised over $300,000 to conserve their brown red pair of Ruby Red Slippers form the *Wizard of Oz*. Restoration would require the removal of every sequins, indexing the sequin, dying red again and adding the finish, sewing each sequin into the original location using the same holes and even faking the original dance wear on the shoes. Conservation treatment will get the Ruby Red Slippers back to shiny red. But if the lighting had been without UV and without IR, the funding could have been raised for another project. The best for the shoes would have been for them to never change color, loose their gloss and not chipped. What could the museum have done with the $300,000?

The examination of paintings is more difficult as so many things impact the work depending upon materials and technique. Usually UV damage is internal. But what looks like damage happing between the canvas, ground and mount (canvas, wood panel, metal, paper) can also be photomechanical damage. Look for tiny, spider thin lines that are not cracks. Look for changes in the gesso or under paint. Look for structural dusting in the canvas or hollowing in the wood. Frankly paintings are durable. But the finest masterpieces should always be lit with the most color balanced light possible and zero UV content with zero IR content. Painting tend to handle IR better, but if the IR is enough to warm and cool the surface daily, the lighting can cause a host of problems from as simple as just making the work dirty to as drastic as the paint falling off the work. Lights with UV content only exacerbate the problem.

Some UV damage can have disastrous impact on value. For example if UV causes the wood to honeycomb and collapse, a delicate Chinese box can be worth less than the cost to try and restore and the conservation treatment will never make the box the same. If UV damage shreds the silks in a flag, again the work may become so difficult to display that it stays in archives and is never handled again. If UV damage cross-links a toy like a plastic horse, the piece can become too brittle to display. Even mounted, it is hard to support the weight of the object. Suddenly it is useless to collectors.

The point is that light damage seriously degrades resell value. What should have escalated into a large return as an investment was capped and depressed by failure to control the lighting and conditions the object was displayed under. The piece might have brought more money in than it was originally purchased as, but it took in pennies on the dollar.

Acrylic Naturally Filters UV

Ultraviolet light is responsible for photochemical damage. But for humans, it can never create sight. Therefore, it needs to be removed.

Fortunately, most plastics filter some if not all UV. The light's spin frequency (wavelength) cannot weave through the material. The problem is that clear plastics are susceptible to yellowing (photochemical damage).

But acrylic's crystalline structure is not only a complete mismatch for UV, but also durable. The ultraviolet light cannot flow through the clear material. It is absorbed within the plastic. Acrylic has such a strong molecular bond that the absorption of the UV does not break apart those bonds. The material stays clear. It can even shed extra electrons through its surface as static. As long as the acrylic is not stressed (under mechanical compression) or chemically attacked by the use of ammonia and other aggressive cleaners, the acrylic stays transparent.

Tests have shown that a thickness as little as 1/32 to 1/16 inch will filter UVA, the larger diameter UV. The more material, the more UV is absorbed. About half the time 1/4" of acrylic, especially with the addition of of a lens at the light fixture, will remove the UV. For the filtering of almost all UV (when the light fixtures have normal UV content), case material of pure acrylic 3/8 inch thick will remove almost all or all the UV from inside the case.

Often acrylic sheet can be safely added to T-bar ceilings. Some fluorescent fixtures are designed and rated to handle thicker acrylic lenses. Some LEDs come automatically with a 1/16 inch acrylic lens. Downlights and tracklights have versions with filter holders that can be rated for holding acrylic. Solutions abound. NoUVIR has seen thick acrylic drinking glasses set over very low watt LED or compact fluorescent lamps (has to be below 70°C for safety as cannot melt the plastic). NoUVIR has seen point-of-purchase cubes set over sensitive artifacts increase the UV filtering. NoUVIR has even seen acrylic added to the top of glass cases inside the light attic. (Warning: One museum did this unsafely and scorched the plastic. The attic has to be cool.)

The ultraviolet is filtered by the crystals of the acrylic plastic. The case can be 3/8 inch thick. Or layers of acrylic the light travels through can add up to 3/8 inch. Or you can use acrylic fiber in a fiber optic system. There is absolutely no UV in an acrylic fiber optic system as fiber is well over 3/8" thick.

Light Summary

Light is responsible for direct photochemical damage. Light is also responsible for direct photomechanical damage and indirect damage through its effect on artifact environment. Most of this damage is caused by non-visible radiation, both UV *and* IR.

UV and IR can represent 90% or more of the output of conventional lighting. Both UV and IR should be eliminated from all museum artifact lighting. Doing so will extend exhibit life 5 to 10 times.

Once that is done, visible light can be balanced to match the color of an artifact, reducing or eliminating absorbed visible light energy that can cause fading. It is possible to calculate the amount of damage a particular light source can do a particular object or class of objects by calculating the color mismatch between the light and the object. This Coefficient of Damage is a mathematical expression of the amount of energy absorbed by an artifact. Reflected Energy Matching can extend artifact exhibit life 50 to 70 times.